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Is new housing a health hazard?

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Abstract: The National Construction Code has been regularly enhanced since 2002 with an effort to reduce greenhouse gas emissions. Many aging, and very young Australians spend most of their time within their homes. Coincidently, in Australia, asthma is the leading cause of disease in children aged 0 – 14 years, accounting for 17.9% of the total burden in boys and 18.6% in girls. Many researchers have supported a connection between damp housing and sensitivity to dust mites and other childhood respiratory symptoms. Within Australia's temperate and cool temperate climates, the commensurate change in energy efficiency requirements in the national building regulations may have inadvertently created ideal interior environments that promote mould growth. If the built environment is promoting mould growth, leading to sick building syndrome, it is a matter of serious concern that could be resulting from design or technical flaws in the building fabric. This concern, which has been raised by medical scientists, requires the action of architects to provide guidance on methods to passively, or actively, manage air-borne moisture within homes and workplaces. This paper attempts to bridge the gap between architectural and medical science perspectives in this area of study.

Keywords: National Construction Code; greenhouse gas emissions; sick building syndrome; childhood respiratory symptoms; condensation; mould.

1. INTRODUCTION

The house is the principal form of Australian dwelling and also a large consumer of energy and a significant contributor to greenhouse gas emissions worldwide (Harrington et al., 1999; McLeod, 2013; Dewsbury, 2015; Ren and Chen, 2015b). Since 1998, the Australian state and federal governments have developed legislation and building regulation to reduce greenhouse gas emissions (AGO, 1998; ABCB, 2003; COAG, 2009; Harrington, 2014). The focus has been to create more thermally comfortable internal environments through enhancement of envelope based energy efficiency requirements for new commercial and residential buildings, thereby reducing simulation based heating and cooling energy needs (Geard, 2011; McLeod, 2013; Ren and Chen, 2015a). Dewsbury (2015) stressed the need for a policy framework to reduce greenhouse gas emissions and improve thermal performance in the Australian housing sector. The Nationwide House Energy Rating Scheme (NatHERS) is established quantify and evaluate building envelope thermal performance (Ballinger and Cassell, 1995; Thwaites, 1995). A focus on Star Ratings for residential buildings has evolved based on reducing heating and cooling energy use. However, the materials and systems used to improve the external envelope demand further careful consideration to avoid the creation of significantly unhealthy interior environments (Dewsbury and Law, 2016b; Dewsbury and Law, 2016a; Dewsbury *et al.*, 2016a; Dewsbury *et al.*, 2016b; Dewsbury *et al.*, 2017; Law and Dewsbury, 2018).

Higher quality indoor environments requiring less conditioning energy demand high-quality water, air and water vapour control layers. In climates that require heating, water vapour must be allowed to passively leave the building envelope. Many have confused vapour control with ventilation or infiltration or building breathability (Ambrose and Syme, 2017). When water vapour is trapped within the envelope the relative humidity and dew-point temperature increase, enabling moisture to form. The combination of a warmer home, a higher relative humidity and the presence of moisture combine to achieve perfect mould growing conditions (Crook and Burton, 2010; Dewsbury and Law, 2016a). Additionally, there is sufficient medical evidence that occupant health is adversely affected by wet or mouldy buildings, which are classed as sick buildings (Davies *et al.*, 2004; WHO, 2009; Fukutomi and Taniguchi, 2015).

2. BACKGROUND

The National Construction Code (NCC) (formerly the Building Code of Australia) is a national standard administered by the Australian State and Territory jurisdictions (ABCB, 1996). The NCC Volume I and Volume II, incorporates provisions for the design of energy efficient Class I and Class II residential buildings (ABCB, 2010). The National Greenhouse Strategy committed Australia to develop a minimum energy performance requirement for new houses and provided opportunities to develop performance measures, or ratings, such as the Nationwide House Energy Rating Scheme (NatHERS) (ClimateWorks, 2010). Australia has actively responded to greenhouse gas emission abatement strategies (ClimateWorks, 2010; IPCC, 2014) and a range of measures have been developed by industry and government to achieve a reduction in greenhouse gas emissions in the residential sector (Head *et al.*, 2014; IPCC, 2014; Dewsbury, 2015). One such measure is the residential house energy star-ratings for new Australian houses (Delsante, 2005; McLeod, 2013; Dewsbury and Law, 2016b).

The NCC does not regulate condensation and mould (Dewsbury *et al.*, 2016c) despite concern from building regulation stakeholders that deficiencies in the regulations can lead new Class 1 and Class 2 buildings to experience unacceptable levels of condensation and mould (Dewsbury and Law, 2016a; Dewsbury *et al.*, 2016c; Viggers *et al.*, 2017). Internationally, in the last ten to thirty years, the building regulations of New Zealand, United States of America, Canada, United Kingdom and Europe have increasingly included regulations pertaining to the management of water vapour and the mitigation of condensation and mould (Dewsbury and Law, 2016a). The Australian Building Codes Board and Industry based partners have increasingly identified a national condensation problem in Australia (Dewsbury and Law, 2016b; Dewsbury *et al.*, 2016b).

High humidity and poor ventilation, leading to condensation and mould, is a problem in many homes in Australia (Ambrose and Syme, 2017). Detailed analysis of Australian regulations is essential to compare thermal performance and energy efficiency of the internal spaces constructed prior to 2003 and now, and to understand the main cause of condensation problems which may not previously have existed. Changes in building materials and construction techniques to improve energy efficiency may be creating unhealthy internal environments (Ambrose and Syme, 2017). There is a strong need to frame Australian building regulations to mitigate condensation and mould in residential dwellings. Condensation and mould problems may continue to increase if we continue to improve energy efficiency without understanding the water vapour control and management detailing that is required of the built fabric (material properties) (Ambrose and Syme, 2017). This suggests an urgent need to determine if any relation exists between energy efficiency and condensation problems in new residential buildings.

2.1 Chronological development of House Energy Rating schemes

In the 1980s, the Five Star Design Rating (FSDR) scheme was developed and adopted in NSW, Victoria and South Australia (ABCB, 1994). The FSDR certified houses that met a number of requirements mainly based on glazing area, thermal mass quantity and insulation levels for energy efficient design (McLeod, 2013). During the 1990s, individual states began to develop their own House Energy Rating Scheme (HERS). HERS are methods of rating the energy performance or energy-efficiency of a house (Williamson et al., 2006; Kordjamshidi, 2011; Daniel et al., 2015). The most effective HERS was for the state of Victoria but was not suited to all climates of Australia. Therefore a more flexible Nationwide HERS (NatHERS), was developed that could be applied to the different climate zones of Australia (McLeod, 2013). The aim was to create a standard rating system throughout the country to determine a house's energy efficiency (Geard, 2011; NatHERS National Administrator, 2012; Daniel *et al.*, 2015; O'Leary *et al.*, 2016). Later HERS was implemented in NSW as the Energy Smart Rating Scheme and was adopted by local councils (ABCB, 2010).

The regulations for households are formulated by the NatHERS, which is adopted in the National Construction Code (NCC) and sets the minimum performance requirements for housing thermal performance in the form of a star rating (ABCB, 2010; 2013; 2015; 2016). NatHERS has established the framework for three endorsed thermal modelling software programs (Geard, 2011): AccuRate; First Rate; and BERS. Building energy efficiency compliance with the NCC can be demonstrated by any one of these programs. In order to achieve the NCC energy efficiency standards, houses generally need to use insulation and weather sealing (airtightness) measures (McLeod, 2013; Dewsbury, 2015). As the amount of envelope insulation and application of airtightness measures have increased, the internal air temperature within cool temperate and temperate climate houses has also increased (Ambrose and Syme, 2017; McLeod and Swainson, 2017). Coincidentally, a 2016 study of condensation in Class 1 and Class 2 buildings identified a nationwide concern (Dewsbury and Law, 2016b).

Indoor environments are a significant determinant of occupant's health. Many people spend considerably more time at home, where the impact of the indoor environment can be a significant health determinant (Howden-Chapman et al., 2007; Samuel, 2009)2007; Samuel, 2009. As regulation regarding the interior environment has not developed in parallel with energy efficiency regulations, internal environments may be increasingly unhealthy due to increased presence of mould (Dewsbury and Law, 2016b; McLeod and Swainson, 2017).

2.2 Healthy indoor environments

Indoor Environmental Quality (IEQ) comprises of Indoor Air Quality, Thermal comfort, Acoustic comfort and Visual comfort (Lipták-Váradi, 2017). Problems with the IEQ of a building have direct effects on the comfort, health and productivity of the occupants (Lin *et al.*, 2007; Heinrich, 2011; Hernberg *et al.*, 2014; Ezzati and Baumgartner, 2017). Wet buildings, or buildings with moisture or the visual presence of mould, fall into the category of sick buildings, as mould spores significantly impact on human health.

Extensive international research has quantified the conditions for mould growth and sporing within buildings. Figure 1 shows a graph from Viitanen & Ojane (2007), which defines substantial mould risk as possible when the temperature is between 20°C and 50°C and the relative humidity is above 77%. This pattern is re-affirmed by other research scientists (Viitanen and Ojane, 2007; Krus *et al.*, 2010; Vereecken *et al.*, 2011; Cederlund and Josefsson, 2015; Vereecken *et al.*, 2015). This research will be further developed to include mould growth algorithms within condensation risk software tools produced in Germany (WUFI).

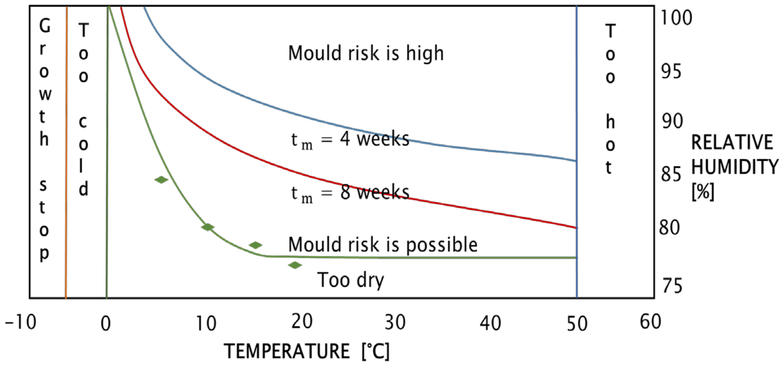

Figure 1: Viitanen and Ojane graph showing mould risk ideal temperatures and relative humidity

PUBMED, MEDLINE and EMBASE databases were searched for epidemiological studies on the adverse health effects of indoor air pollutants among Australian children (prenatal - 14 years) published between January 1995 and January 2018. Searches employed three groups of keywords in combination: dampness, fungi, fungus, mould; health, asthma, wheeze, cough or respiratory; and house, home, or dwelling. The literature reveals sufficient evidence for asthma exacerbation, cough, wheeze, and upper respiratory tract symptom health outcomes being associated with indoor dampness or mould. The current Australian evidence based on long-term health effects of indoor air pollution in children is weak, with few studies conducted. There have not been any detailed studies conducted in Southern Australia on health issues related to condensation problems in homes for vulnerable age groups – the elderly and children. However, several international studies on school children have identified health implications from condensation and mould in the built environment (Fukutomi and Taniguchi, 2015). Coincidentally, Asthma is the leading cause of burden of disease in children aged 0–14 years in Australia, accounting for 17.9% of the total burden in boys and 18.6% in girls (Poulos *et al.*, 2005; Poulos *et al.*, 2007). Dewsbury *et al* identify significant health, social and economic costs in their scoping study for the Australian Building Codes Board (2016a). Moulds are ubiquitous and mould spores are a common component of household environments (Ezzati and Baumgartner, 2017). However, when the amount of mould or mould sporing is greater than the background environment, it has been found to lead to several medical conditions impacting on short and long term human health (WHO, 2009; Crook and Burton, 2010). A detailed study of contemporary residential construction systems in Southern Australia is needed to prevent the uncontrolled development of indoor environments that support the growth of mould.

3. METHODOLOGY

To establish whether the current regulatory approach may be inadvertently making housing unhealthy requires five stages of research, namely: (1) thermal simulation of pre- and post- NCC and NatHERS housing to establish the likely temperature changes within housing from 1996 to 2016; (2) analysis of typical materials used to improve housing thermal conditions, including air-tightness; (3) analysis of what data is available regarding interior relative humidity values; (4) detailed condensation risk analysis of the built fabric; and (5) detailed mould-growth simulation. This paper will discuss the first three parts of this process. Future papers will discuss the final two components of this research.

3.1 Changes in building regulation

To evaluate how house temperatures may have changed, a house was selected for thermal simulation. The selection of the house plan was informed by advice from the Housing Industry Association, Master Builders Association and Building Designers Association. The house was simulated with no thermal improvements and improvements commensurate with NCC changes since 2003, shown in Table 1.

Table 1: Insulation levels from BCA 2003 to NCC 2016

Building Regulation	Insulation levels (R-values)		
	Roof	External Walls	Floor
Pre 2003	-	-	-
BCA 1996 (amndt 12) - 2005	3.8	1.9	1.0
BCA 2006 - 2009	4.3	2.4	1.5
BCA 2010 - 2014	4.6	2.8	2.75
NCC 2015 - 2016	5.1	2.8	2.75

3.2 House thermal simulation

The AccuRate software was used to simulate the house plan. The software calculates the interior temperature and likely heating/cooling energy that may be consumed throughout the year and allocates a star rating. The thermal simulation of the selected 'average sized house' was completed using the AccuRate Sustainability Software (version 2.3.3.13). The simulations were completed and applied the six NatHERS climates represented in Tasmania.

3.3 Condensation risk simulation

The ISO 13788 compliant software JPA Designer was used to simulate the built fabric systems to assess the risk of interstitial condensation. This software has been used to complete simulations for typical external wall systems shown in the NCC. The simulations included the change in insulation levels and air-tightness measures, as described in the NCC.

This method was selected to ascertain what building materials may be in use that could exacerbate or increase the relative humidity or promote the presence of moisture or mould growth. A review of common construction materials used to improve the thermal performance of the building envelope and personal discussions with product manufacturers was undertaken. Data from published reports (Ambrose *et al.*, 2013; Ambrose and Syme, 2017) and buildings measured by UTAS (Dewsbury *et al.*, 2016b) were reviewed to ascertain relative humidity values in new housing.

4. RESULTS & DISCUSSION

The results from the AccuRate simulations, JPA simulations, building material usage and measured relative humidity values is shown and discussed below.

4.1 House thermal simulations

The results from the AccuRate simulations are provided in a text file format, which was imported into Excel for statistical analysis. The data includes a simulated temperature for each conditioned and unconditioned zone in the house. The analysis completed included histogram methods. Figure 2 shows the temperature data from the typical house modelled from the BCA pre-2003 house simulations and NCC 2016 house simulations. A careful analysis of the data shows a dramatic increase in room temperatures (16°C - 22°C) within the simulations from the pre-insulation requirement of 2001 to the current requirements of the NCC 2016.

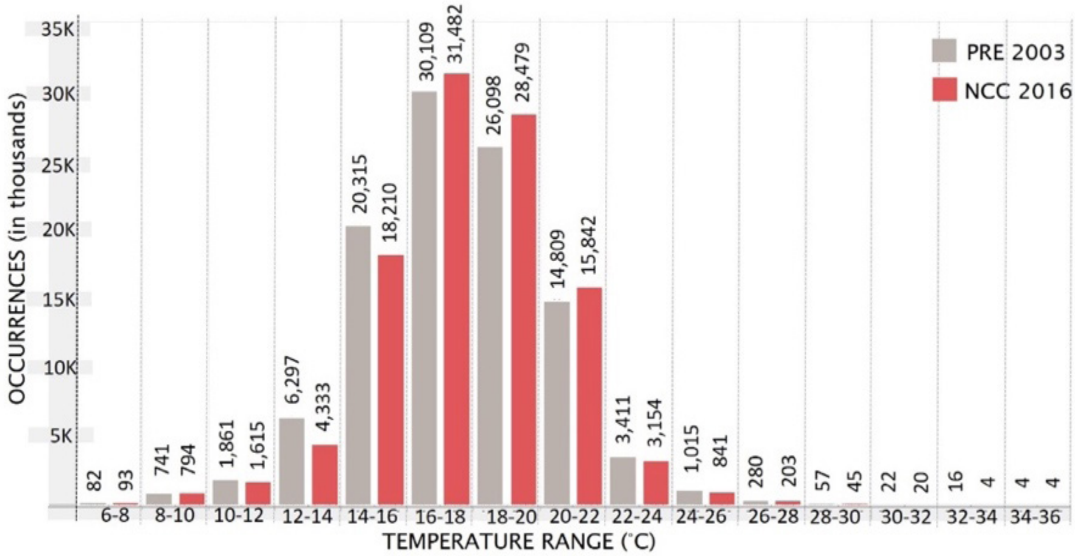

Figure 2: Comparative statistical analysis of temperature data

4.2 Condensation risk simulations

Figure 3 shows an example of the condensation risk diagram produced by the JPA software. The diagram on the left shows the results for BCA pre-2003, where the water vapour is condensing within the membrane and within the cladding system. The diagram on the right shows the simulation result for a typical NCC 2016, where the water vapour is still being trapped within the wall frame. If this includes a vapour impermeable membrane, the amount of moisture trapped in within the wall frame can be in excess of 5kg/m^2. The materials used to construct the external envelope and how the envelope managed water vapour transport had the greatest impact on condensation risk within the built fabric.

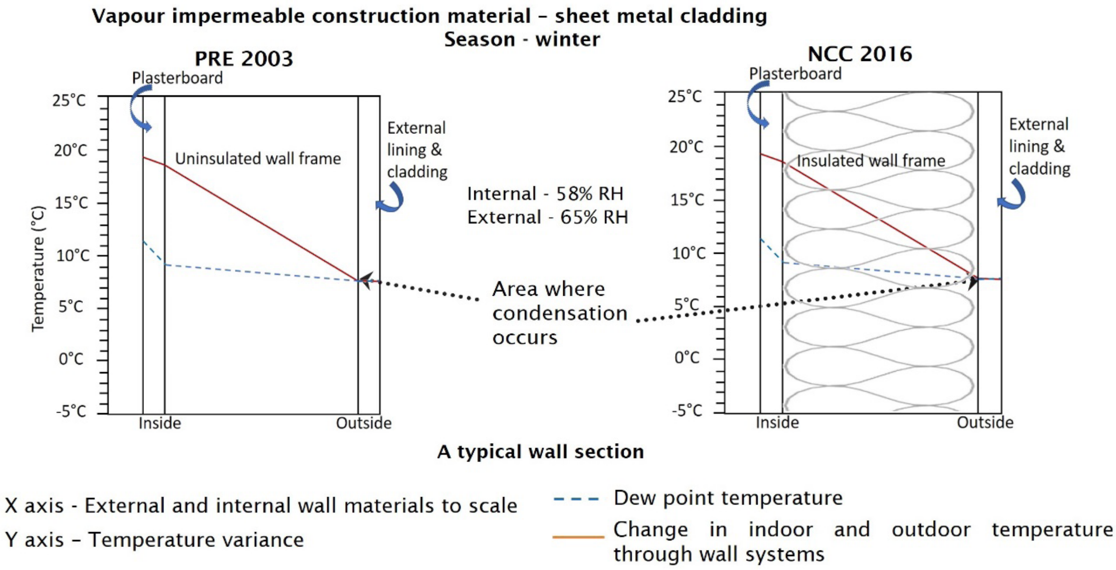

Figure 3: Condensation Risk simulation diagram using JPA software

At face value the data shows temperatures conducive for moulds to grow as discussed by Viitanen and others above. Yet within new buildings, the design and construction professions and building occupants have expressed concern about an increased presence of moisture and mould. This would indicate that other factors may be at play.

4.3 Relative Humidity in Houses

The analysis of the relative humidity values within new homes provides insights. Data from the CSIRO Indoor air study (Cheng *et al.*, 2010) and previous UTAS research measuring interior environments in new homes was analysed. Generally, the relative humidity in a home is expected between 40% and 55%. However, as shown in table 2, the relative humidity values within living zones was as high as 86% and within roof spaces greater than 95%. As the relative humidity increases, so does the dew-point temperature.

Table 2: Measured Relative humidity values

	CSIRO	**UTAS measured houses**		
		House 1	House 2	House 3
House interior RH%	35% to 65%	41% to 71%	23% to 80%	40 to 86%
Roof space RH%		70 to >95%	31 to >95%	38 to >95%

The internal temperatures are rising due to the use of materials that are vapour impermeable. The increase in relative humidity increases dew-point temperature and increases the risk of moisture and condensation. Additionally, as shown by Viitanen & Ojane (2007) above, these higher levels of relative humidity, combined with the warmer interior environments are providing ideal climates for mould growth.

5. CONCLUSION

There is sufficient evidence available from the field of medical science to prove that exposure to mould is linked to asthma exacerbations, and that mould might be a trigger for the development of asthma. The connection between damp housing and sensitivity childhood respiratory symptoms has been well established by many medical experts. There is an urgent need to identify high relative humidity, excess moisture and condensation causing materials in current housing.

Within other developed nations, regulations and simulation tools have been developed to understand the hygrothermal properties of building materials, and construction systems that provide thermal bridges or high water vapour conditions that lead to uncontrolled moisture and mould in buildings. To date, this field of building science has not been applied in Australian building regulations. By using commercially available condensation risk software, this research has demonstrated that contemporary regulatory compliant construction methods may be leading to a significant increase in temperature, relative humidity and moisture, and likely mould growth, within the external envelope of new houses.

There are limitations in JPA software as it follows the hybrid steady state Glaser method. The next stage if this research will use the Wufi software, which simulates heat and water vapour flows within wall systems for each hour of a calendar year (8760 hours), and for multiple years. The results from the Wufi simulations will provide guidance to industry and government about how to best manage heat and moisture transport in new buildings, while buildings are still in the Design & Documentation phase.

Finally, human health is foremost when it comes to assessing the overall comfort of the built environment. If for any reason the built environment is leading to sickness or a negative impact on occupant health, then it is a matter of serious concern and could signify a design or technical flaw in the building system. This field of Architectural science that must be appropriately addressed by Architects and building designers.

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