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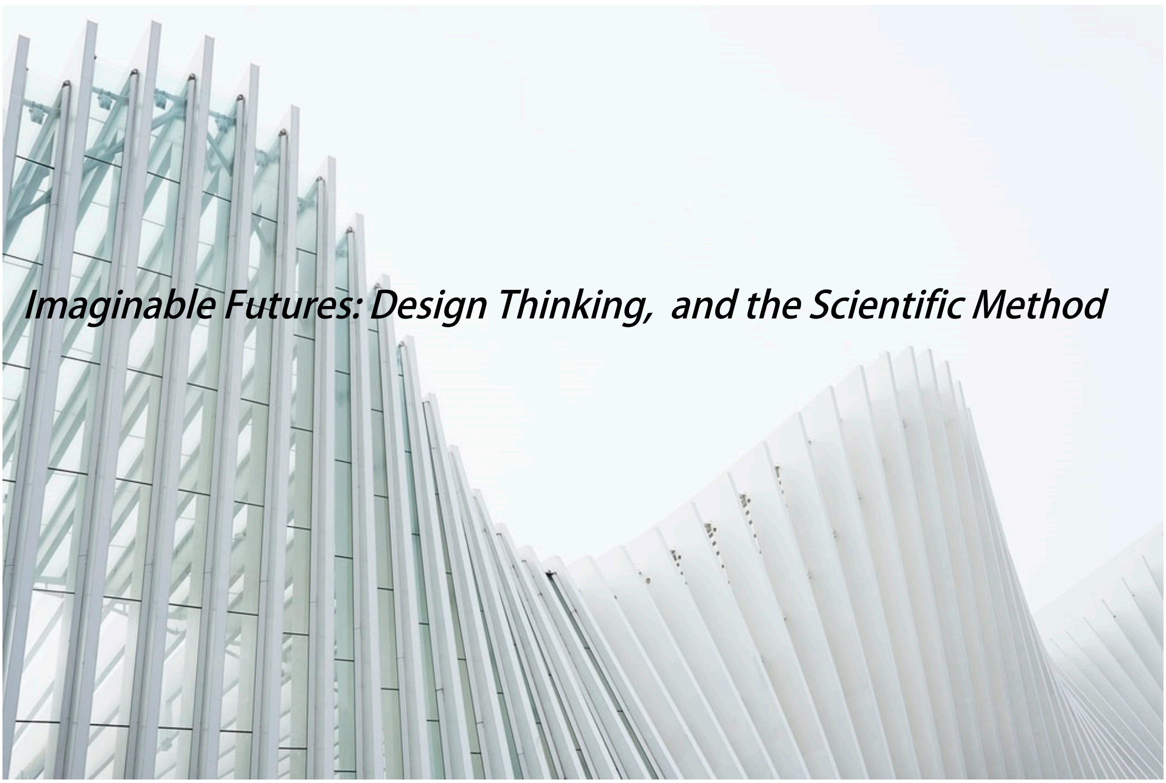

Imaginable Futures: Design Thinking, and the Scientific Method

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New Zealand House Indoor Microclimate and Allergens

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Abstract: The most common indoor allergens and triggers for people with asthma and allergic rhinitis are dust-mites, moulds, pets and pollen. Allergens from dust mites and moulds are strongly associated with indoor microclimate. Indoor microclimate conditions are closely related to house thermal performance and *R*-value of its envelope. Based on the field studies of indoor microclimatic conditions, tests of allergen levels of dust mites and mould growth of a number of sample houses, this study provides physical evidence to identifies thresholds or ranges of indoor microclimatic conditions related to different levels of dust-mite allergen and mould growth, a correlation between dust-mite allergen levels and mould growth levels, the most common type of indoor mould and the minimum requirement of indoor microclimatic conditions to control indoor dust-mite allergens at an acceptable level and prevent indoor mould problem. The study evaluates indoor microclimatic conditions related to indoor allergens of the sample houses with different R-values in their envelopes in accordant to the requirement of the current building code for New Zealand Climate Zone 1 and 2 (New Zealand Standard 4218: 2009) and the previous building code (New Zealand Standard 4218:1996).

Keywords: Dust-mite, indoor allergen, indoor microclimate, mould.

1. Introduction

According to New Zealand Health Survey 2017/18, the New respiratory disease affects 700,000 people, causes one in 10 hospital stays, costs New Zealand NZ$7 billion in healthcare every year, and is the third-highest cause of death. One in eight adults (12.5%) and one in seven children (14.3%) have asthma (MH, 2018). Most of the factors that adversely affect health, such as bacteria, viruses, fungi, mites, etc., have increases associated with high indoor relative humidity. Maintaining the indoor relative humidity between 40% and 60% can minimise the indirect health effects (Arundel, Sterling, Biggin, & Sterling, 1986). New Zealand has some of the highest levels of house dust mite allergens in the world (Siebers, Wickens, & Crane, 2006). Visible mould growth on indoor surfaces is a common problem in over 30% of New Zealand houses (Howden-Chapman *et al.*, 2005). The abundance of two major causes of allergy, mites and mould in New Zealand housing, increase proportionately with average indoor relative humidity. The World Health Organisation recommends a minimum indoor temperature of 18 °C for houses; and 20–21 °C for more vulnerable occupants, such as older people and young children (WHO, 1987; WHO, 2009). Previous studies show that the minimum threshold of indoor temperature required

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for limiting respiratory infections is 16 °C: there is increased risk of respiratory infections when indoor temperatures are below 16 °C (Collins, 1986; Braubach, Jacobs, & Ormandy 2011).

Both indoor relative humidity and temperature can impact indoor dust mite populations and allergen levels. Maintaining indoor relative humidity below 50% can reduce dust mites and their allergens in the home, mite populations are almost eliminated in winter when indoor relative humidity is maintained within 40 to 50% (Arlian, Bernstein, & Gallagher, 1982; Korsgaard, 1982; Murray & Zuk, 1979). A range of 60–80% relative humidity provides ideal conditions for the reproduction of mites. Mites are hardy, surviving and multiplying best when relative humidity is 75-80% and the temperature is around 21 °C (Arundel, Sterling, Biggin, & Sterling, 1986). The indoor relative humidity required by dust mites to thrive is 75–80% or higher, and dust mites prefer temperatures of around 18–25 °C. A decrease in indoor temperature (between 10 °C and 25 °C) can result in reducing dust mite populations (Arlian, Bernstein, & Gallagher, 1982; Arlian, Rapp, & Ahmed, 1990; Arlian, Neal, & Vyszenski-Moher, 1999; Arlian, Yella, & Morgan, 2010; Hart, 1998).

According to international and national standards, indoor relative humidity should be lower than 60% for optimum indoor air quality (ASHRAE, 1993; SNZ, 1990; DBH, 2001). The threshold of indoor relative humidity for mould survival and growth conditions is 60%. Mould growth is likely on almost any building material if equilibrium relative humidity of the material exceeds 75–80% (Coppock, 1951; Block, 1993; Pasanen et al., 1992). Mould spore germination requires not only higher relative humidity but also time (Hens, 2000), Table 1 shows the thresholds of mould spores germination. For example, for 80% of relative humidity, the time needed for mould spore germination is 30 days. One option to prevent mould growth on indoor surfaces is to control the indoor relative humidity to a level below the threshold of mould germination (Su, 2006).

Table 1: The thresholds of relative humidity and time for mould germination.

Substrate	Thresholds of Relative humidity	Time needed for mould spore germination
Porous and dust-	100%	1 day
and fat-covered	89%	7 days
non-porous	80%	30 days

Since 1978, 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 (SNZ, 1977, BIA, 1992). 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 no limitation on the ratio of the window to the wall. The standard was further updated in 2004, principally with regard to limiting the percentage of the window to wall area and mandating that windows should be double glazed (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). Those requirements are mainly related to building energy efficiency.

Based on the field-study data of indoor micro-climate data associated with unacceptable and acceptable levels of indoor dust-mite allergens and different indoor mould growth levels of the sample houses in the Central North Island of New Zealand (Su & Wu, 2019), this study identified threshold of indoor air temperature and relative humidity for the acceptable level of indoor dust-mite allergen. This can be used as the minimum requirement for indoor thermal conditions to control indoor allergens at an acceptable level, and to evaluate winter indoor microclimatic conditions of the sample houses in Auckland, built in different periods of time, with different *R*-values in their envelopes according to under the local climate with mild and wet winter.

2. Research method

Unacceptable indoor dust-mite allergen data and indoor microclimatic data derived from the field study of 13 sample houses of the isolated Māori communities in Minginui, Te Whaiti and Murupara areas of New Zealand. The 13 sample houses were built in the 1920s to the 1970s. Floor areas of the 13 sample houses are 44m^2 to 342m^2. Roof materials are tin (6 houses), iron (4 houses), aluminum (1 house), tile (1 house) and asbestos (1 house). Wall materials are old weatherboard (12 houses), brick (1 house). The 8 sample houses do not have any insulation in their envelopes; The 5 sample houses have only limited, old insulation in either their roof space only or both roof space and floor. For space heating, the 10 sample houses used firewood as fuel for fireplaces, the 2 sample houses used coal or firewood as fuel for stoves (cooking and space heating), one sample house did not use any space heating. All the 13 sample houses did not use any electricity as fuel for space heating. Acceptable indoor dust-mite allergen data and indoor microclimatic data derived from the field study of 2 sample houses built in the 1980s with minimum insulation (Roof: 1.9, Wall: 1.5, Floor: 0.9) in their building envelope and single glazing windows and used electronic heaters for space heating during the winter in Rotorua (Su, & Wu, 2019).

According to the instructions for the Ventia™ Rapid Allergen Test, dust samples on the carpets of living rooms and bedrooms of the 13 sample houses were collected by a vacuum cleaner fitted with a DUSTREAM® collector, and dust samples were then tested using the Rapid Test cassette. Test results can identify four different levels of dust-mite allergens (see Table 2).

Table 2. Four levels of indoor dust-mite allergens

Dust-mite allergen levels	Allergen in dust	Action
Undetectable level	-	No action is needed
Low level (acceptable)	<0.2 micrograms per gram of dust	No action is needed
Medium level (unacceptable)	0.2–1.0 micrograms per gram of dust	Action needed to reduce allergen
High level (unacceptable)	≥ 1 microgram per gram of dust	Action needed to reduce allergen

Air temperatures and relative humidity adjacent to floors and ceilings of different indoor spaces in the 13 sample houses and the 2 sample houses in Rotorua, and shaded outdoor spaces were continuously measured and recorded at 15-minute intervals, 24 hours a day, by HOBO temperature and relative humidity (RH) loggers, from March 2018 to January 2019. According to the instructions of Biodet Services Ltd (consulting industrial microbiologists), the researchers used clear, standard Sellotape to collect mould samples from the indoor surface areas of the 13 sample houses in the Minginui, Te Whaiti and Murupara areas. The Sellotape with the mould samples was then folded in non-stick baking paper and placed into a plastic bag; the samples were then sent to the local testing lab, where they were examined both macroscopically and microscopically.

The study investigated differences and improvements in indoor microclimatic conditions related to indoor allergens from dust-mite and mould of local houses associated with increasing the R-values of the building envelope from 1.9 for the roof, 1.5 for the wall, 1.3 for floor and 0.13 glazing, as required by the New Zealand building standards in 1996, to the 2009 requirements of 2.9 for the roof, 1.9 for the wall, 1.3 for floor and 0.26 for glazing (Climate Zone 1 and Zone 2). Indoor microclimatic data of the local houses derived from the field studies of two Auckland houses with lightweight timber frame construction. House 1 was built in 2000 (R-values for Roof: 1.9, Wall: 1.5, Floor: 1.3, Single Glazing: 0.13). House 1 had 2 occupants and used an electronic heater in the master bedroom only for the evening time during the field study. House 2 was built in 2012 (R-values for Roof: 2.9, Wall: 1.9, Floor: 1.3, Double Glazing: 0.26) in accordant to the current building code. House 2 had 2 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 indoor spaces in two Auckland houses (upstairs northern master bedroom, downstairs northern open living space including living, kitchen and dining room, downstairs southern bedroom and corridor) and under shaded outdoor space were continuously measured at 5-minute intervals 24 hours a day for about 56 days during the winter months by Lascar EL-USB-2 USB Humidity Data Logger (Su, 2017).

3. Data analysis

3.1. Correlations between indoor microclimatic data and indoor allergens

Field-study tests of dust mites and mould in 18 indoor spaces (rooms) of 13 sample houses in Minginui, Te Whaiti and Murupara showed seven sample houses with high levels of dust-mite allergens and six sample house with medium levels of dust-mite allergens. Field-study tests of dust mites and mould in 2 sample houses in Rotorua showed the two sample houses with low levels (acceptable level) of dust-mite allergens and without mould growth on indoor surface. Table 3 shows winter mean indoor microclimatic conditions of the 13 sample houses with medium and high levels of dust-mite allergens in Minginui, Te Whaiti and Murupara and the two Rotorua houses with low levels of dust-mite allergens. To compare indoor microclimatic conditions between the houses with low levels (acceptable level) of dust-mite allergens and the houses with high and medium levels (unacceptable levels) of dust-mite allergens, indoor mean relative humidity adjacent to the floor (69.8%) of the houses with low levels of dust-mite allergens (acceptable level) were clearly lower than 75% (the threshold for dust mites to thrive), indoor mean relative humidity adjacent to the floor of the houses with high allergen levels (78%) and medium allergen levels (87.4%) were clearly higher than 75%, the threshold for dust mites to thrive; test results of dust samples from the carpets of the 13 sample houses showed high or medium dust-mite allergen levels. To compare the indoor microclimatic conditions of the houses with high dust-mite allergen levels and the houses with medium dust-mite allergen levels (although in the houses with both high and medium levels of allergens, the indoor relative humidity met the threshold for dust mites to thrive), indoor mean air temperature and the mean air temperature adjacent to the floor (13.1 °C and 11.2 °C respectively) of the houses with high allergens was 3.5 °C and 3.2 °C higher than in the houses with medium allergens (9.6 °C and 8.0 °C respectively).

According to field-study data of the two Rotorua houses (see Table 4), to control indoor dust-mite allergens at an acceptable level, indoor mean relative humidity adjacent to the floor must be maintained below 70%, indoor relative humidity adjacent to floor must be maintained below 75% (the threshold for dust mites to thrive) for 20 hours (19.7 hours in Table 4) a day during winter and below 80% all the time (99% of winter time or 23.8 hours per day in Table 4) in winter. To achieve these conditions, the indoor mean temperature must be maintained at 17 °C (16.7 °C in Table 4) or higher. If indoor relative humidity adjacent to the floor can be controlled below the threshold for dust mites to thrive (75%) for 20 hours a day during the winter, it will not reach the threshold for mould germination. (The percentage of winter time in the two Rotorua houses, when indoor mean relative humidity was equal to or more than 80%, was only 1%, or 9.2 winter days, which was much lower than the threshold (30 days) for mould germination). If the mould spores never germinate in a house, mould will never grow on indoor surfaces. If indoor dust-mite allergen levels can be controlled at low (acceptable) levels, the house is unlikely to have a mould problem in the local climate with mild and wet winters.

Table 3. Winter mean indoor microclimatic conditions of the 13 sample houses and the 2 Rotorua houses with different levels of dust-mite allergens.

Mite allergen level	High dust-mite allergens		Medium dust-mite allergens		Low dust-mite allergens	
Tested houses	7 houses (9 rooms)		6 houses (9 rooms)		2 Rotorua houses (4 rooms)	
Test points	Indoor mean	Floor mean	Indoor mean	Floor mean	Indoor mean	Floor mean
Mean T	13.1	11.2°C	9.6°C	8.0°C	16.7°C	15.2°C
Time T≥16°C	21%	4%	3%	0%	60%	35%
Time T≥18°C	12%	0%	1%	0%	34%	5%
Time T≥20°C	7%	0%	1%	0%	9%	0%
Time T≥22°C	4%	0%	0%	0%	1%	0%
Mean RH	71.2%	78.0%	80.8%	87.4%	63.9%	69.8%
Time RH≥50%	91%	99%	99%	100%	99%	100%
Time RH≥60%	81%	98%	97%	99%	72%	96%
Time RH≥70%	63%	80%	86%	96%	19%	51%
Time RH≥75%	49%	65%	76%	93%	4%	18%
Time RH≥80%	30%	45%	61%	88%	0%	1%
Time RH≥85%	13%	22%	37%	73%	0%	0%
Time RH≥90%	3%	5%	14%	36%	0%	0%
Time RH≥100%	0%	0%	0%	0%	0%	0%

Table 4: Winter mean indoor microclimatic conditions of the two Rotorua houses with low levels of dust-mite allergens.

Mite-allergen level	Low dust-mite allergens (acceptable level)					
Tested houses	2 Rotorua houses (4 rooms)					
Test points	Ceiling mean	Indoor mean	Floor mean	Ceiling mean	Indoor mean	Floor mean
Mean T	18.3°C	16.7°C	15.2°C	18.3°C	16.7°C	15.2°C
Mean RH	58%	63.9%	69.8%	58%	63.9%	69.8%
Time in winter	Percentages of time in winter			Time per day		
Time T≥16°C	71%	60%	35%	17.0h	14.4h	8.4h
Time T≥17°C	62%	47%	18%	14.9h	11.3h	4.3h
Time T≥18°C	53%	34%	5%	12.7h	8.2h	1.2h
Time T≥20°C	32%	9%	0%	7.7h	2.2h	0.0h
Time T≥22°C	14%	1%	0%	3.4h	0.2h	0.0h
Time RH≤70%	87%	81%	49%	20.9h	19.4h	11.8h

Time RH≤75%	97%	96%	82%	23.3h	23h	19.7h
Time RH≤80%	100%	100%	99%	24h	24h	23.8h

3.2. Correlation between dust-mite and mould

Most of the sample houses with a high level of dust-mite allergens also had an abundant or moderate level of Cladosporium, most of the sample houses with a medium level of dust-mite allergens also had low to moderate levels of Cladosporium (see Table 5). Cladosporium was the only identified type of mould, and had the highest frequency of detected mould in the 13 sample houses. Cladosporium is the most important indoor allergen, and a well-known trigger for asthma (Peternel, Culig, & Hrga, 2004; Flannigan, Samson, & Miller, 2001; Piecková & Jesenská, 1999). During most of the time in winter, indoor mean relative humidity of the sample houses was higher than 50% and 60% (thresholds of dust-mite survival and mould growth conditions, respectively). The threshold (75–80% or higher) of relative humidity for dust mites to thrive and the threshold (80% or higher) of relative humidity for mould spore germination are quite close. If a house has high or medium levels of dust-mite allergens, it is likely to have a mould growth problem, and vice versa. The occupants can find visible mould growth on indoor surfaces but cannot see dust mites in the carpet. There was no Cladosporium detected on the indoor surfaces of five sample houses. This does not necessarily mean there could not have been higher levels of Cladosporium in these houses, but that it was present at low levels at the time of testing. This could be explained by cleaning, by the location of sampling, or other factors. Mould test results can be influenced by occupants' daily life and depend on how often the occupants clean the indoor surfaces, especially for the areas with visual mould.

Table 5: Sample houses with high or medium level of dust-mite allergens and mould in test results.

Houses	1	2	3	4	5	6	7
Dust-mite allergens	High	High	High	High	High	High	High
Cladosporium	Moderate	Abundant	-	Abundant	-	-	Abundant
Unidentified fungus	-	-	Low	-	-	Low to Moderate	-
Houses	**8**	**9**	**10**	**11**	**12**	**13**	
Dust-mite allergens	Medium	Medium	Medium	Medium	Medium	Medium	
Cladosporium	Moderate	No	Low	No	Moderate	Low to moderate	
Unidentified fungus	Low	Moderate	Low to moderate	Moderate to abundant	Moderate to abundant	Low	

3.3 Evaluating indoor microclimatic conditions of houses with different *R*-values

To control indoor dust-mite allergens at an acceptable level and prevent indoor mould problem in an indoor space, indoor mean relative humidity adjacent to the floor must be maintained below 70%, indoor relative humidity adjacent to the floor must be maintained below 75% (the threshold for dust mites to thrive) for 20 hours a day during winter and below 80% all the time in winter. To achieve these conditions, the indoor mean temperature must be maintained at 17 °C or higher.

For house 1 (see Table 6), except the upstairs north master bedroom using temporary space heating, indoor mean relative humidity adjacent to the floor in the live room (70%), the downstairs south bedroom (75%) and the corridor (70%) were equated to or higher than 70%; time per winter day in the live room (19.0h), the downstairs south bedroom (11.5h) and the corridor (18.0h), when indoor mean relative humidity adjacent to the floor were below 75%, were less than 20h, and time per winter day in the live room (22.8h), the downstairs south bedroom (19.2h) and the corridor (21.8h) when indoor mean relative humidity adjacent to the floor were below 80% were less than 24h a day. The indoor mean temperature of the live room (15.5°C), the downstairs south bedroom (14.2°C) and the corridor (15.3°C) were lower than 17°C.

Table 6. Winter time related to different ranges of indoor temperature and RH of the Houses 1

Indoor spaces	Live room		Downstairs south bedroom		Upstairs north master bedroom		Corridor		
Test points	Indoor mean	Floor mean	Indoor mean	Floor mean	Indoor mean	Floor mean	Indoor mean	Floor mean	Outdoor
Mean T	15.5°C	14.9°C	14.2°C	13.7°C	16.9°C	16.2°C	15.3°C	14.8°C	10.4°C
Time T≥16°C	34.7%	14%	11.2%	0%	69.2%	63%	34.0%	10%	1.70%
Time T≥18°C	4.6%	0%	0%	0%	32.7%	20%	2.9%	0%	0%
Time T≥20°C	0.1%	0%	0%	0%	6.7%	1%	0%	0%	0%
Time T≥22°C	0%	0%	0%	0%	0.1%	0%	0%	0%	0%
Mean RH	67.7%	70%	73.4%	75%	64.3%	60%	67.9%	70%	85%
Time RH≥50%	100%	100%	100%	100%	100%	100%	100%	100%	99.9%
Time RH≥60%	90.8%	99%	100%	100%	69.7%	86%	90.4%	96%	97.4%
Time RH≥70%	34.7%	52%	71.4%	82%	24.6%	31%	35.8%	53%	86.8%
Time RH≥75%	12.3%	21%	38.2%	52%	8.8%	10%	15.6%	25%	77.8%
Time RH≥80%	0%	5%	13.4%	20%	0%	0%	1.5%	9%	68.4%
Time/day RH≤70%	15.7h	11.5h	6.9h	4.3h	18.1h	16.6h	15.4h	11.3h	3.2h
Time/day RH≤75%	21.0h	19.0h	14.8h	11.5h	21.9h	21.6h	20.3h	18.0h	5.3h
Time/day RH≤80%	24.0h	22.8h	20.8h	19.2h	24.0h	24.0h	23.6h	21.8h	7.6h

For house 2 without space heating (see Table 7), except the downstairs south bedroom, indoor mean relative humidity adjacent to the floor in the live room (65%), the master bedroom (62%) and the corridor (61%) were clearly lower than 70%; time per winter day in the live room (23.3h), the master bedroom (23.8h) and the corridor (23.8h) when indoor mean relative humidity adjacent to the floor were below 75% were more than 20 h, and indoor mean relative humidity adjacent to the floor of those rooms were lower than 80% for 24h a day. The indoor mean temperature of the live room (16.8°C), the master bedroom (17.9°C) and the corridor (17.0°C) were also equated to or higher than 17°C. Although the indoor microclimatic condition of the downstairs south bedroom did not meet the requirement to control indoor dust-mite allergens at an acceptable level, winter time (21.2 days for 23% of winter time) in the downstairs south bedroom, when indoor relative humidity adjacent to the floor, was lower than 30 days, the threshold of mould spore germination.

Southern 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. A smaller floor area could potentially result in big ratios of external wall area to the indoor space volume or window area to the floor area of that room. Increasing the ratio of external surface area to indoor space volume of a southern bedroom will increase heat exchange between indoor and outdoor and heat loss through wall and window areas during the winter. Windows are commonly a weak part of the building envelope for thermal resistance, even double glazed windows, compared with wall and roof with sufficient insulation. Big ratio of window area to indoor space volume of the southern downstairs bedroom can negatively impact indoor thermal comfort conditions. The negative impact of a big ratio of window to indoor space volume of the southern downstairs bedroom could overrule or degrade the positive impact of higher insulation levels and double glazed windows on its indoor thermal comfort conditions.

Table 7. Winter time related to different ranges of indoor temperature and RH of the Houses 2

Indoor spaces	North live room		Downstairs south bedroom		Upstairs north master bedroom		Corridor		
Test points	Indoor mean	Floor mean	Indoor mean	Floor mean	Indoor mean	Floor mean	Indoor mean	Floor mean	Outdoor
Mean T	16.8°C	16.5°C	14.8°C	14.3°C	17.9°C	17.2°C	17.0°C	16.9°C	10.4°C
Time T≥16°C	78.7%	78%	28.3%	20%	71.1%	69%	76.2%	69%	1.70%
Time T≥18°C	21.8%	13%	4.9%	1%	44.9%	41%	30.7%	34%	0%
Time T≥20°C	1.0%	0%	0%	0%	18.7%	15%	4.0%	9%	0%
Time T≥22°C	0%	0%	0%	0%	6.4%	3%	0.2%	0%	0%
Mean RH	62.8%	65%	68.6%	76%	61.1%	62%	63%	61%	85%
Time RH≥50%	99.4%	100%	100%	100%	97.5%	99%	100%	100%	99.9%
Time RH≥60%	69.2%	81%	95.7%	100%	58.6%	68%	69.7%	60%	97.4%
Time RH≥70%	11.8%	20%	41.4%	83%	8.0%	11%	10.8%	6%	86.8%
Time RH≥75%	1.3%	3%	12.6%	57%	0.3%	1%	1.2%	1%	77.8%
Time RH≥80%	0%	0%	2.5%	23%	0%	0%	0.04%	0%	68.4%
Time/day RH≤70%	21.2h	19.2h	14.1h	4.1h	22.1h	21.4h	21.4h	22.6h	3.2h
Time/day RH≤75%	23.7h	23.3h	21.0h	10.3h	23.9h	23.8h	23.7h	23.8h	5.3h
Time/day RH≤80%	24.0h	24.0h	23.4h	18.5h	24.0h	24.0h	24.0h	24.0h	7.6h

4. Conclusions

The study identified that there were correlations between dust-mite and mould problems in indoor spaces of the sample houses with insufficient insulation. If a house had a dust-mite allergen problem (medium or high levels of dust-mite allergens), it was likely to have a mould problem, and vice versa, in a temperate climate with mild and wet winters. According to field-study data, to control indoor dust-mite allergens at a low (acceptable) level, indoor mean relative humidity adjacent to the floor must be maintained below 70%, indoor relative humidity adjacent to the floor must be maintained below 75% (the threshold for dust mites to thrive) for 20 hours a day during winter and below 80% all the time in winter. To achieve these conditions, the indoor mean temperature must be maintained at 17 °C or higher. If indoor relative humidity adjacent to the floor can be controlled below the threshold for dust mites to thrive (75%) for 20 hours a day during the winter, it will not reach the threshold for mould germination. If the mould spores never germinate in a house, mould will never grow on indoor surfaces. If indoor dust-mite allergen levels can be controlled at low (acceptable) levels, the house is unlikely to have a mould problem in a temperate climate with mild and wet winters.

For an Auckland house with sufficient insulation and double glazing windows (R-values for Roof: 2.9, Wall: 1.9, Floor: 1.3, Double Glazing: 0.26) in accordant to the current building code, except the south indoor space, the baselines of indoor temperature and relative humidity of indoor spaces without using space heating can meet the minimum requirement to control indoor dust-mite allergens at an acceptable level and prevent mould problem under a temperate climate with mild and wet winters. A further study can focus on adding more insulation in the southern wall and limiting the ratio of window area to indoor space volume of the southern indoor space for improving indoor thermal and health conditions of southern indoor spaces.

For an Auckland house with based insulation and single glazing windows (R-values for Roof: 1.9, Wall: 1.5, Floor: 1.3, Single Glazing: 0.13 required for Climate Zone 1 and 2 in New Zealand) in accordant to NZS 4218P:1996 Energy efficiency: Housing and small building envelope, the baselines of indoor temperature and relative humidity of indoor spaces without using space heating cannot meet the minimum requirement to control indoor dust-mite allergens at an acceptable level and prevent mould problem. With temporary space heating, indoor temperature and relative humidity of indoor can meet the minimum requirement to control indoor dust-mite allergens at an acceptable level and prevent mould problem.

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