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LOW-CARBON INTENSITY TIMBER FAÇADE SYSTEMS FOR MID-RISE BUILDINGS

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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 buildings. The energy efficiency regulations have led to increased amounts of insulation within façade systems, combined with a greater focus on exterior weather-tightness and interior building-sealing (airtightness). Furthermore, most Australian mid-rise façade systems comprise composite structures of high-embodied energy concrete, steel and clay brick components. This research seeks to establish what the built fabric requirements for timber-framed and solid-wood mid-rise high-performance façade systems may need to comprise for Australia's warm-humid, temperate and cool temperate climates such that they do not accumulate moisture or support surface or interstitial mould growth

KEYWORDS: Timber-framed, Condensation, Mould, Hygrothermal, Mid-rise

1 – INTRODUCTION

This research is exploring the built fabric requirements for the design and construction of timber-framed façade systems for mid-rise, (3 to 8 storey) buildings in Australia. Whilst balloon framing is seemingly common in north America [1-3], and northern Europe [4], the majority of mid-rise façade systems in Australia are constructed from masonry (concrete and clay brick) and/or composite steel structures [5]. Recognising the need to reduce the carbon-intensity of mid-rise façade systems, this research is exploring how Australian solid wood and engineered wood products may be utilised within high-performance mid-rise buildings Whereas parallel research is exploring aspects of structure and prefabrication [6], this research is focussing on hygrothermics and the built fabric assemblages that may be needed to illuminate long-term moisture accumulation and mitigate surface and interstitial mould growth [7]. A national survey conducted by the Australian Building Codes Board and directed at design and construction professionals identified that up to 40% of multi-residential buildings had a concerning presence of condensation and/or mould [8]. The confluence of weather-tightness and energy efficiency requirements within the Australian national building regulations and ventilation have been identified as significant contributors to this increased presence of condensation and mould within Australian buildings [9-13].

2 – BACKGROUND

In Australia the gradual shift to a low-carbon economy is driving an exploration of methods to reduce the carbon intensity of the predominant concrete and steel façade systems [14, 15]. However, this may also allow for an opportunity to explore the use of timber-framed facade systems that could provide a lower carbon intensity [16-18]. It is also internationally recognised that all construction materials, whether they be concrete, steel or timber, are susceptible to damage from mismanagement of inward- and outward-bound moisture. Timber products can provide a lower carbon intensity but if the design and construction of moisture control is not adequately completed, there are significant durability and human health implications.

Cross disciplinary research conducted in Australia has highlighted the connection between the energy efficiency regulations and the presence of condensation and mould in buildings. However, much of this research has focussed on the design of low-rise timber-framed external wall systems and unconditioned (cold) roof spaces[8, 12, 19-25]. Managing moisture and mould within buildings and within the building envelope systems not a new problem [26-37], 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 [34, 38-41],

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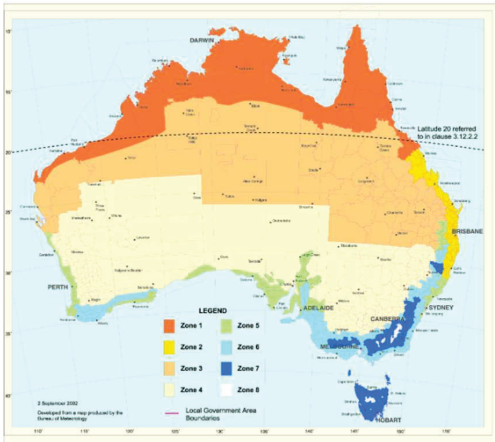

Fig. 1. Climate zone map for thermal design [42]

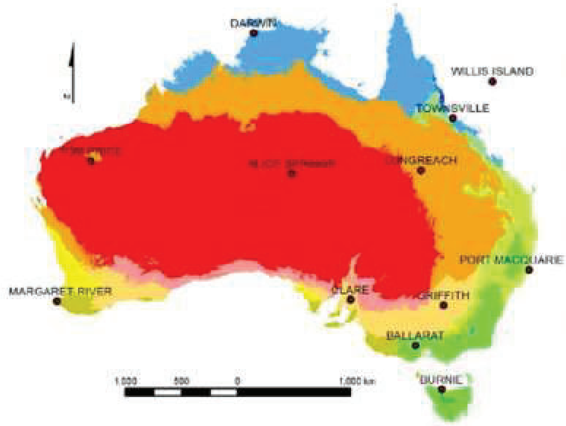

Fig. 2. Koppen-Geiger climate classification map for Australia for 1980–2016 [43]

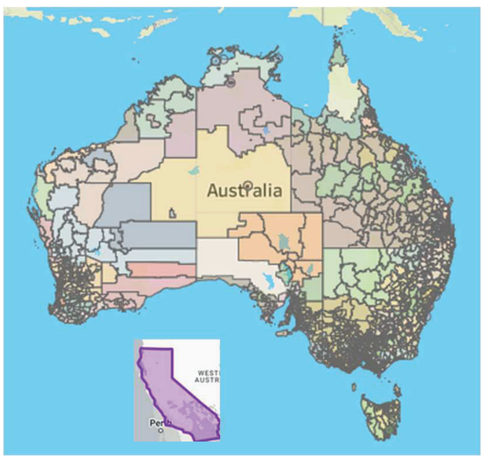

Fig. 3. NatHERS climate zone map for thermal design [44]

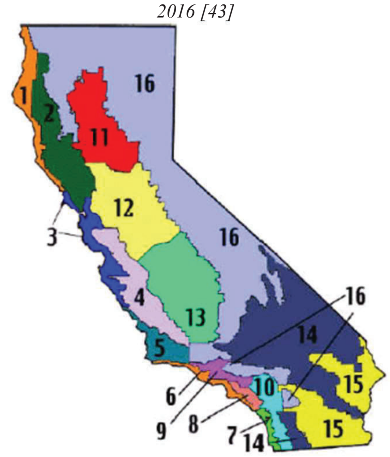

Fig. 4. CEC Title 24 Residential Compliance Manual [45]

- Since the 1980's as governments around the world have attempted reduce energy used to condition buildings [46-52]

Fortunately, the climate typology in many countries can be quite finite, supporting a focussed guidance for design and construction professionals and building occupants. However, the large landmass of Australia, with significant areas of coastal fringe, encompasses several climate types.

Fig. 1 shows the NCC climate zone map for Australia, which has been specified since 2003 [42] and includes eight climate types, from hot and humid to cool-temperate. Fig. 2 shows a recent Koppen-Geiger climate classification map for Australia which includes sixteen climate classifications. Recognising some of these limitations, a more detailed climate segregation was established by the Nationwide House Energy rating Scheme, which established 69 broad climate zones for Australia (Fig. 3) [44]. However, even within the NatHERS postcode derived climate zones, some locations ask the user to select one from up to three climate zones for simulation purposes. For comparison purposes, the sixteen climate zones from the Title 24 climate map for California [45] is shown in Fig. 4, and the purple inset in Fig. 3 shows the relative size of California to Australia. Significantly, the method to ascertain and select data for building energy rating purposes does not consider precipitation or background relative humidity [53], yet these two inputs are critical for hygrothermal simulation [54-56].

Surface and interstitial mould that is visible to the human eye can pose a significant risk to human health [57-59], and Nath [60] identified that Australia has twice the Asthma rate of the OECD. United Kingdom researchers identified in 2021, that up to £1Billion of the National Health Service budget is spent on the treatment of human health conditions resulting from moisture and mould in buildings[61].

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 [34], whilst the first standard in the United Kingdom was produced in 1975 [35], 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 [62-64], with regular updates until 1974. North America, including Canada, had their own challenges and the 'condo crisis' in during the 1980s and 1990s [37, 65, 66]. 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 [66-68]. Recent estimates have established that the leaky building syndrome in New Zealand has cost its economy more than NZD$47B [69, 70].

Most of the previous research in Australia has focussed on low-rise residential buildings. That research has identified that the external wall systems of new housing within temperate and cool-temperate Australia, with an airtightness of <8ACR@n50, should include:

- a vented and drained cavity behind the primary cladding system, combined with
- a vapour permeable membrane on the exterior side of the insulation, and
- a vapour control membrane on the interior side of the insulation layer [71-75].

But do these same principles apply to mid-rise buildings? In Australia, low-rise timber-framed buildings generally have low internal moisture loads and rates of occupancy. Subject to the mid-rise building's function, the interior occupancy rates could be five to seven times greater than a residential building. The median house size in Australia is 232m^2 [76], with an average of 2.52 persons per household [77], which equates to 92m^2 of household floor space per person. By comparison densely populated office spaces include <10m^2 per person [78]. Whether this building passively or mechanically manages the interior generated vapour load, it will be at least nine time greater than a residential building, and as noted above, Australia seems to currently have a condensation and mould problem in new housing.

Within this context, this research intends to explore the inter-relationship between built fabric choices, insulation, airtightness, weather-tightness, and ventilation, of timber-framed and solid-wood mid-rise façade systems.

3 – PROJECT DESCRIPTION

This research will use a combination of international literature, one dimensional (1D) and two dimensional hygrothermal simulation software and test walls located within test buildings to ascertain:

- What the most climatically appropriate material assemblages for a timber-framed or CLT facade systems should be in at least three different Australian climate types,
- Establish if one- and two- dimensional hygrothermal simulation results are similar to measured moisture and temperature conditions within test walls
- Provide data to further calibrate hygrothermal simulation tools.

This research will not be exploring other regulatory aspects, like fire. This research will provide guidance to industry and government policy makers regarding options for mid-rise timber-framed and CLT façade systems that adequately manage moisture and may provide a pathway to a low-carbon and sustainable future.

4 – EXPERIMENTAL SETUP

This research which comprises a cross-disciplinary research team and industry collaborators will explore the hygrothermal design parameters via four distinct stages, namely:

- An international literature review, to establish some likely assemblage patterns for cool-temperate, temperate and warm humid climates.
- The completion of one dimensional hygrothermal simulations to confirm climatic suitability for the nominated mid-rise facade systems.
- The completion of two dimensional hygrothermal simulations to confirm climatic suitability for the nominated mid-rise facade systems.
- The construction, installation and detailed measurement of test walls, and
- The analysis of simulated and measured data to inform software calibration.

4.1 INTERNATIONAL LITERATURE REVIEW

The first stage of the research involves the cross disciplinary academic- and industry-based team working with a PhD candidate to complete an international literature review examining the hygrothermally successful and unsuccessful use of solid-wood and engineered-wood products within mid-rise façade systems. Case studies will include published data from northern Europe, Canada, the United States of America, the United Kingdom and some low to mid-rise examples from Australia.

4.2 ONE- AND TWO- DIMENSIONAL HYGROTHERMAL AND BIO-HYGROTHERMAL SIMULATION

The façade systems identified within the literature review stage will be tested via transient hygrothermal and transient mould growth calculation to ascertain mould growth risks and/or moisture accumulation. The transient simulation methods will adopt principles established in previous research [79-82] and the principles of ASHRAE Standard 160 [83] and the Australian AIRAH guideline DA-07 [84]. Recognising the significantly different climatic conditions in Eastern Australia, the hygrothermal simulations will explore options for Launceston (cool-temperate), Sydney (marine-temperate), and Brisbane (warm-humid). These three climate types encompass the largest areas of development and construction in Australia.

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One-dimensional simulation will analyse assemblages at a façade system level, whilst two-dimensional simulations will be used to explore:

- individual component performance,
- facade component connections, and
- Façade-floor plate/column connections.

The completion of the hygrothermal simulations will provide a deep understanding of the software capabilities and impacts of various interior climate, exterior climate and material physical property inputs.

4.3 Test wall empirical data

Empirical studies have been extensively explored for the development and calibration of building energy rating software [85]. In a similar fashion, since the 1990's countries and academic institutions have been exploring the empirical validation of hygrothermal simulations tools. This has included test buildings, test walls and component testing in Germany, Finland, Japan, Canada, the USA and New Zealand [85-90].

Recognising the diverse climates of Australia, this stage of the project will select high-performance timber-framed façade systems identified in the hygrothermal simulation stage of the project and construct full-scale test walls. The test walls will be installed onto existing test buildings in Launceston (Fig. 5), Sydney (Fig. 6) and Brisbane (Fig. 7). The interior of each test building

Fig. 5. The Launceston test buildings (cool-temperate climate)[85]

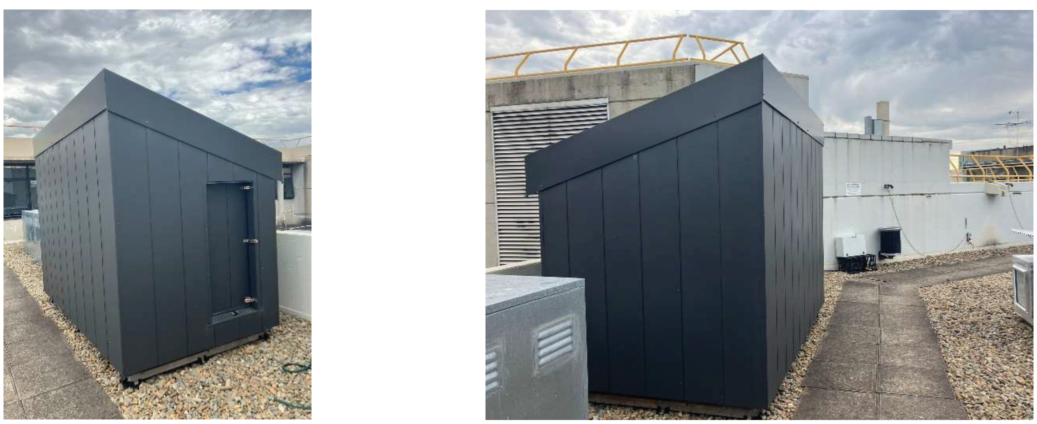

Fig. 6. The University of Sydney test building (temperate climate)

Fig. 7. The Queensland Department of Agriculture and Fisheries test building, Salisbury (warm-humid climate)[87]

will be controlled in a manner that maintains the temperature and relative humidity to agreed values that represent a chosen function. To represent human occupation, humidifiers will add moisture to the air and dehumidifiers will keep the interior relative humidity below internationally accepted values (i.e., <65%RH).

Each wall system will include a series of data logger connected temperature, relative humidity and moisture sensors, enabling a longitudinal data acquisition. The test wall will be tested and commissioned prior to the southern hemisphere winter and will be monitored for one calendar year, to allow for the measurement of winter moisture adsorption and summer drying. The sensor array will allow for the observation of inward and outward flow of heat and moisture.

Recognising the importance of mould growth and the development of mould growth algorithms [91-99] if the timber elements maintain a higher than expected moisture content, or the insulation layer maintains a higher than expected value for relative humidity, there will be the opportunity for a forensic analysis of mould growth.

4.4 Software calibration

An integral part of any empirical research is the collection of simulation based and site measured data to allow for the calibration of simulation tools [98, 100-106]. This process will allow for the comparison of:

- Simulated and measured temperature
- Simulated and measured relative humidity
- Simulated and measured timber moisture content

The comparison of these data sets may identify algorithms that need improvement and/or construction material physical properties that need further refinement.

5. RESULTS AND DISCUSSION

As this research is in its early stages, this paper is presenting the research methodology. As the research progresses, further articles will be published.

6. CONCLUSION

This research aims to explore opportunities and built fabric assemblages for the design and construction of mid-rise timber-framed façade systems in Australia. Whilst timber-framed mid-rise façade systems are common in many parts of the northern hemisphere, they are not common in Australia, showing a gap in both system knowledge and system performance. With a focus on hygrothermal performance and recognising Australia's diverse climates, the research will include an in-depth one and two dimensional hygrothermal analyses of likely systems, followed by the installation and detailed measurement of full-scale test walls in Launceston (cool-temperate), Sydney (marine temperate) and Brisbane (warm humid). The findings of the research will be lead to the development of design guides for the design and construction professions, and policy makers.

The data collected will support ongoing calibration of hygrothermal and bio-hygrothermal (mould growth) simulation tools.

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