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Advancing Timber for the Future Built Environment

MOULD GROWTH RISKS FOR LOW-RISE TIMBER-FRAMED RESIDENTIAL BUILDINGS IN SOUTH-EASTERN AUSTRALIA

Dewsbury, M.[1], Künzel, H.[2]

ABSTRACT: Since 2010 there has been an increasing presence of surface and interstitial moisture and mould within single- and multi-residential buildings in Australia. The increasing presence of moisture and mould has coincided with the adoption of national energy efficiency regulations, which have aimed to reduce the energy needed to heat and/or cool new dwellings. Whilst the research until 2012 focused on international practices for the design and construction of modern façade systems, in 2013 several thousand non-transient moisture calculations were completed to identify typical external wall systems that may be at risk of moisture accumulation. Recognising the deficiency of this method, in 2017 the research adopted transient hygrothermal and mould growth calculation methods. Through a mix of State and Industry funded research activities transient moisture and mould risk assessments have been completed for hot and humid, warm-humid, temperate and cool temperate climates in Australia. This paper reports on the most recent research that explored simulated Mould Index calculations for the temperate and cool-temperate climates of south-eastern Australia. The research identified significant deficiencies in the regulatory framework and the need for significant changes in design and construction practices to ensure timber-framed dwellings are durable, sustainable and provide healthy interior environments.

KEYWORDS: Timber-framed, Condensation, Mould, Hygrothermal, Energy Efficiency

1 – INTRODUCTION

Using transient hygrothermal simulation, this research sought to establish if regulation compliant low-rise timber-framed residential buildings within south eastern Australia could be susceptible to increased risks associated with moisture and mould. To establish if this is a recent phenomenon, the research explored risks associated with the external wall system insulation and air control components present in typical 6-Star and 7-Star regulatory compliant pattern that have been in place since 2010 [1] and 2022 [2-4] respectively. If a risk was identified, enhancements were then explored with the aim to reduce the simulation based risks.

2 – BACKGROUND

The Australian National Construction Code (NCC) previously known as the Building Code of Australia, describes minimum performance requirements, methods, systems and verification methods for new buildings to demonstrate regulatory compliance. Internationally, and in Australia, there is a widely observed correlation between:

- buildings that create significantly different temperature and relative humidity conditions between the interior and exterior environments, and
- susceptibility to moisture and mould on interior and interstitial surfaces.

Since 2008, national research conducted by the University of Tasmania has highlighted the connection between the energy efficiency regulations and the presence of condensation and mould in buildings. Since 2014, this has included the study of existing buildings and desktop based hygrothermal calculations and simulation [5-11]. Whilst many in Australia blamed occupants for mould [12, 13], internationally it was generally agreed that the building design was normally at fault and it was identified that there was a causal link between moisture and mould in buildings and human health [14-20]. Managing moisture and mould is not a new problem [21-32], but has become an increasingly apparent issue from two very different perspectives, namely:

- Since the 1950’s as governments around the world have attempted to improve the interior air quality for human health reasons [29, 31-33],
- Since the 1980’s as governments around the world have attempted reduce energy used to condition buildings [34-39]

From 2013 to 2017 the research had utilised non-transient simulation tools [10, 11, 40] which were identified as inadequate due to their calculation methods and lack of mould growth simulation. [41-43]. This led to the

[1] Mark A Dewsbury, School of Architecture and Design, University of Tasmania, Launceston, Australia, mark.dewsbury@utas.edu.au ORCID: 0000-0002-3607-3637

[2] Hartwig M Künzel, Fraunhofer-Institut für Bauphysik, Holzkirchen, Germany, hartwig.kuenzel@ibp.fraunhofer.de ORCID: 0000-0001-8305-0262

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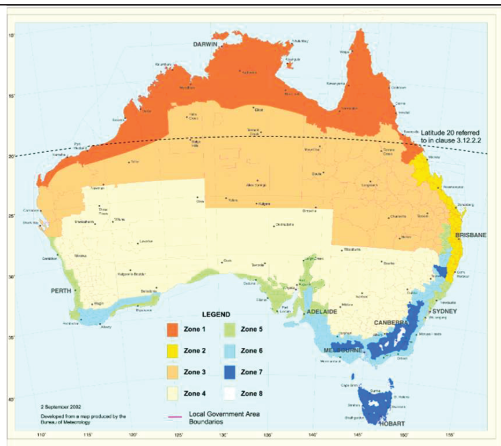

Fig 1. Climate zone map for thermal design [44]

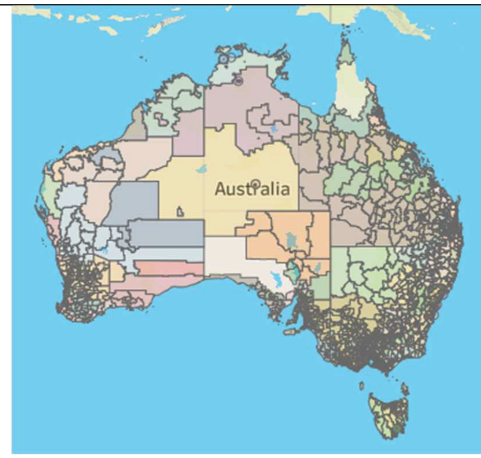

Fig. 2: NatHERS climate zone map for thermal design [45]

adoption of transient simulation methods [42, 46]. In liaison with Fraunhofer Institute of Building Physics, Nath's [47] simulation based research applied international best practice exploring the impacts of both moisture and mould growth through the lens of changes in Australian timber-framed external wall system construction from 2002 (pre-energy efficiency regulation), through to 4-Star, 5-Star, 6-Star and 7-Star energy efficiency regulations.

One of the significant challenges for an Australian 'singular' approach to this problem of moisture and mould are the different climate types across its large land mass, it's sparsely distributed population. Fig 1 shows the NCC climate zone map for Australia, which has been specified since 2003 [44] and includes eight climate types, from hot and humid to cool-temperate. Figure 2 shows the 2006 Nationwide House Energy Rating Scheme (NatHERS) climate map [45], where Australia has been divided into 69 climate types.

The establishment of these climate classifications is based on average temperature and solar radiation, where the three general classifications include:

- Zones 1 & 2: Predominantly require cooling,
- Zones 3, 4, 5 & 6: Require both cooling and heating, to various degrees, and
- Zones 7 & 8: Predominantly require heating.

Significantly, and in a similar pattern to other nations, this data and climate selection does not consider precipitation or background relative humidity [48].

The 2016 Australian Building Codes Board (ABCB) national survey of building design and construction professions established that approximately 40% of residential and multi-residential buildings constructed in the previous decade had a concerning presence of condensation and/or mould [8]. This is not a problem unique to Australia. As noted above, similar experiences have occurred in most developed nations from the 1930s. The German standards system published its first moisture management guidelines in 1952 [29], whilst the first standard in the United Kingdom was produced in 1975 [30], both with many updates since. In Australia, the now defunct National Building Technology Centre, published three notes in 1964; NSB 32: House design for Australian cold-winter climates, NSB 61: Condensation in dwellings and NSB 78: Some condensation problems [49-51], with regular updates until 1974. North America, including Canada, had their own challenges and the 'condo crisis' in during the 1980s and 1990s [32, 52, 53]. New Zealand's 'leaky building syndrome' which commenced in the 1990s, identified two key and often mis-diagnosed causes, namely moisture ingress and water vapour diffusion and many blamed the shift to performance-based building regulation [53-55]. Recent estimates have established that the leaky building syndrome in New Zealand has cost its economy more than NZD$47B [56, 57]. Since insurance is only for events, data is often anecdotal, making economic estimates of Australia's mouldy buildings situation difficult to quantify. Discussions with individual builders involved in mould remediation provide a range for rectification works from Au$30,000 to demolition and rebuild >Au$10,000.

In 2018 Nath [42, 58, 59] and Dewsbury established the need to apply a hybrid transient hygrothermal simulation method for Australia, which recognized the best elements from DIN4108 [29], ASHRAE160 [60], with recent learning by the Fraunhofer Institute of Building Physics, (the developers of the WUFI suite of software). However, the TMY data that was available for Australia did not include hourly data for precipitation. The research reported here includes climate data that includes hourly precipitation data.

3 – PROJECT DESCRIPTION

This research utilised the Fraunhofer Institute of Building Physics one dimensional (1D) hygrothermal simulation software WUFI Pro and the post processing WUFI VTT mould growth simulation software to establish potential mould growth risks within typical low-rise timber-framed external wall systems in south-eastern Australia. The greater project included more than 10,000 simulations and included nine different external wall systems. The external wall systems included lightweight and more massive cladding systems.

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4 – EXPERIMENTAL SETUP

The completion of the hygrothermal simulations required a deep understanding of the software capabilities and inputs The basis for the simulation methodology used within this research combines the consideration of Australian NatHERS defined interior thermostat settings, combined with collaborative method established by Nath and researchers from the Fraunhofer Institute of Building Physics in 2019 [43]. The methodology described within ASHRAE Standard 160 [60] follows the same principles as developed by Nath [47].

4.1 External wall types

The external wall systems discussed here represent the most common timber-framed low-rise external wall systems used for housing in south eastern Australia [59]. The external wall systems examined, included:

- Timber cladding, with insulated timber structural frame
- Compressed fibre cement sheet (CFCS) cladding, with insulated timber structural frame
- Clay masonry veneer, with insulated timber structural frame
- Concrete blockwork masonry, with insulated timber structural frame
- Externally insulated clay masonry, with insulated timber structural frame
- Extruded polystyrene (XPS) cladding, with insulated timber structural frame
- Expanded polystyrene (EPS) cladding, with insulated timber structural frame
- Autoclaved Aerated Concrete (AAC) masonry cladding, with insulated timber structural frame
- Flat sheet-metal cladding, with insulated timber structural frame

Typical construction of the light-weight clad timber-framed external wall systems (timber, CFCS, XPS, EPS, and sheet-metal) are shown in Fig. 3 and Fig. 4. Typical construction of the massive clad timber-framed external wall systems (clay masonry veneer) is shown in Fig. 5 and Fig. 6.

The sources of the physical properties of each element in the selected external wall systems was sourced from either:

- manufacturer's data, and/or
- NatHERS material properties database and/or
- AIRAH Handbook [61] and/or
- National databases within the WUFI Pro software.

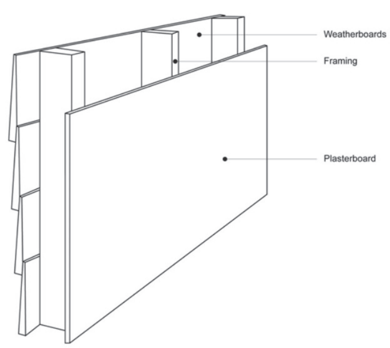

Fig. 3: Image of hardwood board clad external wall from NCC 2019

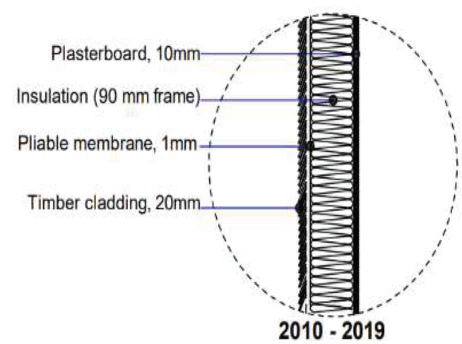

Fig. 4: Section of lightweight clad external wall system

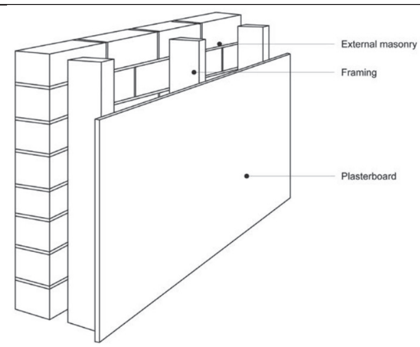

Fig. 5: Image of clay masonry veneer external wall system from NCC 2019

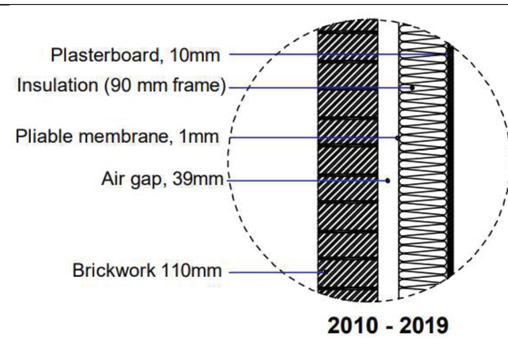

Fig. 6: Section of clay masonry veneer external wall system

Table 1: Enhancements explored for typical lightweight clad timber-framed external wall system, that are not required to include a vented and drained cavity.

Enhancements	External wall system composition
Stage 1	As per NCC 2019 requirements for the external weather resistive pliable membrane
Stage 2	As per NCC 2019 with three to four steps of increased water vapour diffusion permeance properties for the external weather resistive pliable membrane
Stage 3	As per NCC 2019 requirements for the external weather resistive pliable membrane, and the addition of a vented and drained cavity, with an ACR of 20, between the cladding system and the external pliable membrane
Stage 4	As per Stage 3, with three to four steps of increased water vapour diffusion permeance properties for the external weather resistive pliable membrane
Stage 5	As per Stage 1 and Stage 3, with the addition of an interior vapour control layer.

Table 2: Enhancements explored for the typical massive, clay masonry veneer, clad timber-framed external wall system, with a vented and drained cavity.

Enhancements	External wall system composition
Stage 1	As per NCC 2019 requirements for the water vapour diffusion properties of the external weather resistive pliable membrane
Stage 2	As per NCC 2019, with three to four steps of increased water vapour diffusion permeance properties for the external weather resistive pliable membrane
Stage 3	As per Stage 1, with the addition of an interior vapour control layer.

Previous research had demonstrated benefits from increasing the vapour permeance of the exterior to insulation, weather resistive pliable membrane and the addition of a vented and drained vapour cavity [62-64]. Recognising the impact an interior vapour control membrane can have on interstitial moisture; this research applied this additional enhancement.

At the time of writing the only external wall systems required to include a vented and drained cavity include were those clad in either clay or concrete masonry [2-4, 20]. Table 1 shows the enhancements explored for the lightweight clad external wall systems, and Table 2 shows the enhancements for the massive clad external wall systems. The properties of external weather resistive pliable membranes applied to the external wall systems are shown in Table 3

Table 3: Physical properties of vapour control membranes

Classific-ation [65]	R Value	Non-reflective	Vapour Permeancec ug/N.s	Water vapour diffusion resistance factor
Class 1	0.001	Yes	0.001	200,000
Class 3	0.001	Yes	0.143	1,398
Class 4-1	0.001	Yes	1.1403	175
Class 4-2	0.001	Yes	2.0	100
Class 4-3	0.001	Yes	9.5	21

All four cardinal orientations were explored. However, recognising the international knowledge base and local experiences, only the non-equatorial, southern, facing walls are reported here.

4.2 External climate data

Eight NatHERS climate types for south-eastern Australia were adopted. The selected climate zones accounted for most areas of development where residential and multi-residential buildings may be constructed and fit within the NCC climate zones, 6. 7 and 8 (Fig. 1) which include areas within Queensland, New South Wales and Victoria and all land areas with Australian Capital Territory and Tasmania. The NCC climate zone classifications prescribe the minimum water vapour permeance properties for the weather resistive pliable membranes. NCC 2019 required a minimum class 3 membrane for climate zones 6, 7 & 8, and NCC 2022 requires a minimum Class 3 pliable membrane for NCC climate zones 4 & 5, and a Class 4 pliable for NCC climate zones 6, 7 & 8.

Previous research has identified the need for precipitation data to be included in hygrothermal simulation for Australian buildings [48, 66-68]. The precipitation data was added to the existing NatHERS climate files. This required:

- the reformatting of the NatHERS RMY climate data into an appropriate format for the hygrothermal simulation software (EPW),
- the sourcing of new precipitation data that corresponded with the RMY climate file month and years, and
- the addition of hourly precipitation data sourced from the Bureau of Meteorology to the newly created EPW climate files.

4.3 Interior Climate

Whereas ASHRAE Standard 160 [60] requires an interior minimum heating thermostat setting of 21.1°C, the Australian NatHERS protocol has an interior heating thermostat set point of 20.0°C, and a cooling set point for the selected climates between 23.9°C and 24.0°C [69]. In this research the NatHERS thermostat set points of 20.0°C and 24.0°C for heating and cooling respectively were selected.

The Air Exchange per Hour (AEH) for the simulations applied three variables that reflect three possible scenarios observed residential buildings [70-72]. The highest simulated AEH of 0.5 was selected as it reflects the maximum leakiness of the built fabric, as specified in NCC 2022 [3] for a new residential building. The minimum AEH of 0.25 was selected, as it reflects the minimum requirement prior to the inclusion of compulsory supplementary mechanical ventilation [73] The third option of AEH 0.375 reflect recent data on the airtightness of new homes. Due to control parameters within the international Hygrothermal simulation software (WUFI Pro), the relative humidity cap was set

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to 70%RH. Parallel research is exploring the impact of uncontrolled interior relative humidity due to a current gap in Australian building regulations. The interior volume adopted in this research reflects a typical house plan, Fig. 7 that has been used in previous research activities, with an interior volume of 366m^3.

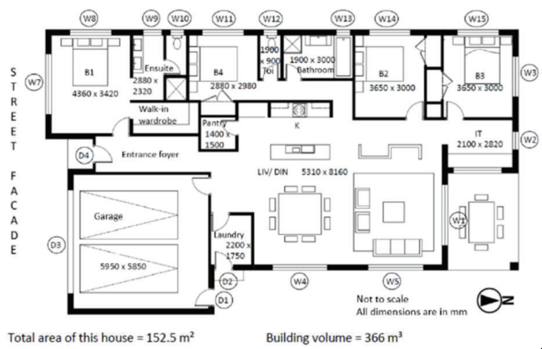

Fig. 7: House plan (Not to scale)

4.4 HYGROTHERMAL AND BIO-HYGROTHERMAL SIMULATION

In this research, adopting the principles of the most recent version of the German Standard DIN-4108, ASHRAE Standard 160 and the recently adopted AIRAH guideline DA07 [74], the simulations were completed for a period of ten-years. The results from the ten-year hygrothermal simulations were then post processed by the WUFI VTT mould growth prediction software.

5. Results and discussion

Table 4 shows a summary of the simulation results for the nine external wall systems located within NatHERS climate zones 21, 22, 27, 60, 61, 63, 64 and 66 and applying the construction and insulation principles for NCC climate zone 6. The light purple filled row represents requirements for the non-clay masonry construction systems within NCC 2019. The light blue filled row represents requirements for the non-clay masonry construction systems within NCC 2022. The blue highlight shows that only 53% of external wall systems, with an AEH-0.5, that do not require a vented and drained cavity, but do require a class 4 pliable membrane, achieved a MI of <3. In the walls without a vented and drained cavity, increasing the water vapour diffusion properties of the exterior membrane has, for AEH-0.5, -0.375, and -0.25, only increases the number of scenarios with a MI of <3 by 6%, 5% and 3% respectively.

Exploring this data in a vertical fashion, if a vented and drained cavity behind the cladding system, and the exterior pliable membranme is a minimum Class 4 product, (as shown in the red shading), this increases to 69%, 52% and 24% for AEH-0.5, -0.375 and -0.25 respectively. If, as Ambrose [70] has shown, the AEH of m,any new homes is <7.0 AEH, this would indicate that at least 50% of the southern, non-equatorial, external wall systems are at significanmt risk of mould growth.

For 85% of the simulated external wall systems to have a MI of <3.0 requires:

Table 4: Summary of external wall system hygrothermal; and bio-hygrothermal calculated Mould Index (MI) results

Exterior memb.	Vented and drained cavity	Interior vapour control membrane	Percentage of simulations with a MI ⩽3				Percentage of simulations with a MI ⩽1		
			AEH-0.5	*AYH-0.375*	*AEH-0.25*		*AEH-0.5*	*AYH-0.375*	*AEH-0.25*
Class 3 (1398)	No	Nil	63% (30/48)	42% (20/48)	0% (0/48)		46% (22/48)	21% (10/48)	0% (0/48)
Class 4-1 (175.4)	No	Nil	53% (42/80)	30% (24/80)	1% (1/80)		41% (33/80)	18% (14/80)	0% (0/80)
Class 4-2 (100)	No	Nil	58% (46/80)	30% (24/80)	3% (2/80)		45% (36/80)	18% (14/80)	3% (2/80)
Class 4-3 (21)	No	Nil	59% (47/80)	33% (26/80)	4% (3/80)		46% (37/80)	20% (16/80)	3% (2/80)
Class 3 (1398)	Yes	Nil	53% (34/64)	25% (16/64)	0% (0/64)		44% (28/64)	9% (6/64)	0% (0/64)
Class 4-1 (175.4)	Yes	Nil	69% (72/104)	52% (54/104)	24% (25/104)		61% (63/104)	39% (41/104)	19% (20/104)
Class 4-2 (100)	Yes	Nil	78% (81/104)	63% (65/104)	39% (41/104)		69% (72/104)	55% (57/104)	29% (30/104)
Class 4-3 (21)	Yes	Nil	87% (90/104)	75% (78/104)	57% (59/104)		77% (80/104)	66% (69/104)	55% (57/104)
Class 3 (1398)	No	Yes	83% (40/48)	75% (36/48)	48% (23/48)		73% (35/48)	63% (30/48)	29% (30/48)
Class 4-1 (175.4)	No	Yes	89% (71/80)	81% (65/80)	60% (48/80)		75% (60/80)	68% (54/80)	41% (33/80)
Class 3 (1398)	Yes	Yes	97% (62/64)	94% (60/64)	84% (54/64)		95% (61/64)	91% (58/64)	77% (49/64)
Class 4-1 (175.4)	Yes	Yes	96% (100/104)	96% (100/104)	96% (100/104)		96% (100/104)	96% (100/104)	96% (100/104)

- for AEH-0.50, a Class 4 exterior pliable membrane with a water vapour resistance factor of ≤21, teamed with a vented and drained cavity.
- For AEH -0.375, a Class 4 exterior pliable membrane with a water vapour resistance factor of ≤175.4, teamed with an interior vapour control layer.
- For AEH-0.25, a Class 3 exterior pliable membrane with a water vapour resistance factor of ≤1398, teamed with a vented and drained cavity and interior vapour control membrane.

The best results of 96% of simulations with a simulated MI of <3.0 occur when the exterior wall systems combines a Class 4 exterior pliable membrane with a water vapour resistance factor of ≤175.4, teamed with a vented and drained cavity and interior vapour control membrane. This is a good result, however the 4% of wall systems that are still failing the test need further investigation. The wall systems that comprised this 4% were all massive cladding systems (concrete and clay masonry). For the clay masonry veneer external wall systems, when , a Class 4 exterior pliable membrane with a water vapour resistance factor of ≤175.4, was teamed with a vented and drained cavity and interior vapour control membrane the number of external wall systems with a simulated MI of <3.0 were 50% for AEH0.50, AEH-0.375 and AERH0.25. A preliminary exploration included making the exterior membrane more vapour permeable, but due to inward vapour pressure, the calculated MI results became worse.

The reason for including the data from MI <1, even though the NCC describes the verification method with a MI of <3, the software and its associated international guidelines clearly state if a wall system has a simulated MI >1 but <3, further analysis is needed. This is due to the software simulating a perfect wall, and rarely is a perfect wall constructed.

6 – CONCLUSION

This research has utilised one dimensional hygrothermal and bio-hygrothermal simulation software to explore if regulatory compliant low-rise timber-framed external wall systems, commonly constructed in the temperate climates of south-eastern Australia, may accumulate moisture or promote interstitial mould growth. The post processing of the hygrothermal simulation results with the bio-hygrothermal software (WUFI VTT) highlighted that the timber-framed external wall systems, built in full compliance with national building regulations often had a calculated MI ≥3.0. This indicates they may be supporting unacceptable levels of interstitial mould growth, which may not become present to building occupants until a significant structural failure occurs, or the smell of mould (and mould spores) emanates from the problematic external wall system. The external wall system assemblages applied the typical low-rise timber-framed external wall system construction methods in accordance with NCC 2019 and NCC 2022 for a NatHERS 6-Star and 7-Star home, located within south-eastern Australia may or may not promote simulation based moisture accumulation and/or mould growth. It is clear from the results of this research that 99% and 47% of the external wall systems simulated had a mould index >3.0 for AEH-0.25 and AEH 0.05 respectively. This may be a significant cause for concern.

The results from the transient bio-hygrothermal simulations identified that as a building's airtightness was improved, the simulated mould index increased. When the simulated air exchange rate (AEH) was <0.40, an exterior vapour control membrane with a very low water vapour resistance may establish an adequate simulated mould index value. However, in most cases when the air exchange rate (AEH) was <0.40, there was the need to include an interior vapour control membrane.

The second aspect of this research was to explore simple, actions that could improve simulation results, namely, increasing the exterior pliable membrane water vapour permeability; adding a vented and drained cavity; and adding an interior vapour control membrane.

The results show that increasing the water vapour permeability of the exterior membrane significantly increases the number of external wall simulations with a Mould Index of <3 and <1. However, 76% and 31% of the external wall systems simulated still had a mould index >3.0 for AEH-0.25 and AEH 0.05 respectively, demonstrating that this action improved the results. It should be noted that many developed nations treat the external cladding system as a rain control layer and not a water barrier. This is due to the common expectation that moisture forms on the interior surface of cladding systems, and moisture migrates through cladding systems due to a combination of rain and wind pressure. The ability for a cladding system to freely drain this unwanted moisture, without it contacting the next layer of the envelope system provides significant durability benefits

The results regarding the inclusion of an interior vapour control layer further increased the number of external wall system simulations at achieved a Mould Index of <3 to 96% for all three AEH scenarios. Within this context, the results identified that an external wall system comprising Class 4 exterior pliable membrane with a water vapour resistance factor of ≤175.4, teamed with a vented and drained cavity and an interior vapour control membrane provided the most robust external wall system

A significant variance was identified between lightweight cladding systems and massive cladding systems (concrete and clay masonry). In many cases the capacity of the massive cladding system to absorb and store moisture led to them having the worst simulated mould index results. In parallel research options like increasing the ventilation in the vented and drained cavity, changing the water vapour adsorption properties of the in-wall batt insulation and the addition of an exterior-to-timber-frame rigid insulation product are being explored to address this concern. This is of great importance, as more than 60% of this type of building typically adopts a clay masonry veneer external wall system.

6.1 FURTHER RESEARCH

The primary focus of this research was to enhance existing external wall construction systems to achieve a

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Mould Index of <3, or better, for all nine wall systems with the eleven NatHERS climate zones of south-eastern Australia. Many of the external wall systems did not achieve this goal. This leads to several aspects that need further research, namely:

- International research has shown that applying a layer of insulation to the exterior of the building frame further reduces risks associated with interstitial moisture and mould growth risk. This improvement should be applied to wall systems that did not provide an appropriate Mould Index.
- The poor results for the clay masonry veneer external walls was unexpected. However, a review of recent experiences in Canada and research from Europe [75] has identified significant moisture and mould concerns relating the clay masonry veneer external walls. As this external wall type comprises a large percentage of new buildings, it is a matter of urgency that this external wall system is further analysed and enhanced such that acceptable Mould Index values are achieved.
- The international software tools that provide hygrothermal design guidance have generally been developed in climates much cooler than Australia, where constant conditioning is needed to ensure building interiors are kept warm for human health reasons. Australia's more temperate climates have led to a 'intermittent' conditioning regime. In hot and humid climates day-time conditioning provides the greatest hygrothermal risk. Whilst in cooler climates, night-time conditioning may provide the greatest hygrothermal risk. Within this context, more complex simulations should be completed that assess the effects of intermittent conditioning on hygrothermal simulation results for climates in southern Australia.
- This research has applied the international requirement that the relative humidity within building interiors does not exceed 70%. Data from previous research has identified that the relative humidity within many Australian buildings exceeds this condition. Further hygrothermal simulations need to be completed that include interior relative humidity conditions above 70%RH.
- This research is based on simulations completed by software that has been empirically validated in Europe, England, Canada and the United States of America. Similar forms of empirical validation need to occur within Australia, that explores typical Australian external wall systems.

6.3 Regulatory Intervention

This research highlights a few key aspects requiring regulatory intervention, namely:

- Current code compliant construction methods for the nine external wall systems simulated in this research did not provide suitable simulated Mould Index values for south facing wall systems, (and wall systems facing other orientations that are shaded). This indicates that they do not meet the verification method requirements of H4V5 of NCC as prescribed in NCC 2022. This aspect of the national building regulations requires urgent action, prior to Australia experiencing its own 'Leaking building syndrome' or 'condo crisis'.
- This research has highlighted the inter-relationship of Health and Amenity and Energy Efficiency regulations. A key aspect to this research is the rate of air changes per hour within a new low-rise timber-framed buildings. As mentioned above, the hygrothermal simulation software expects that interior relative humidity is kept below 70%. Law and Dewsbury have both identified that when applying the NatHERS method, many locations within Australia have limited times when a window or door should be opened. The Condensation section within Health and Amenity applies the AIRAH DA07 (ASHRAE160) simulation method that expects interior RH to be managed and kept below 70%. The Ventilation section within Health and Amenity includes relative humidity as one of the listed pollutants that must be controlled. The DTS ventilation method within the NCC prescribes the 5% of operable windows/doors for ventilation. However, operating these is likely to conflict with the conditions expected within the Energy Efficiency section. This is before aspects of better air sealing are considered. The hygrothermal simulation software uses the input term Air Exchange per Hour (AEH). This represents a combination of building air-sealing (air-tightness) and ventilation. That is, a building may have a measured air tightness of 0.1 AEH, but is required to have a minimum AEH of 0.25, thus requiring a mechanical ventilation system of 0.15 AEH. This aspect of the code needs to be improved, such that it recognises contemporary construction and building air-sealing methods.

7 – MODEL LIMITATIONS

It should be noted that there are several limitations to the results from this research, including:

- the physical properties of the materials simulated. If water vapour diffusion resistivity value of a material is higher than what has been simulated, the element may then trap more water vapour within the wall system leading to mould growth and/or moisture accumulation. Conversely, if water vapour diffusion resistivity value of a material is lower than what has been simulated, the element may then allow more water vapour to leave the wall system leading to lower mould growth and/or moisture accumulation.
- as per international requirements, the software has a cap on the interior relative humidity of 70%. However, as there is no numerical requirement for interior relative humidity control in Australian homes. Academic and business based researchers have measured interior relative humidity conditions well over 70% and

80% in many homes. This elevated relative humidity condition would create a greater mould growth risk than what the software currently simulates.

- the climate data used in the research has applied average climate data. Simulations that include extreme weather events would create different moisture accumulation and mould growth results.
- if a home was heated to more than 20^0C, the vapour load within the home would increase, leading to a greater risk of mould growth.
- the software is simulating a 'perfect wall'. However, walls are rarely made perfectly. Subject to construction practices, a wall may be less, or more insulated, may be less or more leaky, or may allow for a greater ingress of moisture.

Each of these scenarios would increase risks associated with moisture and mould. Within this context, the results presented here may be conservative.

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