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Field Studies to Investigate Impact of Increasing R-value of Building Envelope on Winter Indoor Relative Humidity of Auckland Houses

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Abstract

Purpose / Context - The study investigates relationships of winter indoor relative humidity and R-value of building envelope of the Auckland houses.

Methodology / Approach – Field study of indoor micro climatic conditions. Air temperatures and relative humidity adjacent to floors and ceilings of different indoor spaces of the two houses with different R-value in their envelopes and shaded outdoor spaces were continuously measured and recorded at 15 minute intervals, 24 hours a day, by Lascar EL-USB-2 USB Humidity Data Logger during the winter months.

Results – The study identifies the differences of winter indoor relative humidity of Auckland houses with different insulation and glazing in their envelopes and the major problems of building thermal design of local house with lightweight timber frame construction.

Key Findings / Implications – Increasing R-value in building envelope of Auckland houses in accordance with the requirements from NZS 4218:1996 to NZS 4218:2009 can significantly increase 19.6% of winter time when indoor relative humidity are 40% and 60%. Maintaining indoor relative humidity between 40% and 60% can minimize the indirect health effects.

Originality – Quantitative relationships between R-value in building envelope and winter indoor relative humidity, and the identified thermal design problems of local houses with lightweight timber frame construction can be good references for improving indoor health conditions of the future Auckland housing development.

Keywords - Building Envelope, Indoor Health, Insulation, House, Relative Humidity

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1. Introduction

Auckland has a temperate climate with comfortable warm, dry summers and mild, wet winters. Common problems of indoor micro-climatic conditions of Auckland houses are low air temperature and high relative humidity during the winter (Figure 1). The World Health Organisation recommends a minimum indoor temperature of 18°C for houses; and 20-21ºC for more vulnerable occupants, such as older people and young children (WHO 1987). The current New Zealand Building Code does not have a general requirement for the minimum indoor air temperature, although it has a requirement of 16ºC for more vulnerable occupants, such as older people and young children (DBH 2001; SNZ 1990). The previous study shows that most of the health effects such as bacteria, viruses, fungi, mites, respiratory infections, allergic rhinitis, asthma, etc. have increases associate with increase of indoor relative humidity (Figure 2). Maintaining indoor relative humidity between 40% and 60% can minimize the indirect health effects (Arundel *et al*. 1986). High relative humidity during the Auckland winter is a major issue for building indoor health conditions. The abundance of two major causes of allergy, mites and fungi, increase proportionately with average indoor relative humidity. New Zealand has some of the highest levels of house dust mite allergens in the world (Siebers, Wickens, and Crane 2006). Visible mould growth on indoor surfaces is a common problem in over 30% of New Zealand houses (Howden-Chapman *et al.* 2005). Mould growth is likely on almost any building material if the relative humidity exceeds 75-80% (Coppock and Cookson 1951; Block 1953; Pasanen *et al*. 1992). One option to prevent mould growth on indoor surfaces is to control the indoor humidity level under the threshold (80%) of mould gemmation. If the mould spores never start gemmation then moulds will not grow on indoor surfaces (ASHRAE 1993; Su 2006). According to international and national standards, the indoor relative humidity should be lower than 60% for indoor air quality (ASHRAE 1992; ASHRAE 2001; SNZ 1990). High relative humidity can not only cause some physical discomfort but also negatively affect indoor health conditions.

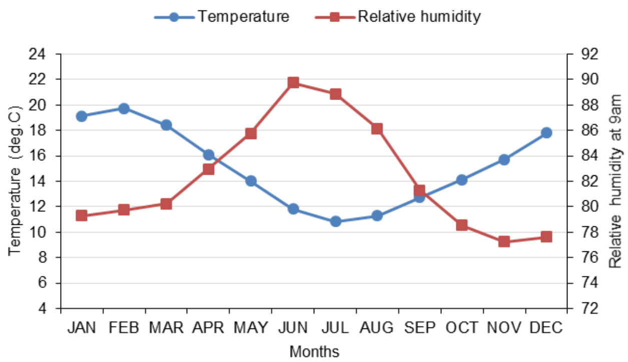

Figure 1 Auckland monthly mean temperature and relative humidity (source: NIWA)

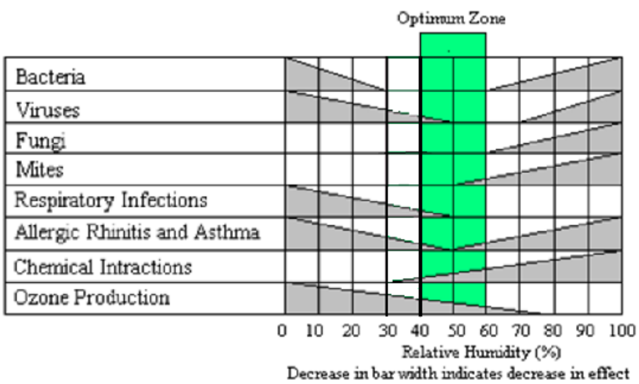

Figure 2 Health effects and indoor relative humidity (source: Arundel et al. 1986)

On 25 November 1977 legislation was introduced making it compulsory for new homes to be insulated and these requirements came into force on 1 April 1978 (SNZ 1977, BIA 1992). Minimum R-values for building elements (Roof: 1.9, Wall: 1.5, Floor: 0.9 for New Zealand Climate Zone 1) were required in accordance with NZS 4218P:1977. In 1996, the standard was updated and the new regulations came into force at the end of 2000 (SNZ 1996, DBH 2000). Minimum R-values for building elements (Roof: 1.9, Wall: 1.5, Floor: 1.3 for New Zealand Climate Zone 1) were required in accordance with NZS 4218P:1996. There are no R-value requirements for glazing and not limitation of ratio of window to wall. In 2004, the standard was again updated, the main change being a limitation of the proportion of window area and the use of double glazing under the Schedule Method (SNZ 2004). Minimum R-values for building elements (Roof: 1.9, Wall: 1.5, Floor: 1.3, Glazing: 0.15 for New Zealand Climate Zone 1) were required in accordance with NZS 4218:2004. In 2009, the standard was again updated (SNZ 2009). The new term 'construction R-value' has been introduced to distinguish the performance values from insulation material R-values. There are new requirements for high thermal mass construction to ensure that the thermal mass is adequate and effective, conceding that thermal mass is relevant when considering R-values. Increased R-values are aligned with New Zealand Building Code Clause H1 (DBH 2007). Minimum R-values for building elements (Roof: 2.9, Wall: 1.9, Floor: 1.3, Glazing: 0.26 for New Zealand Climate Zone 1) were required in accordance with NZS 4218:2009 (SNZ 2009).

Two Auckland houses were selected for the field studies of winter indoor micro-climatic conditions associated with different insulation and glazings in their envelopes. House 1 is a two-storeyed and brick-tile townhouse built in 2000 having four bedrooms with a total floor area of 210 m^2 and single glazed windows. Insulation in its envelope is in accordance with NZS 4218:1996. House 1 had two occupants and used an electronic heater (an oil-filled radiator) for space heating in the master bedroom only for the evening and night time during the field study. House 2 is a two-storeyed and brick-tile townhouse built in 2012 having five bedrooms with a total floor area of 250 m^2 and double glazed windows. Insulation in its envelope is in accordance with NZS 4218:2009. House 2 had two occupants and did not use any space heating during the field study, although there is a heat pump. Air temperatures and relative humidity adjacent to floors and ceilings of different indoor spaces of the two houses and shaded outdoor spaces were continuously measured and recorded at 15 minute intervals, 24 hours a day, by Lascar EL-USB-2 USB Humidity Data Logger during the winter of 2014.

This field study not only investigates and identifies the difference of relative humidity of houses with different insulation, but also difference of percentage of winter time, when indoor relative humidity meets or does not meet the guidelines of healthy conditions. All field study data of relative humidity of indoor and outdoor have been converted into percentages of winter times when indoor relative humidity is greater than or equal to 40%, 50%, 60%, 70%, 75%, 80% and in the range of 40% to 60% for the purposes of comparing indoor thermal comfort and healthy conditions of the three houses with different insulation and glazing in their envelopes and different heating methods. The study also investigates and identifies the major problems of house thermal design, which negatively impact indoor health conditions related to indoor relative humidity, in a climate with a mild and wet winter.

2. Indoor Health Conditions of the Two Houses

Winter mean air temperatures of different indoor spaces of House 2 are 0.6°C – 1.7°C higher than House 1 indoor spaces without space heating (Table 1). Although occupants in House 1 used a heater in the master bedroom during the field study, mean air temperature of the master bedroom of House 2 is still 1°C higher than the master bedroom of House 1 and percentages of winter time, when indoor air temperatures are higher than or equate to 16°C, 18°C and 20°C, are higher than the master bedroom of House 1. For the whole house, indoor mean air temperature of House 2 is 1.1°C higher than House 1 and percentage of winter time of House 2, when indoor air temperatures are higher than or equate to 18°C (the minimum requirement of thermal comfort and health conditions), is 17.5% higher than House 1 (Table 2). Increasing R-value of building envelope and using double glazed windows can not only improve winter indoor thermal conditions but also improve winter indoor health conditions related to relative humidity as indoor relative humidity decreases with increase of indoor air temperature. Winter mean relative humidity of different indoor spaces of House 2 are 3.2% – 5.1% lower than House 1 (Table 3). Percentages of winter time of House 2, when indoor relative humidity is higher than 60%, is 4.3% – 21.6% lower than House 1 (Table 3). For the whole house, the percentage of winter time of House 2 when indoor mean relative humidity is between 40% and 60%, is 19.6% higher than House 1 (see Table 4).

Major indirect health effects in Auckland houses during the winter such as bacteria, viruses, fungi, mites, respiratory infections, allergic rhinitis and asthma increases associated with increase of indoor relative humidity. According to the relationships between the major indirect health effects and indoor relative humidity (Arundel et al. 1986) and the field study data of winter indoor relative humidity of House 1 and House 2, figure 3-4 show winter indoor health conditions related to the health effects such as bacteria, viruses, fungi, mites, respiratory infections, allergic rhinitis and asthma of House 1 and House 2. The percentage of winter time of House 2 when indoor mean relative humidity is between 40% and 60%, which can minimize the indoor indirect health effects, is higher than House 1. Winter indoor health condition of the House 2 is better than the House 1.

Table 1: Percentages of winter time and air temperature ranges of different indoor spaces

Indoor spaces	≥16°C	≥18°C	≥20°C	≥22°C	≥24°C	≥26°C	Mean
House 1							
Living	34.7%	4.6%	0.1%	0%	0%	0%	15.5
Downstairs bedroom	11.2%	0%	0%	0%	0%	0%	14.2
Upstairs master bedroom	69.2%	32.7%	6.7%	0.1%	0%	0%	16.9
Corridor	34.0%	2.9%	0%	0%	0%	0%	15.3
House 2							
Living	78.7%	21.8%	1.0%	0%	0%	0%	16.8
Downstairs bedroom	28.3%	4.9%	0%	0%	0%	0%	14.8
Upstairs master bedroom	71.1%	44.9%	18.7%	6.4%	0.9%	0.1%	17.9
Corridor	76.2%	30.7%	4.0%	0.2%	0%	0%	17.0

Table 2: Percentages of winter time and mean indoor air temperature ranges of the two houses

	≥16°C	≥18°C	≥20°C	≥22°C	≥24°C	≥26°C	Mean	Max.	Min.	Fluctuation
House 1	35.3%	3.9%	0%	0%	0%	0%	15.5	19.8	11.4	8.4
House 2	61.0%	21.5%	2.5%	0.01%	0%	0%	16.6	22.1	11.2	10.9

Table 3: Percentages of winter time and relative humidity ranges of different indoor spaces

Indoor spaces	≥40%	≥50%	≥60%	≥70%	≥75%	≥80%	40% - 60%	Mean
House 1								
Living	100%	100%	90.8%	34.7%	12.3%	0%	9.2%	67.7%
Downstairs bedroom	100%	100%	100%	71.4%	38.2%	13.4%	0%	73.4%
Upstairs master bedroom	100%	100%	69.7%	24.6%	8.8%	0%	30.3%	64.3%
Corridor	100%	100%	90.4%	35.8%	15.6%	1.5%	9.6%	67.9%
House 2								
Living	100%	99.4%	69.2%	11.8%	1.3%	0%	30.8%	62.8%
Downstairs bedroom	100%	100%	95.7%	41.4%	12.6%	2.5%	4.3%	68.6%
Upstairs master bedroom	100%	97.5%	58.6%	8.0%	0.3%	0%	41.4%	61.1%
Corridor mean	100%	100%	69.7%	10.8%	1.2%	0.04%	30.3%	63%
Outdoor	100%	99.9%	97.4%	86.8%	77.8%	68.4%	2.6%	85%

Table 4: Percentages of winter time and mean relative humidity ranges of the two houses

	≥40%	≥50%	≥60%	≥70%	≥75%	≥80%	40%-60%	Mean
House 1	100%	100%	92.2%	37.6%	16.5%	1.0%	8.8%	68.3%
House 2	100%	100%	71.60%	11.90%	1.70%	0%	28.4%	63.4%

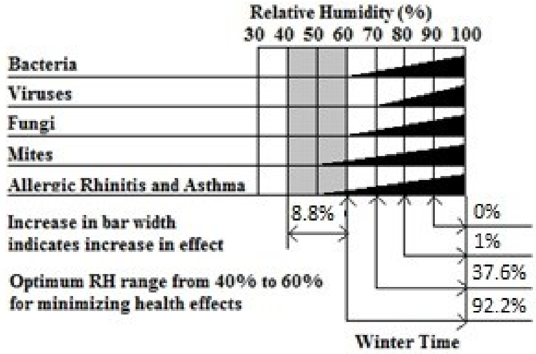

Figure 3 Indirect health effects and indoor RH of House 1

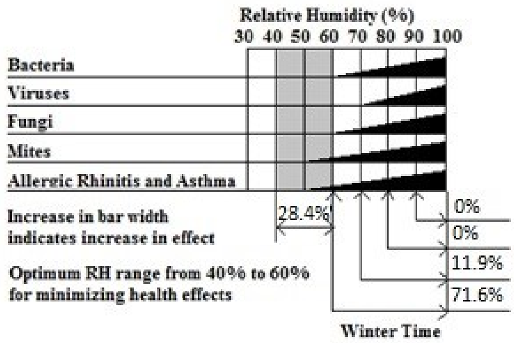

Figure 4 Indirect health effects and indoor RH of House 2

3. Major Problems of Local House Thermal Design

Winter indoor mean air temperatures of House 2 are generally higher than House 1 and relative humidity of House 2 are generally lower than House 1 (Table 2 and Table 4). Fluctuations of winter indoor air temperatures and relative humidity of House 1 and House 2 are both large (Table 2, Figure 5-6). House 1 and House 2 are lightweight timber frame construction with internal insulation and external cladding. For this type of lightweight building envelope without sufficient thermal mass in the walls, the indoor space air temperature is heated up quickly by solar radiation and rising outdoor air temperatures during winter daytime and also cooled down quickly during winter night time. House 2 with more insulation (higher R-value) and double glazed windows in building envelope can increase the winter indoor mean air temperature, but cannot make indoor the air temperature more stable. As indoor relative humidity increases or decreases associated with decrease or increase of indoor air temperature, large fluctuations of winter indoor mean air temperature can result large fluctuations of winter indoor mean relative humidity, which can negatively impact indoor thermal comfort and health conditions.

Indoor mean air temperatures of living room, upstairs mast bedroom, corridor of House 2 are 1-1.7°C higher than House 1. Indoor mean air temperature of southern downstairs bedroom of

House 2 is only 0.6°C higher than House 1 (Table 1). Indoor relative humidity of Southern downstairs bedrooms of both House 1 and House 2 are significantly higher than other indoor spaces (Table 3). Southern downstairs indoor spaces do not have any direct sunlight during the winter and are on the cold side of the house. Floor areas of southern bedrooms are commonly smaller than the northern bedrooms and the other spaces; the floor area of the southern downstairs bedroom (10.3m2) of House 2 is smaller than the master bedroom (17.7m2) and the open living space (68.2m2). A southern bedroom with a smaller floor area could potentially result in big ratios of external wall area to indoor space volume or window area to floor of that room. Negative impact of a big ratio of window to floor could overrule or degrade the positive impact of higher insulation levels and double glazed windows on indoor thermal comfort and health conditions of a particular indoor space, especially a southern indoor space.

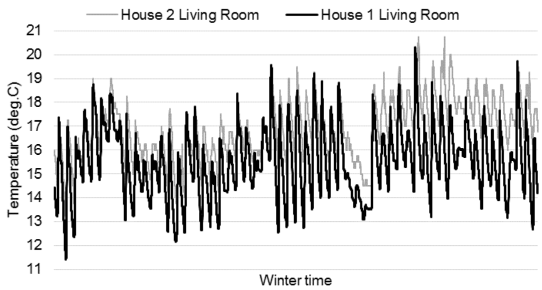

Figure 5 Indoor air temperatures of living rooms of House 1 and House 2

Figure 6 Indoor relative humidity of living rooms of House 1 and House 2

4. Conclusion

According the field study data of House 1 and House 2, increasing R-value of building envelope from 1.9 for roof, 1.5 for wall, 1.3 for floor and 0.13 for glazing, as required by the New Zealand building standards in 1996, to the 2009 requirements of 2.9 for roof, 1.9 for wall, 1.3 for floor and 0.26 for glazing significantly improves winter indoor thermal conditions. Increasing R-value of building envelope and using double glazed windows can not only improve winter indoor thermal conditions but also improve winter indoor health conditions related to relative humidity. Maintaining indoor relative humidity between 40% and 60% can minimize the indirect health effects. Percentages of winter time of House 2 with sufficient insulation and double glazing windows, when indoor mean relative humidity is between 40% and 60%, is 19.6% higher than House 1 with insufficient insualtion and single glazed windows.

Although upgrading insulation and using double glazing windows can significantly increase 19.6% of winter time when indoor relative humidity are 40% and 60%, there is still 71.6% of winter time when indoor relative humidity is higher than 60%. An Auckland house with sufficient insulation and double glazing windows needs space heating to achieve winter indoor thermal comfort and health condition. Local conventional lightweight timber frame construction houses can cause large fluctuations of winter indoor air temperatures and relative humidity. For this type of lightweight building envelope without sufficient thermal mass in the walls, increasing insulation and adding double glazed windows in building envelope can increase the winter indoor mean air temperature and decrese the winter indoor mean relative humicity, but cannot make indoor air temperature and relative humidity more stable. For both of two houses, winter indoor air temperatures in sorthern downstairs bedrooms are apprently lower than other indoor spaces and relative humidity are also apprently higher than other indoor spaces. Adding more insulation and further the limiting window area on the southern external wall could be an option to increse indoor air temperature and decrease relative humidity of southern downstairs bedroom.

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