Study Report SR452 [2021]

Indoor climate and mould in New Zealand homes

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Reference

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Abstract

This study looked at 88 homes across New Zealand and measured temperature and relative humidity during the winter months at locations in Auckland, Wellington, the upper South Island and Dunedin in 2016 and again in Wellington in 2017. The median temperature inside bedrooms was 16.4°C, and relative humidity levels were above 65% for 46% percent of the time. The bedrooms where found to be below 18°C for 84% of the night and morning time period (23:00–09:00).

We also determined the mould index at each home, indicating that many homes show mould growth in bedrooms and/or bathrooms. These results indicate a lack of heating and/or ventilation in these dwellings causing mould growth with its potential adverse health effects. Air and dust samples were also taken to determine the fungal spore count in the air and the presence of mycotoxins in the dust. Very high spore counts were observed in several homes, which were subsequently remeasured to confirm the findings.

Keywords

Indoor temperature, humidity, mould, comfort, heating habits, ventilation habits

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Executive summary

Temperature and relative humidity are important factors influencing comfort and health of building occupants. Cold temperatures and excessive moisture give rise to mould growth, presenting a health risk and causing building material deterioration. In this study, we looked at 88 homes across New Zealand and measured temperature and relative humidity during the winter months at locations in Auckland, Wellington, the upper South Island and Dunedin in 2016 and again in Wellington in 2017. The median temperature inside bedrooms was 16.4°C, and relative humidity levels were above 65% for 46% percent of the time. The bedrooms were found to be below 18°C for 84% of the night and morning time period (23:00–09:00).

We also determined the mould index at each home (as described by Shorter et al., 2018), indicating that many homes show mould growth in bedrooms and/or bathrooms. These results indicate a lack of heating and/or ventilation in these dwellings causing mould growth with its potential adverse health effects. Air and dust samples were also taken to determine the fungal spore count in the air and the presence of mycotoxins in the dust. Very high spore counts were observed in several homes, which were subsequently remeasured to confirm the findings. The dust samples enabled us to try a new technique to show the presence of mycotoxins in the house from past and present fungal metabolism.

The homes selected for the 2016 study where a subset of the 2015 BRANZ House Condition Survey and were located in Auckland (30 homes), Wellington (19 homes), upper South Island (6 homes) and Dunedin (9 homes), with a total of 151 bedrooms. For the 2017 study, the homes where recruited from the Wellington region (25 homes, 58 bedrooms).

All households participating in the 2016 study were sent a short questionnaire about their ventilation practices and comfort in the home. A total of 64 questionnaires were returned. The results showed that, for two-thirds of respondents (66%) their bedroom was colder than they would have liked for at least some of the time in winter. This compares to 42% reporting the main living area being colder than they would have liked at some time in winter. For 11% of households surveyed, the bedrooms were 'often' or 'always' colder than they would have liked over winter.

The 2017 study extended this questionnaire to a more in-depth semi-structured face-to-face interview. This was completed with all participants in their home at the end of the monitoring period. The interview explored heating and ventilation habits and problems experienced in the home over winter. Responses showed there was a high tendency to ventilate by opening windows and to heat the living area at some time in winter, most commonly in the evening. There was far less tendency to directly heat bedrooms, relying instead on heat flow from the living area and/or methods to maintain comfort, such as using extra blankets and hot water bottles. Interviewees' perceptions of comfort, damp and mould in the home were wide ranging, starting from those who felt their home was 'freezing' to those who considered it 'a warm home' and those reporting no problems of damp or mould. There were some extreme cases of visible mould in bedrooms and signs of damp/leaks to the extent that, in one case, the bedroom was uninhabitable.

1. Introduction

Temperature and relative humidity are important factors influencing comfort and health of building occupants. Cold temperatures and excessive moisture give rise to mould growth, presenting a potential respiratory health risk and causing building material deterioration.

This report presents findings from two studies that monitored the temperature and relative humidity in a sample of homes throughout New Zealand in winter of 2016 and 2017. The homes in 2016 study are a subset of the House Condition Survey 2015. The additional data available for these homes was not analysed as part of this project. The second study (2017) extended measurements to include fungal spores. In some houses, dust samples were also collected to evaluate the potential for this method to analyse the presence of fungal and bacterial mycotoxins. The results of this part of the study are presented but not discussed in detail as the focus was on testing the technique and whether qualitative and quantitative analysis of the mycotoxins is possible. In a later study, we will use this technique to investigate lung function in the presence of mycotoxins.

Both studies explored occupant-reported ventilation behaviour and perceptions of problems in the home.

2. Methods

2.1 Temperature and humidity sensors

For the 2016 study, temperature and relative humidity sensors were installed in bedrooms and bathrooms. These locations were chosen as the focus of the study was moisture condensation and mould. Visible mould is most commonly observed in bathrooms, being a high moisture area of the home (White & Jones, 2017), while mould in bedrooms can present particularly high risk to occupant health due to exposure time (Shorter et al., 2018).

For the 2017 study, temperature and relative humidity sensors were installed in every room of the home, apart from utility rooms. This was done to provide additional information and the ability to report on the indoor climate conditions of bedrooms, bathrooms and living rooms separately.

Table 1 provides a summary of the two studies.

Table 1. Summary of study samples.

Study year	2016	2017
Location	Auckland, Wellington, upper South Island, Dunedin	Wellington region
Sample size (number of houses)	64	25[1]
Total number of sensors	309	132
Areas of the home measured for temperature and relative humidity	Bedrooms Bathrooms	Bedrooms Bathrooms Living areas Kitchens (all rooms except utility)
Additional measurements	-	Fungal spores, dust samples
Occupant-reported behaviour	Self-completion questionnaire	In-depth semi-structured face-to-face interview (n=24[2])

The sensors were placed on the inside face of the doors at 1.9 m above the floor to keep them out of reach and sight as much as possible. This height will, however, over-represent the room temperature during heating periods (from heaters and solar gain) due to temperature stratification. Depending on the type of heating source (radiative or convective), the temperature at the sensor height can be about 0.25–0.5°C warmer than at 1.5 m height (Pollard, 2001). This slight overestimation during heating periods is not of concern here as we are focusing on unheated conditions and cold temperatures where such an effect is not observed.

The sensors used in both studies were SHT15 by Sensirion, with a typical temperature and relative humidity accuracy of ±0.3°C and ±2.0%, respectively. The sensors were calibrated using a traceable instrument (Vaisala MTI41) just before being installed in

[1] One household joined the study too late for temperature and humidity monitoring but took part in the interview and fungal spore sampling.
[2] One participant declined to take part in the interview.

the homes. After 6 months in the field, the sensors were collected and their reading again compared with the calibration instrument. The typical deviation in temperature we found was about 0.3°C with a maximum of 0.4°C. The relative humidity was found to be within the instrument's uncertainty of ±2%.

A total of 309 temperature and relative humidity sensors were installed during the 2016 study and 132 sensors for the 2017 study. As the sensors were connected to the internet, any malfunction could be readily discovered and the sensor replaced. Whilst none of the sensors malfunctioned, some were lost due to system failure, and two homes had to be switched off. In a few areas, the lack of good cell network coverage was a challenge, as the sensors have limited capacity to store data when offline.

Outside temperature and relative humidity were obtained from Metservice and not measured with sensors.

2.2 Fungal spores

The fungal spore samples were taken with an aerosol sampling pump (Buck BioSlide B1020), which pumped 15 litres of air per minute past an polymeric adhesive (GEL) covered slide for 10 minutes, giving a trace of bioaerosols (mould, pollen, bacteria etc.). The sampling pump was mounted on a tripod placed in the bedroom and outdoors at a height of 1.2 m. The sampling took place at the time of the home visit, which was usually late morning to early afternoon. The indoor sampling was done with closed windows and before any vacuuming was done. The outdoor air was sampled a few metres away from the building. Conditions were always dry, with no need to sample during rainy days. The sampling slides were analysed by professional fungal analysis lab Biodet in New Zealand using phase contrast microscopy at 1,000 times magnification. The whole trace was analysed following ASTM D7391-09 *Standard test method for categorization and quantification of airborne fungal structures in an inertial impaction sample by optical microscopy*. The viable spore sampling was done using a MAS-100 Eco sampler with agar Petri dishes inside. The sampling was placed similarly to the slide sampling but the sampling time was only 1 minute so as not to overwhelm the Petri dish with spores.

The dust samples were taken by vacuuming a 1 m^2 area of floor for 2 minutes in the main bedroom (see Shorter, 2013). The vacuuming was done in a way to sample a representative ratio of the different floor coverings in the room. The sampling area was usually located between the bed and the window, if possible. A household vacuum cleaner was used equipped with a pre-weighed nylon collection sock (25 µm pore size) and a 0.63 mm mesh pre-filter (to separate any coarse material such as fibres or hair from the dust) fitted over the tube end of the upholstery nozzle attachment. The extension tube of the cleaner was then fitted on to the nozzle in the normal way, making a tight seal with the filter. After the dust was collected, the pre-filter was removed and the fine filter was placed into a sample jar (100 ml) and weighed. The samples were collected in a small dust bag mounted just behind the vacuum nozzle. The dust samples were then weighed and frozen at -40°C until they were shipped for analysis to the Institute for Analytical Chemistry in Vienna, Austria.

2.3 Questionnaires and interviews

The 2016 houses that are part of this study were recruited from the pool of houses that were part of the representative 2015 House Condition Survey. The 2017 homes were selected from members of Kōkiri Marae.

The 2016 study included a short self-completion questionnaire that asked participants about their ventilation habits (use of extractor fans and opening windows) and their perception of warmth in the main living area and bedrooms over winter. Further questions asked about any problems in the home, including with damp and mould. The questionnaire was sent to all participants at the end of the study period. A total of 64 questionnaires were returned.

The 2017 study extended this questionnaire to a more in-depth semi-structured face-to-face interview. This was completed with all participants in their home at the end of the monitoring period (November 2017). The interviews typically lasted around 20 minutes and were audio-recorded and transcribed. The interviews explored householder ventilation and heating habits, comfort and problems experienced in the home over winter.

3. Data analysis

With the sensors reporting data in real time into the BRANZ database, data consistency and quality was routinely checked during the study period. The data was divided into four time intervals – morning (07:00–09:00), day (09:00–17:00), evening (17:00–23:00) and night (23:00–07:00). For each category, a probability histogram was produced showing the likelihood of experiencing a certain temperature in bedrooms and (2017 study only) living rooms. Distributions of temperature and relative humidity for each bedroom were also analysed in a box and whisker plot. Note that the box and whisker plots indicate the quantiles 0.1, 0.25, 0.5, 0.75 and 0.9. We do not show the minima and maxima as we are more interested in the distribution of the temperature and relative humidity than short-term extremes.

4. Results

4.1 Temperatures

The indoor temperatures recorded in bedrooms during the winter months of 2016 (1 June 2016 to 31 August 2016) ranged from:

- 7.5–25.3°C for Auckland
- 9.5–24.5°C for Wellington
- 8.5–23.0°C for the upper South Island
- 5.1–21.7°C for Dunedin.

For the winter 2017 Wellington study a bedroom temperature range of 5.3–27.6°C was recorded and a living room temperature range of 6.8–31°C.

Figure 1 shows the temperature distribution in bedrooms of all participating homes of the 2016 study. The red line in the graph represents 18°C, which is the minimum indoor temperature recommended by the World Health Organization (WHO).

Similar results are shown for the Wellington 2017 study in Figure 2. Both figures show that the temperature of a number of bedrooms fell below the 18°C mark (red line) for a large portion of time.

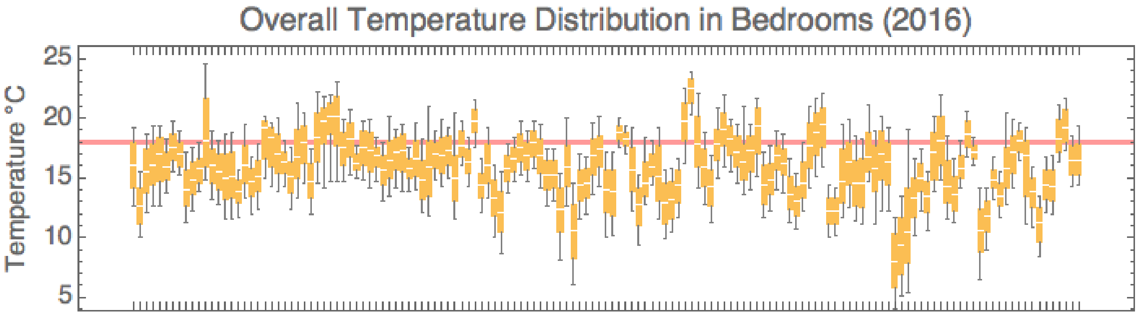

Figure 1. Bedroom temperature distribution (5, 25, 50, 75 and 90 percentile) in Auckland, Wellington, upper South Island and Dunedin from the winter 2016 study.

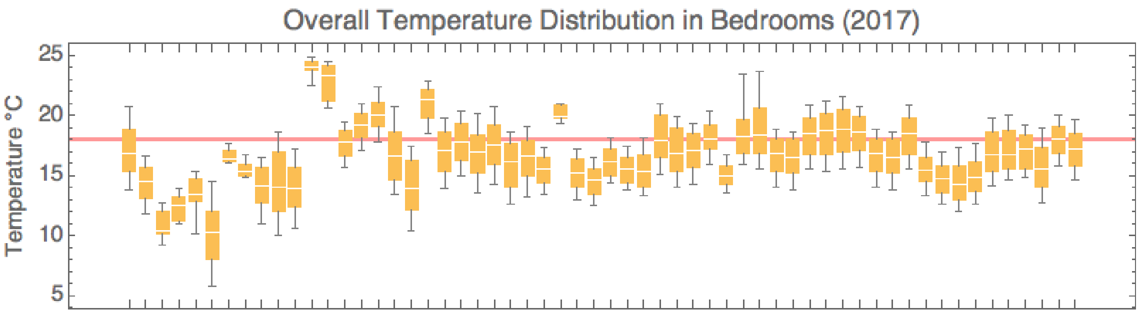

Figure 2. Bedroom temperature distributions (5, 25, 50, 75 and 90 percentile) in Wellington from the 2017 study.

Mean temperatures in bedrooms in Auckland, Wellington, upper South Island, and Dunedin measured during the winter of 2016 and for the Wellington region again in 2017 are listed in Table 2 and Table 4, respectively. As expected, during the night and morning hours as the outdoor temperature reaches its minimum, so do the bedroom temperatures, with an average of 15.1°C and 15.6°C.

Table 4 provides evidence of occupants in the Wellington 2017 study heating their home sometime in the evenings, with heating then being switched off, resulting in bedrooms cooling to an average temperature of 15.6°C by the morning.

Table 3 and Table 5 show the percentage of time and the percentage of bedrooms that reached less than a certain temperature threshold. For example, for the 2016 study, all of the bedrooms experienced a temperature of less than 18°C for up to 76% of the time.

During the 2017 study in Wellington (Table 5), 95% of the bedrooms reached a temperature of less than 18°C for up to 70% of the time.

Table 2. Mean temperatures in bedrooms and outdoors by location and time period.

Location	Overall	Morning 07:00–09:00	Day 09:00–17:00	Evening 17:00–23:00	Night 23:00–07:00	Number of rooms
Auckland	16.3°C	15.1°C	17.2°C	17.4°C	15.4°C	48
Auckland (outdoors)	12.1°C	10.9°C	13.8°C	12.0°C	10.9°C	NA
Wellington (2016)	15.4°C	14.2°C	16.1°C	16.7°C	14.9°C	25
Wellington (outdoors)	9.6°C	8.7°C	11.3°C	9.3°C	8.5°C	NA
Wellington (2017)	16.6°C	15.6°C	16.6°C	17.5°C	16.3°C	58
Wellington (outdoors)	9.5°C	8.1°C	11.3°C	9.4°C	8.3°C	NA
Upper South Island	15.2°C	13.5°C	15.7°C	16.8°C	14.8°C	13
Upper South Island (outdoors)	7.5°C	5.6°C	10.4°C	7.2°C	5.5°C	NA
Dunedin	14.5°C	13.2°C	15.2°C	15.6°C	14.2°C	18
Dunedin (outdoors)	10.4°C	9.6°C	11.7°C	10.2°C	9.5°C	NA
Average bedroom	**16.0°C**	**15.1°C**	**17.0°C**	**17.3°C**	**15.6°C**	**162**

Table 3. Temperature readings for all bedrooms from the 2016 study showing the percentage of time a bedroom was below that temperature and how many bedrooms recorded below that temperature.

Readings	Proportion of time	Percentage of bedrooms
Less than 10°C	3%	54%
Less than 12°C	10%	86%
Less than 14°C	25%	96%
Less than 16°C	50%	99%
Less than 18°C	76%	100%
Less than 21°C	96%	100%

Table 4. Mean temperatures for the 2017 Wellington study by room and time period.

Location	Overall	Morning 07:00–09:00	Day 09:00–17:00	Evening 17:00–23:00	Night 23:00–07:00	Number of rooms
Wellington living room	17.3°C	15.5°C	17.0°C	19.1°C	16.6°C	25
Wellington bedroom	16.6°C	15.6°C	16.6°C	17.5°C	16.3°C	58
Average	**17.0°C**	**15.6°C**	**16.8°C**	**18.3°C**	**15.6°C**	**162**

Table 5. Temperature readings for all bedrooms from the 2017 study showing the proportion of time a bedroom was below that temperature and percentage of bedrooms recorded below that temperature.

Readings	Proportion of time	Percentage of bedrooms
Less than 10°C	2%	29%
Less than 12°C	6%	60%
Less than 14°C	19%	89%
Less than 16°C	44%	93%
Less than 18°C	70%	95%
Less than 21°C	94%	100%

Figure 3 shows the temperature histograms for the four time periods for the 2016 study (panels a to d) and for the 2017 study (panels e and f).

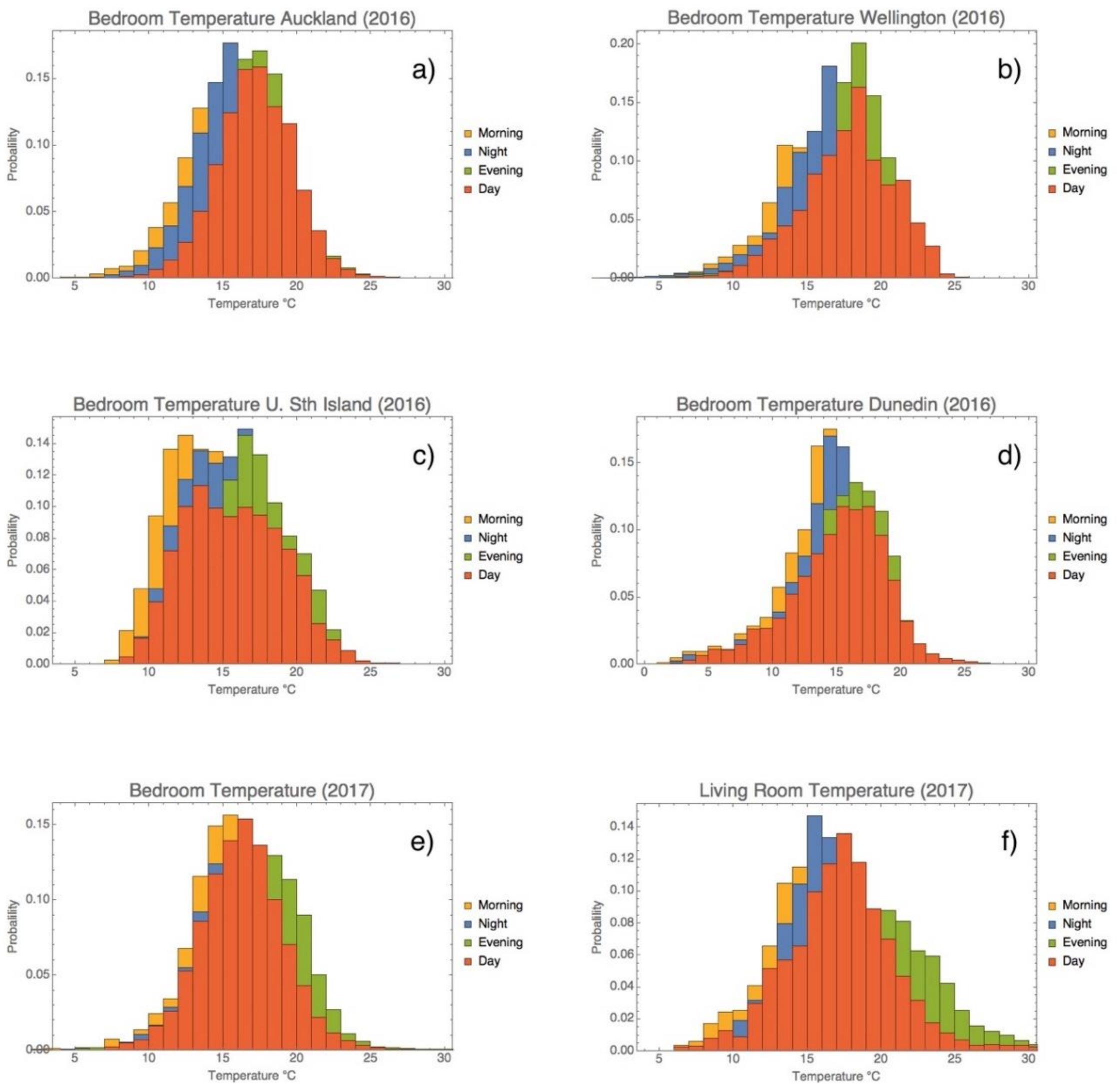

Figure 3. Temperature histograms for the four time periods.

The 2016 data shows that, for Auckland, little heating was provided to the bedrooms during the evening as the likelihood of experiencing temperature above 18°C in the bedrooms rises very little if at all above the daytime likelihood for those temperatures.

Bedroom temperature data from the 2016 study in Wellington, the upper South Island and Dunedin provide evidence of some heat input, with evening temperature distributions being above the daytime data.

The 2017 data (Figure 3e) shows evidence that some bedroom heating occurred, even more so in this sample of Wellington homes compared to the 2016 data.

Figure 3f shows that, while some bedrooms were heated, the living rooms were the most likely place to be heated, with an average temperature of 19.1°C (Table 4).

4.2 Relative humidity

The median relative humidity recorded in bedrooms for the 2016 and 2017 studies was 64%. This was over the full day. During the night time, when the bedrooms were typically occupied, this gave basically the same median relative humidity of 65%. This means that, for 50% of the time, the bedrooms had a moisture load high enough to warrant ventilation or heating to reduce the elevated moisture level. The moisture level is too high and should not exceed 65% relative humidity to stay well clear of levels that will promote mould growth. Figure 4 and Figure 5 show that the moisture level was above the 65% relative humidity line most of the time for many bedrooms.

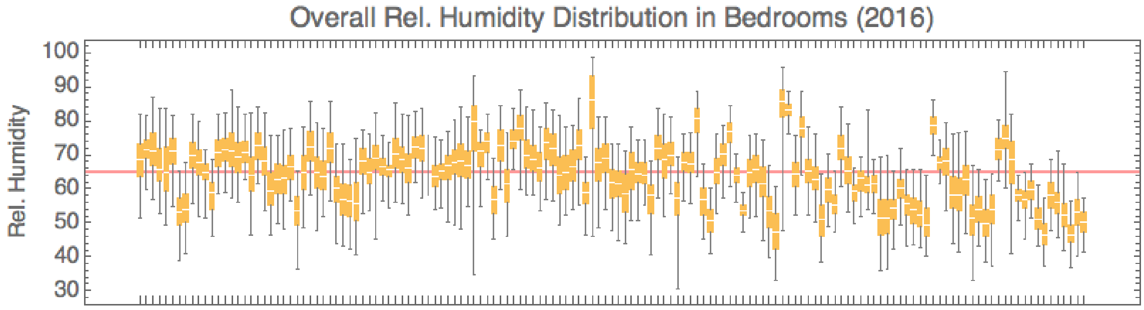

Figure 4. Relative humidity over the whole day in the bedrooms of the 2016 survey – median relative humidity was 64%.

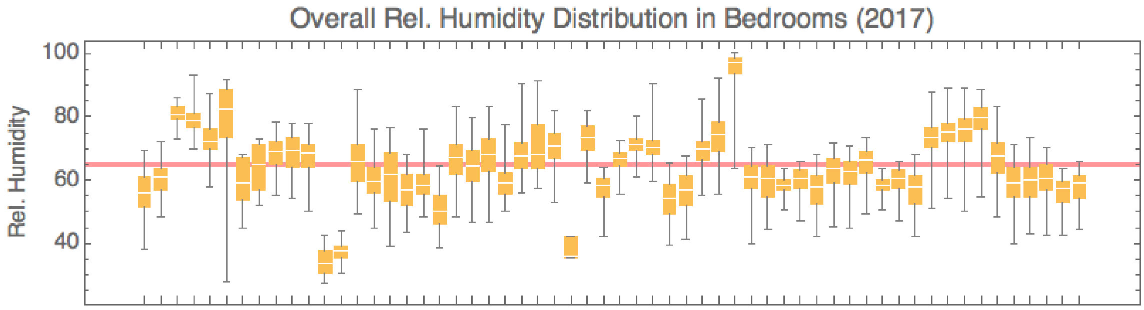

Figure 5. Relative humidity over the whole day of the 2017 survey in bedrooms in Wellington – median relative humidity was 64%.

Figure 6 compares the relative humidity of the 2017 study houses with an adjusted relative humidity that would have resulted if the bedrooms were heated to a minimum WHO-recommended temperature of 18°C. For some bedrooms, this heating to 18°C would result in a reduction in relative humidity. For others however, ventilation would be required to remove excess moisture.

Bedrooms 3 to 6 in **Error! Reference source not found.** show a strong reduction in relative humidity under the adjusted heated to 18°C scenario. This suggests that the lack of heating in these houses may be the only or most significant cause of the excess moisture.

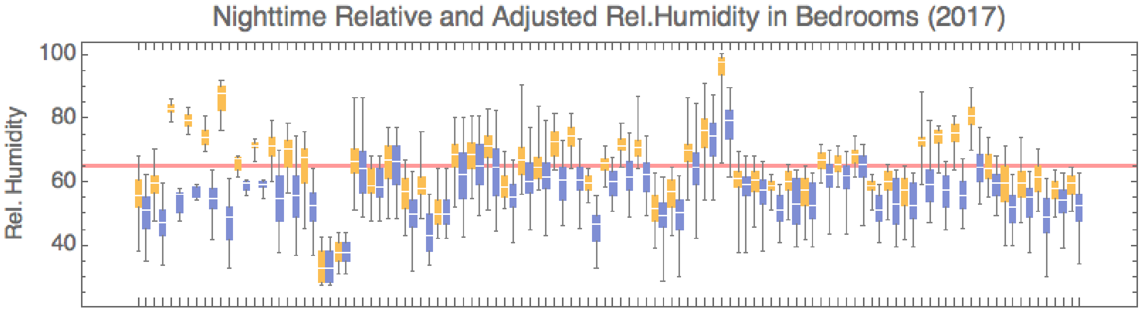

Figure 6. Night-time relative humidity for the bedrooms of the 2017 survey (orange) and adjusted relative humidity (blue) that would have resulted if the bedrooms were heated to a minimum of 18°C.

Other bedrooms were already at a temperature close to 18°C, and no significant change in relative humidity would be observable under the heated to 18°C scenario.

Some bedrooms were at an adequate temperature but showed a high relative humidity. To reduce the relative humidity in these rooms, reducing or eliminating moisture at the source and/or improved ventilation would be required.

Table 6 shows the percentage of time and the percentage of bedrooms that reached more than a certain relative humidity in the 2016 study. For example, this shows that 94% of bedrooms experienced a relative humidity of more than 65% for 54% of the time. During the 2017 study in Wellington (Table 7), 95% of the bedrooms exceeded a relative humidity of 65% for 46% of the time.

Table 6. Relative humidity readings for all bedrooms from the 2016 study showing the proportion of time a bedroom was above the relative humidity and percentage of bedrooms recorded above that relative humidity.

Readings	Proportion of time	Percentage of bedrooms
More than 90%	1%	11%
More than 80%	4%	58%
More than 75%	11%	71%
More than 70%	23%	86%
More than 65%	54%	94%
More than 60%	71%	96%

Table 7. Relative humidity readings for all bedrooms from the 2017 study showing the proportion of time a bedroom was above the relative humidity and the percentage of bedrooms recorded above that relative humidity.

Readings	Proportion of time	Percentage of bedrooms
More than 90%	2%	16%
More than 80%	6%	45%
More than 75%	13%	62%
More than 70%	28%	83%
More than 65%	46%	95%
More than 60%	66%	95%

4.3 Fungal spores and metabolites

Table 8 summarises the results of the air sampling for fungal spores. An air sample was obtained from various rooms, using an airflow of 15 litres per minute for 10 minutes. The detection limit is 7 spores per m^3, so a 0 indicates there were fewer than 7 spores per m^3 of air. The full results are shown in Appendix A.

Stachybotrys spores were detected in one sample from a bedroom. This spore type is indicative of a prolonged leak or major wetting event and is toxigenic. There was no evidence of a visible leak but this wetting event could have been a while ago or may have been due to hidden water damage.

Chaetomium spores were detected in a low level in the living room in one house (CH1.3) and bathroom in another two properties (AK1.1 and DN1.2). Like *Stachybotrys*, the presence of this fungus is also indicative of a prolonged leak or major wetting event. *Chaetomium* is also considered to be toxigenic and is undesirable in indoor air.

Penicillium/Aspergillus spore levels were excessive in bedrooms of six houses (DN1.5, AK1.1, WN2.1, AK3.4, AK2.2 and WN3.1) and in the living room of one property (DN1.5). Spores were elevated (when compared with Biodet's database guidelines) in the bedroom of two houses, bathroom of two houses and living room of one property. In addition, two houses had slightly raised spore levels (bedroom in AK4.1 and the bathroom in CH1.3). These fungi grow indoors in response to a raised relative humidity. This could be due to moisture ingress issues or to an accumulation of condensation in an area lacking good ventilation resulting in localised superficial fungal growth.

The *Cladosporium* level was excessive in a bedroom of three different houses (AK1.1, WN2.1 and WN3.1). The level was elevated in a further three properties (living room of DN1.5 and bedroom of CH2.3 and AK1.3). Like *Penicillium/Aspergillus*, these spore types will grow indoors where there is a raised relative humidity, and the spores may be allergenic to sensitive people.

The presence of high levels of bacterial clusters found in one bathroom and one living room is unusual. In the case of the bathroom, it is more likely to be indicative of condensation and a lack of good ventilation. In the case of the living room, this would be more likely be due to increased moisture resulting in bacterial growth.

According to the experts at Biodet, the presence of high levels of bacterial clusters can be a classic symptom of water-damaged carpet. Although the types of bacteria cannot be determined from the type of sampling performed here, there is a high probability of gram-negative bacteria being present. These bacteria may cause respiratory symptoms involving allergic type reactions. Gram-negative bacteria are so small they may be capable of deep penetration into the lung upon aerosolisation. They possess endotoxin, which can be a respiratory irritant. The endotoxin is part of the gram-negative cell wall. Although the bacteria may be rendered non-viable (dead), the endotoxin remains, even through extremely high temperatures. Symptoms typically involve elevated temperatures, followed by malaise and respiratory distress. Occasionally, skin reactions may occur (Hess-Kosa, 2010).

Table 8. Summary of the results of the airborne spore sampling conducted in the main bedroom.

House ID	*Stachybotrys*	*Chaetomium*	*Penicillium/ Aspergillus*		*Cladosporium*		Bacterial clusters (high levels)	Other spore types
			Excessive	Elevated	Excessive	Elevated		
AK4.3	Bedroom 1							
DN1.5			Bedroom 1 Living room	Bathroom		Living room	Living room** Bedroom 1	Living room
AK1.1		Bathroom*	Bedroom 1	Bathroom Living room	Bedroom 1		Bedroom 1 Bathroom*** Living room	Bedroom 1 Living room
WN2.1			Bedroom 3		Bedroom 3		Bedroom 3	Bedroom 3
AK3.4			Bedroom				Bedroom	Bedroom
AK2.2			Bedroom 2				Bedroom 2	
WN3.1			Bedroom 3		Bedroom 3		Bedroom 3	
CH2.3				Bedroom 1		Bedroom 1	Bedroom 1	
AK1.3				Bedroom		Bedroom	Bedroom	Bedroom
AK4.1				*Bedroom**				Bedroom
CH1.3		Living room*		Bathroom*				Living room Bathroom
DN1.2		Bathroom*						

* Observed level only slightly raised – unlikely to result in health issues.
** Likely to be due to increased moisture resulting in bacterial growth.
*** Likely to be indicative of condensation and a lack of good ventilation.

Other spore types were found elevated in several houses (eight in total), notably so in the bedrooms of home AK4.1 and the living room and bathroom of home CH1.3, in which *Wallemia* was observed to be a proportion of these counts. This fungus is a xerophile but has also been associated with damp building materials. *Wallemia* is also regarded as allergenic and may cause infections.

Extraneous particulate levels such as fibres and skin cells were mainly moderate to high in most of the areas, which is not unusual in a domestic environment, particularly bedrooms. It may be an indication that there is little ventilation or air movement in these areas.

The fungal count results found were presented to the homeowners/occupants, and remedies and mitigation strategies were discussed to help avoid excessive outbreaks in the future.

4.4 Fungal spore counts compared to reference case

Fungal spore counts measured in different rooms of the study houses were compared with a reference scenario. The reference counts (Figure 7) were obtained from the Biodet database and show the typical fungal spore count in a non-air conditioned house without moisture problems.

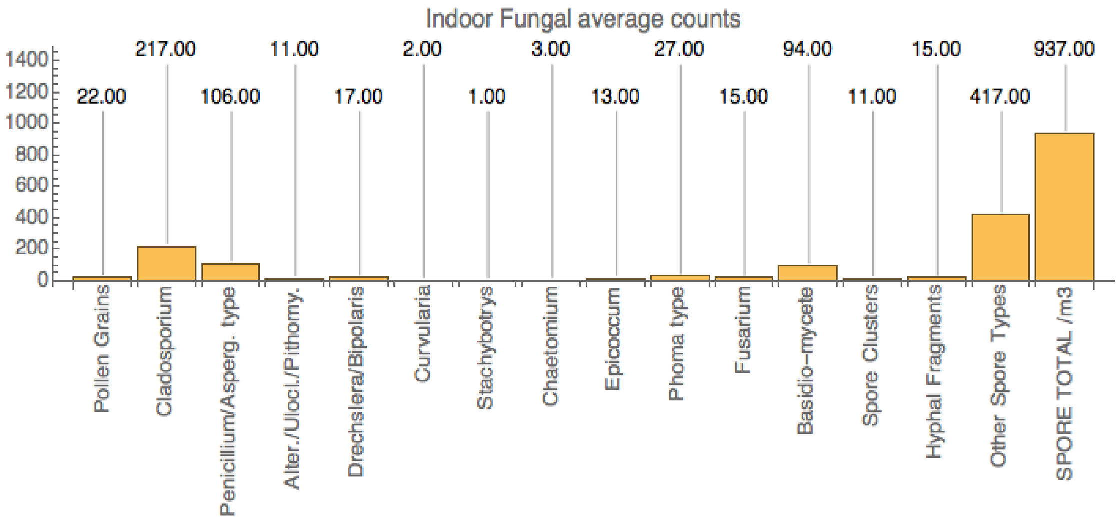

Figure 7. Average airborne fungal counts based on New Zealand houses without moisture problems.

The figures below show the ratio of measured fungal spore counts in study houses to these reference counts. Results are shown for living rooms, bathrooms and bedrooms (Figure 8, Figure 10, Figure 13 and Figure 15) and bedrooms only (Figure 9, Figure 11, Figure 14 and Figure 16).

The data described here provides evidence of different scenarios of fungal spore exposure and conditions in study houses. These scenarios include:

- elevated and concentrated levels in specific rooms of the home – the room type is important as it affects the level of exposure and risk to occupants
- elevated levels throughout the home (i.e. not contained to specific rooms)
- temperature and humidity that could either foster mould growth or help prevent it.

Houses AK4.1 and AK1.1 had high ratio counts compared to the reference counts. In these properties, the spore counts in the bedroom were further elevated when compared to the living area and bathroom.

Bedrooms are considered a high exposure environment, where occupants are likely to spend most of their time when at home. High spore counts in these areas therefore may pose greater risk to occupant health than if found in and contained to other areas of the home.

House AK4.1

Figure 8 and Figure 9 show fungal count ratios to reference counts for house AK4.1, showing particularly elevated levels in the bedroom.

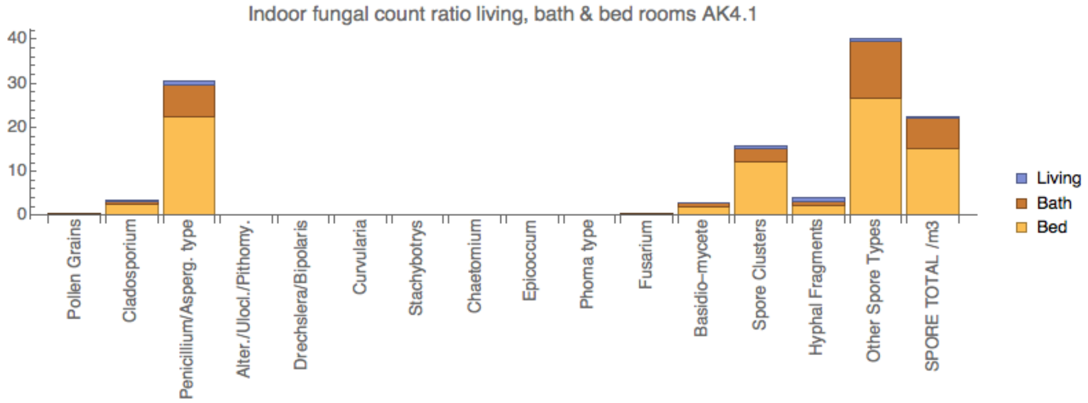

Figure 8. Fungal count ratios against the reference counts found in the living room (blue), bathroom (brown) and bedroom (orange) of house AK4.1.

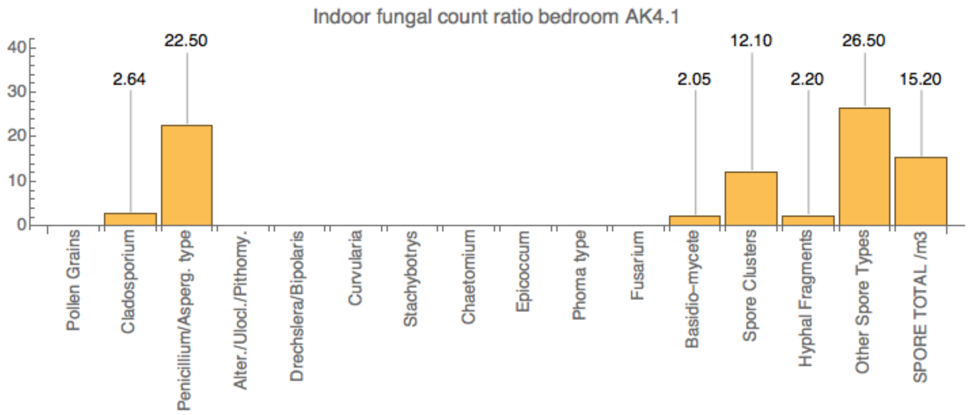

Figure 9. Fungal count ratios against the reference counts measured in the main bedroom of house AK4.1.

House AK1.1

Figure 10 and Figure 11 show fungal count ratios to reference counts for house AK1.1, highlighting particularly elevated levels in the main bedroom. The bottom graph in Figure 12 shows temperature and humidity in the same bedroom.

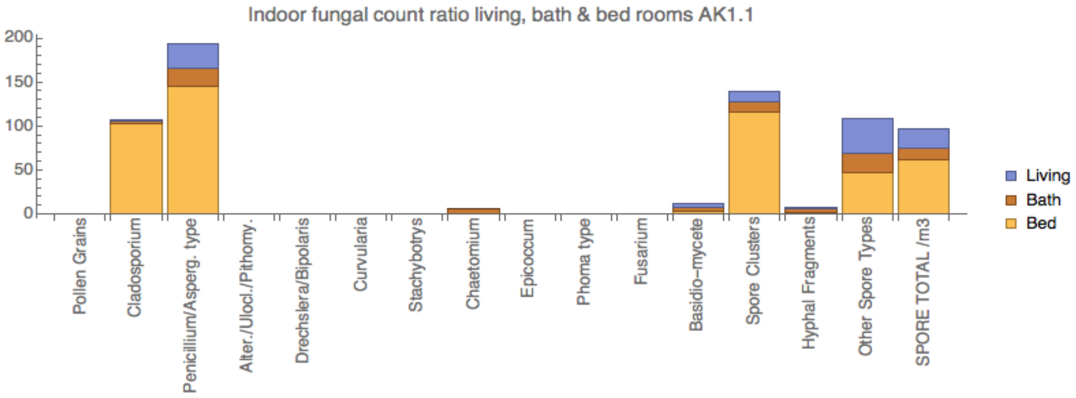

Figure 10. Fungal count ratios against the reference counts found in the living room (blue), bathroom (brown) and bedroom (orange) of house AK1.1.

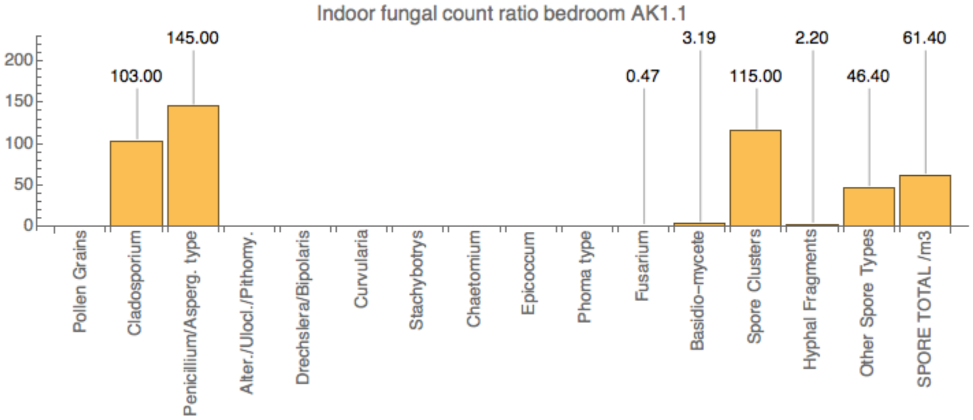

Figure 11. Fungal count ratios against the reference counts measured in the main bedroom of house AK1.1.

Figure 12 shows the temperature and relative humidity in the main bedroom for house AK1.1. While the average temperature is only slightly below recommended levels during the night/early hours of the morning (falling to an average of 17°C), the relative humidity is consistently quite high at 60–70% throughout the whole day. These conditions could foster the mould growth observed in this room. In contrast, the living room average relative humidity was only 52%, which relates to the considerable less mould found in this room.

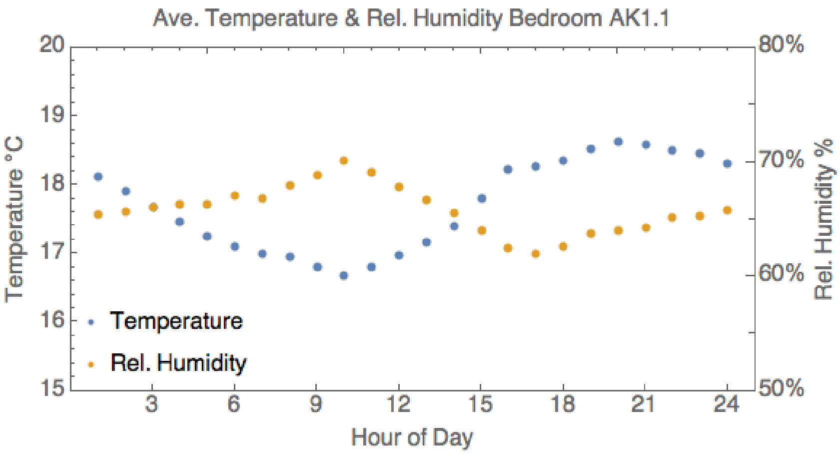

Figure 12. Temperature (blue) and relative humidity (orange) in the main bedroom of house AK1.1.

House DN1.5

House DN1.5 had elevated spore counts compared to the reference house, but these were not concentrated in the bedroom, unlike houses AK4.1 and AK1.1. Rather, the ratio of the counts in the bedroom and living area were similar and around 200 times that of the reference counts. This presents another high-risk/high-exposure environment for occupants. The high counts in the living area were most likely caused by a strong moisture event, such as a leak.

Figure 13 and Figure 14 show fungal count ratios to reference counts for house DN1.5, showing elevated levels in both the bedroom and living area. The high counts in the living room indicate that there is or has been a water leak or prolonged moisture issue.

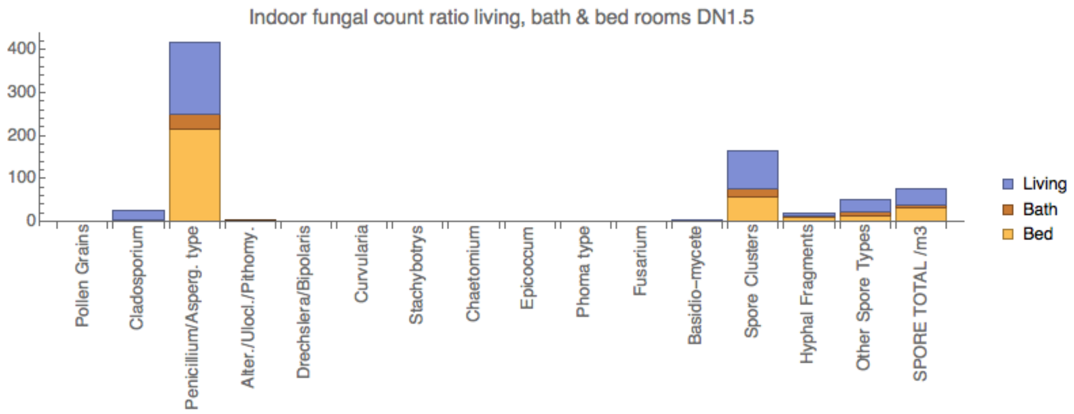

Figure 13. Fungal count ratios against the reference counts found in the living room (blue), bathroom (brown) and bedroom (orange) of house DN1.5.

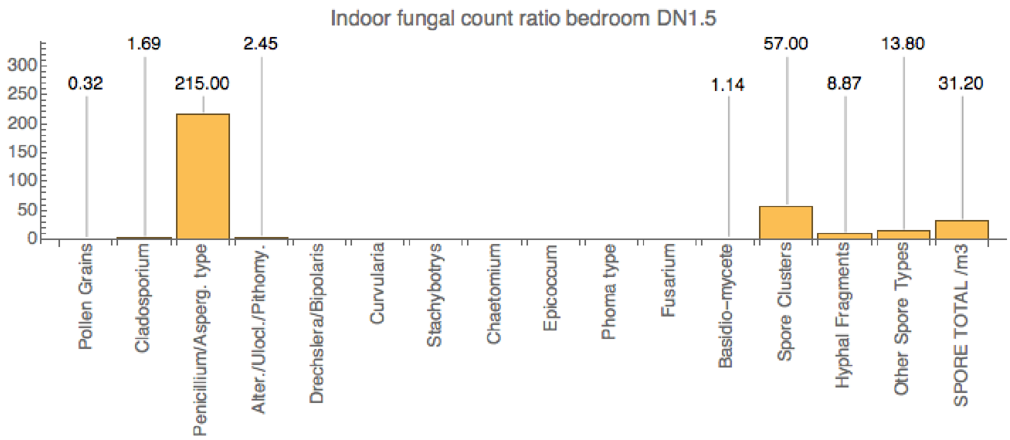

Figure 14. Fungal count ratios against the reference counts measured in the main bedroom of house DN1.5.

House DN1.2

House DN1.2 also showed similar ratios of spore counts in the bedroom and living area, but readings were below 10 (i.e. far less elevated than the other houses shown) compared to the reference counts (with the exception of other spore types, which is 20). The average indoor climate of this house was warm (24°C) and very dry (with an average relative humidity of 34%) – very different from conditions in the property with the elevated spore levels.

Figure 15 and Figure 16 show fungal count ratios to reference counts for house DN1.2 and temperature and humidity in the bedroom. Ratio counts were lower compared to study houses shown above, and the conditions were warm and dry (Figure 17).

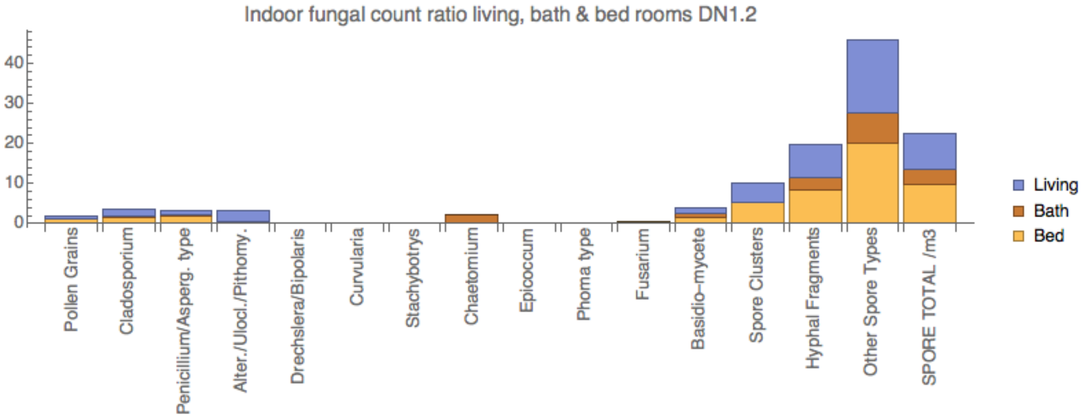

Figure 15. Fungal count ratios against the reference counts found in the living room (blue), bathroom (brown) and bedroom (orange) of house DN1.2.

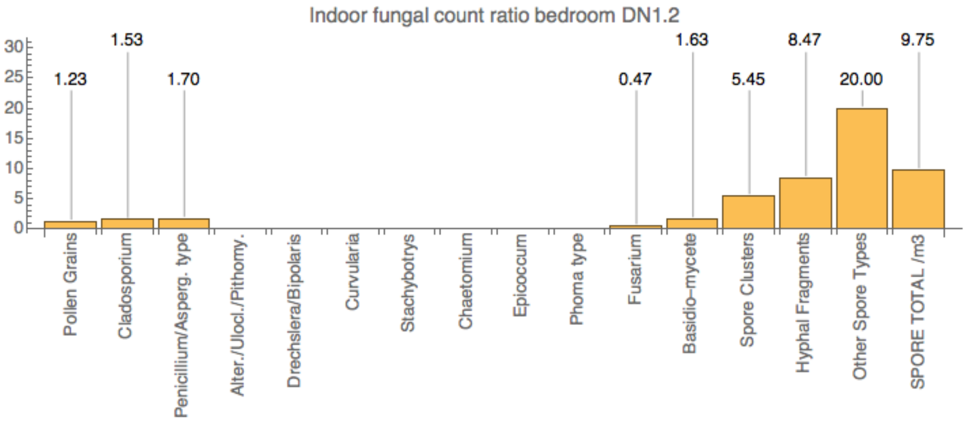

Figure 16. Fungal count ratios against the reference counts measured in the main bedroom of house DN1.2.

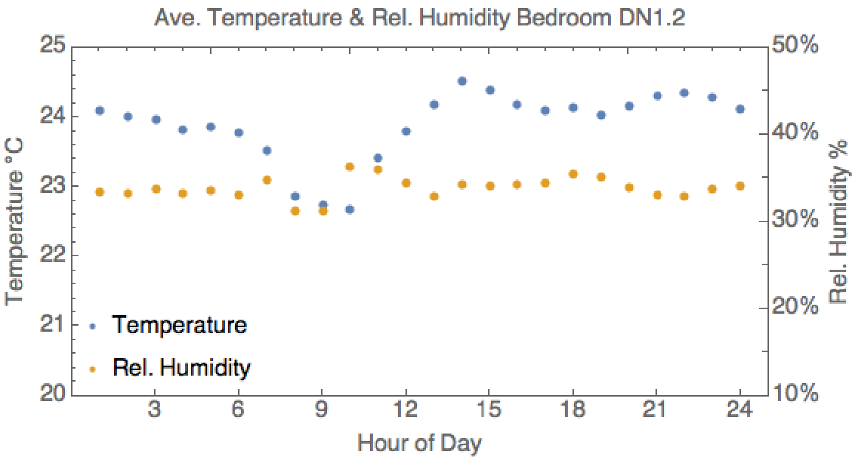

Figure 17. Temperature (blue) and relative humidity (orange) in the main bedroom of house DN1.2.

4.5 Extreme spore counts

The two case study examples described below represent the highest and lowest spore count in the sample of 25 homes from the 2017 study.

4.5.1 Case study 1: Cold and damp

Figure 18 shows the spore count ratios for the main bedroom in property WN3.1. **Error! Reference source not found.** shows the average daily climate in that room. The temperature fell to 13°C at night and the relative humidity reached over 80%, with an average consistently over 70%. These conditions increase the risk of mould growth, which aligns with the measured spore counts in this room.

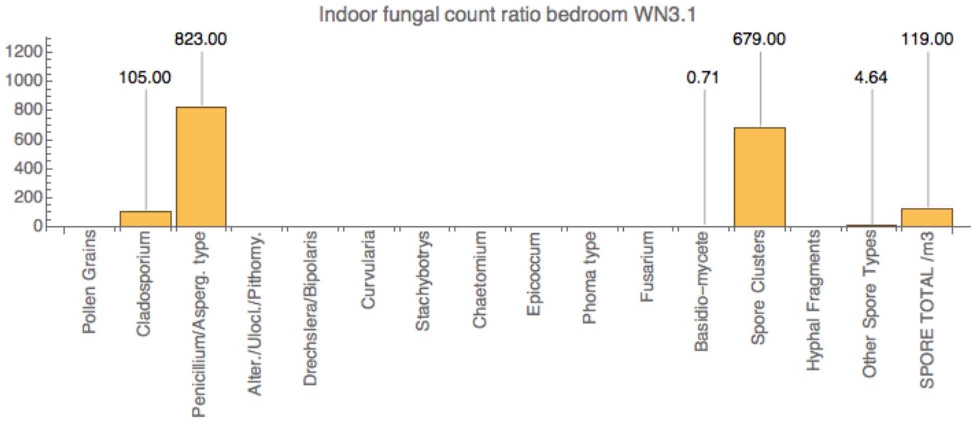

Figure 18. Fungal count ratios of a bedroom in WN3.1 against the reference counts. *Penicillium/ Aspergillus* type exceeds the reference by a factor of over 800 and the spore clusters are also very high.

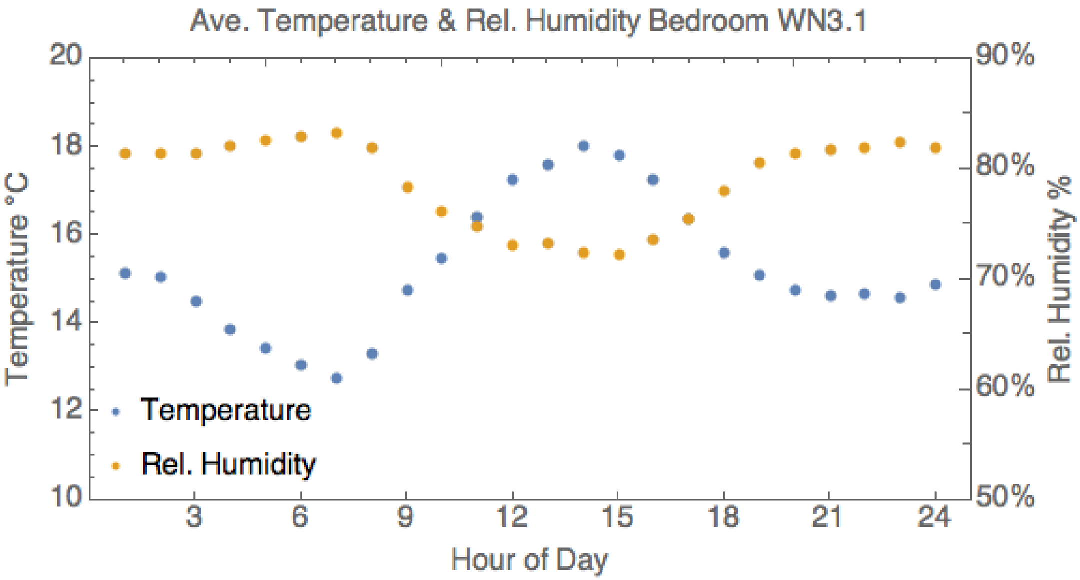

Figure 19. Temperature (blue) and very high relative humidity (orange) in the main bedroom.

The occupant's account (through the householder interview) of living conditions in this property also aligns with the results shown above. The property is a 4-bedroom, single-storey stand-alone 1950s weatherboard house. The occupants (three adults and two children) rented from a private landlord and had lived there for about 2 years. This was the only study participant to respond negatively when asked if they liked living in their home. This was partly due to space (smaller and more cramped than their previous home), but also due to the poor state of repair, significant moisture problems, feeling cold, and difficulty getting their landlord to undertake repairs.

> "This is a real cold place in the winter. I think it's cold because of water. When it comes, it sits … on the ground [around the house]. I think that could be it. Because that garage is always wet." [WN3.1]

> "We had really heavy rain. Got up in the morning and the roof was falling down, and the batts showed through. So they came and just put some tin on the roof, but they didn't do anything about the batts. I would have thought they would have changed them. It was really sagging." [WN3.1]

> "We have that [woodburner] going. We've got a heater down the passage. For a small house, we shouldn't. But it's so cold in that end bedroom. And we don't use this bedroom in winter. I normally sleep with my mokopuna." [WN3.1]

The occupant talked of:

- "an indoor pool" in the attached garage due to a major leak
- obvious signs of damp and moisture accumulation around the exterior of the property (which backs on to a hill)
- a leak in the roof, which resulted in part of the ceiling falling in and insulation sagging
- draughts around windows and exterior doors
- difficulty maintaining a warm home, despite heating (often for many hours a day) with a wood burner and an electric heater
- being unable to sleep in one bedroom in winter due to extreme cold
- smell of damp in two bedrooms and visible mould on window frames
- a bathroom "covered in mould" despite attempts to clean it.

Figure 20. Mould on bathroom ceiling in house WN3.1.

This property had no mechanical extract in the kitchen (which was open plan with the living space). Occupants would not open windows around the house in winter (even when cooking) due to it being "too cold". The only rooms with windows open over winter were the bathroom and laundry. The house did have a whole-house ventilation system, and the occupant reported using this and noticing some difference (improvement) in condensation levels when it was on (for example, when cooking). However, they seemed unsure of how to use it to best effect.

The problems of damp and mould and poor indoor environmental quality observed in this dwelling seem to stem from a combination of house location/siting (backing on to dense bush-clad hill, lacking natural light and poor drainage), poor maintenance and thermal performance (leaks and inadequate insulation) and occupant behaviour (not feeling able to open windows due to cold).

4.5.2 Case study 2: Warm and dry

The conditions in house WN3.3 were quite different from those described above. The spore count ratios for the main bedroom in this property were very small and close to the reference spore count (Figure 21). The indoor climate in this bedroom, shown in Figure 22, shows that, while the night-time temperature fell slightly below the recommended 18°C, the average relative humidity remained below 60%. These conditions help reduce the risk of mould growth in this room.

The householder interview provided further evidence to support the results from the spore samples. The property is a 1960s semi-detached 2-bedroom, 2-storey house, owner-occupied with two adult occupants. The property was well maintained, and occupants reported insulation in the roof space and subfloor and a ground vapour barrier (although this was not assessed by the researcher so is based on the occupants' account only).

The living area is heated with a heat pump, and there is a whole-house ventilation system, both of which the occupants found very efficient and effective in providing a comfortable, healthy living environment. Whilst they did not have mechanical extract ventilation in the kitchen or bathroom, they reported always opening windows when cooking and would "rarely shut' the bathroom window, but would keep the door closed (preventing moisture and cold air escaping to the rest of the house).

> "It was really cosy, with the heat pump … It's very efficient. And because the place is insulated and everything, it really minimises the amount of heat you have to use." [WN3.3]

Based on the above, low spore counts and healthy temperature and humidity levels observed in this property may be a combination of a number of factors including a good, well-insulated and well-maintained thermal envelope, efficient and effective use of heating and ventilation systems and positive occupant behaviour in opening windows enough to remove moisture without cooling the home to excess.

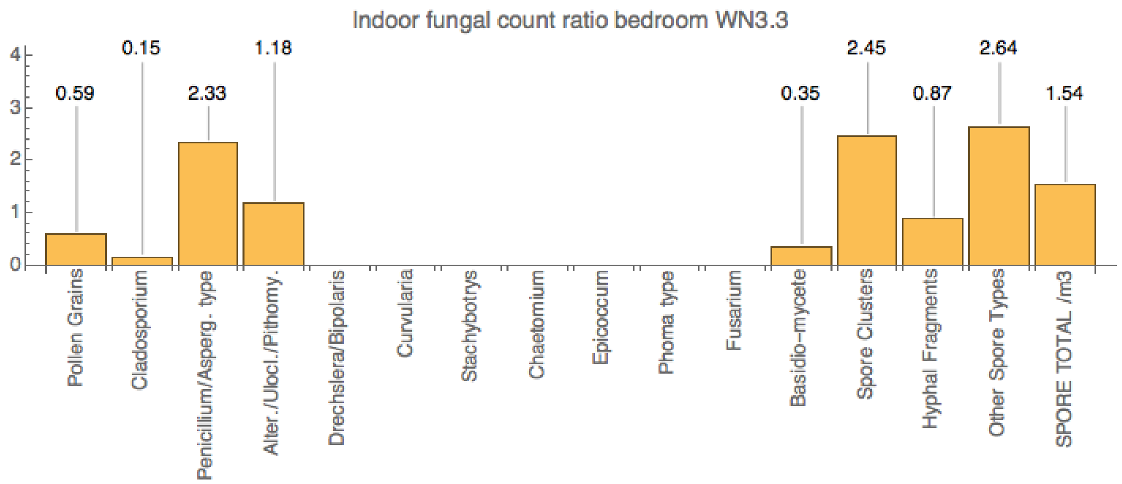

Figure 21. Fungal count ratios of a bedroom in WN3.3 against the reference counts.

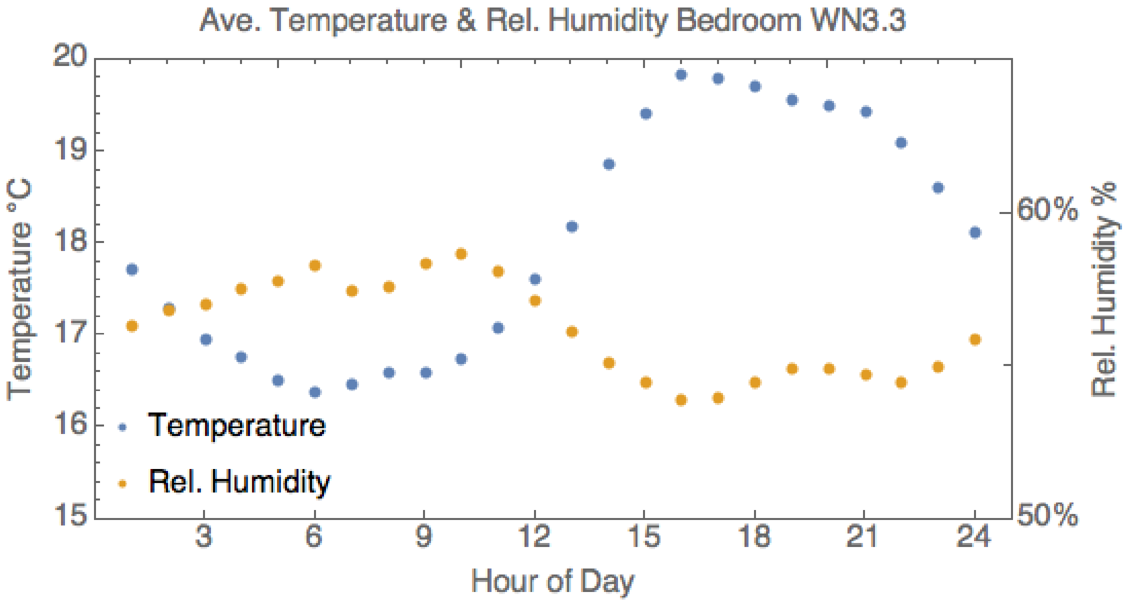

Figure 22. Temperature (blue) and relative humidity (orange) in the main bedroom.

4.6 Fungal metabolites

The metabolites of bacteria and fungi were measured to assess the sensitivity of the method in identifying mycotoxins and therefore the presence of certain fungi in the home. If successful, this methodology would provide a fast, reliable and cost-effective way to identify the presence of toxic fungi associated with respiratory health problems.

This project was not designed to answer these questions but to be a pilot and to establish whether and which metabolites can be identified. A new research project is under way trying to establish whether there is a link between the presence of certain metabolites and health outcomes.

The metabolites of fungi and bacteria were measured in the main bedroom by taking a dust sample from the carpet. This sample was taken by vacuuming 1 m^2 of carpet for 2 minutes and collecting the dust into a 'sock'. This sample was then placed into a sample container and stored at -40°C until all samples were ready to be sent off to the analysis lab in Austria. Table 9 shows the full range of metabolites detected across these samples.

The specificity of the *Stachybotrys* Satratoxin-G results obtained need to be verified as only peak intensities were available. This needs to be established with more systematic research, which is now under way. *Stachybotrys* was identified in the airborne spore samples in one home just reaching the detection limit of 7 spores (Table 8). Satratoxin-G was found in three samples (houses WN2.10, AK1.3 and AK4.1). Unfortunately, a sample was not available from AK4.3, which showed the *Stachybotrys* in the airborne sample, as the participant declined to take part in this aspect of the study.

Table 9. Mycotoxins identified in at least one of the samples.

Category	Metabolites									
Sterigmatocystin and biosynthetic precursors	Sterigmatocystin	Methoxysterigmatocystin	Versicolorin C	Nidurufin	Viridicatol	Averantin	Averufin	Norsolorinic acid		
Penicillium metabolites	Amoxycillin	Penicillin G	Andrastin A	Chanoclavin	Citreohybridinol	Agroclavine	Festuclavine	Flavoglaucin	Oxaline	Quinolactacin A
Aspegillus metabolites	3-Nitropropionic acid	Fumigaclavine	Integracin A	Integracin B	Aspulvinone E	Orsellinic acid				
Alternaria metabolites	Alternariol	Alternariolmethylether								
Fusarium metabolites	Antibiotic Y	Aurofusarin	Bassianolide	Beauvericin	Enniatin A	Enniatin A1	Enniatin B	Enniatin B1	LL-Z 1272e	
Stachybotrys?	Satratoxin G									
Bacterial metabolites	Chloramphenicol	Nonactin	Monactin							
Plant toxins	Linamarin	Lotaustralin	Xanthotoxin							
lichen	Usnic acid									
Anthraquinone derivatives - unspecific	Chrysophanol	Citreorosein	Emodin	Endocrocin	Fallacinol	Iso-Rhodoptilometrin	Norlichexanthone	Physcion	Skyrin	
Dipeptides - unspecific	Brevianamid F	cyclo(L-Pro-L-Tyr)	cyclo(L-Pro-L-Val)							
Others - unspecific	N-Benzoyl-Phenylalanine	Asperglaucide	Asperphenamate	Neoechinulin A						

4.7 Observed mould

In addition to the air and dust sampling, the level of visible mould was assessed in the main bedroom by the researcher at the time of the interview at the end of the monitoring period. This assessment was applied to the walls, ceiling, floor, windows and curtains individually and used an indicator scale from 0 to 3, described as none, small, moderate or large/extensive (see Shorter et al., 2018 for more details).

The results showed windows were the most common place for mould to be observed, with 14 out of the 23 homes assessed as having visible mould. Windows were also the site where the most severe cases of mould were observed (Table 10).[3]

Table 10. Results from mould assessments in the main bedroom from the 2017 study.

	Count of houses with visible mould in the main bedroom				
Mould scale	**Walls**	**Ceiling**	**Floor**	**Windows**	**Curtains**
None	20	18	22	9	11
Small	1	4	0	5	6
Moderate	1	0	1	6	3
Large or extensive	1	1	0	3	3

Figure 23 shows the average, minimum and maximum mould index score for each property assessed. The average was derived from taking the mean of all the mould index ratings for each of five individual surfaces assessed. For example, a property with a mould score of 1 for walls, 1 for ceilings, 0 for floors, 2 for windows and 2 for curtains would equate to an average mould index score of 1.2. The minimum and maximum show that, within one room, the prevalence of visible mould could range from none to extensive, depending on the surface. Only six houses had no visible signs of mould anywhere in the main bedroom.

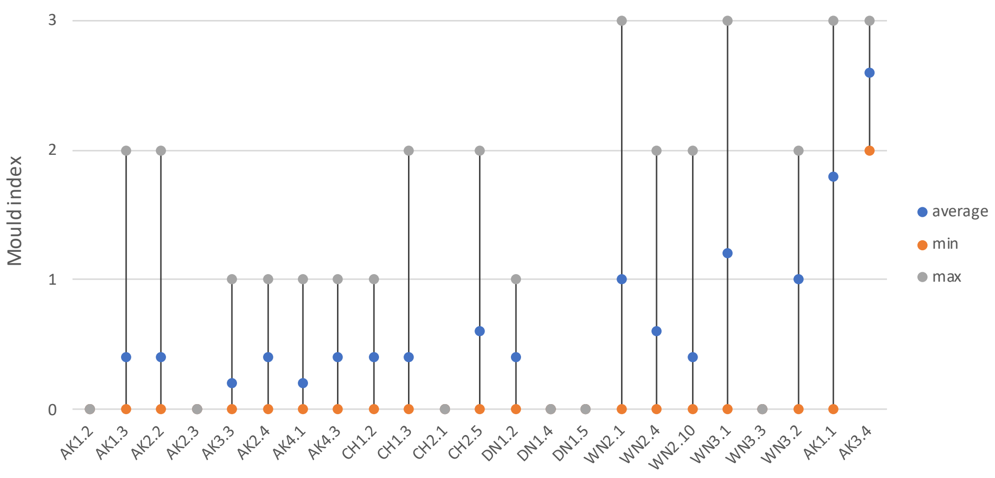

Figure 23. Average, minimum and maximum mould index recorded in the main bedroom of each property in the 2017 study.

[3] Mould levels were not assessed in two homes as the interview was conducted off site.

5. Occupant behaviour

This section of the report draws on findings from the householder questionnaire in the 2016 study and participant interviews in the 2017 study. For these aspects of the studies, the methods were quite different, and the results are therefore not intended to be directly comparable. Instead, they are intended to provide some insight and understanding into household behaviours that may affect and explain some of the findings from the temperature, humidity, fungal spore and metabolite measurements.

5.1 Heating living areas – comfort and heating habits

Results from the 2016 householder questionnaire showed that, for 59% of participants, the temperature in the main living area was considered adequate ('never colder' than the occupant would have liked), but for 35%, it was 'sometimes colder' (and for 5% 'often' and 2% 'always') (Figure 24).

The semi-structured interviews with participants in the 2017 study explored heating habits and comfort in different areas of the home in more depth. Compared to the 2016 study results, participants in the 2017 study showed a slightly higher propensity to report colder than desired temperatures in the main living area. For around half of participants, the living room was at some time colder than they would have liked over winter.

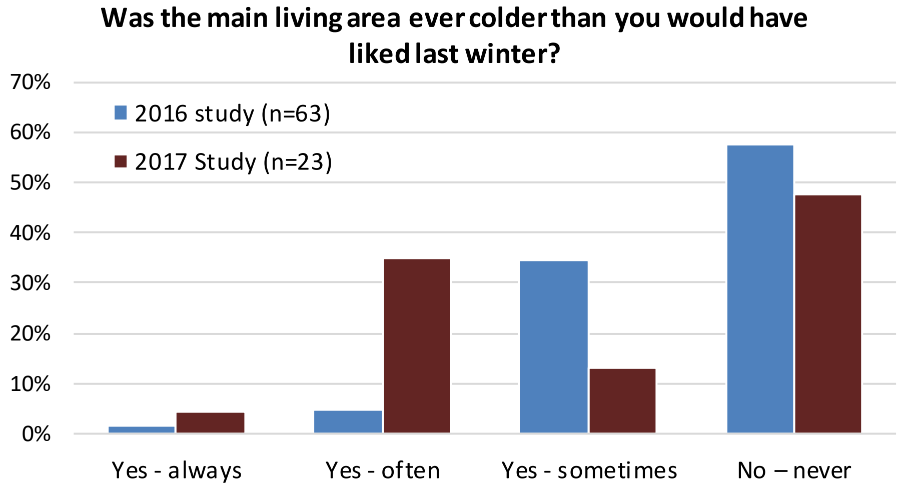

Figure 24. Frequency of main living area being colder than the householder would have liked last winter.

While reporting living area temperatures lower than desired was not uncommon amongst 2017 study households, participants would often comment that this was only when the area was not being heated. There was a high tendency to heat the living area, particularly in the evening (as observed in the temperature data – see Table 4), and for many participants, this level of heating was considered sufficient to make the living area warm.

Whilst heating the living area was common practice amongst study participants, there was an element of frugality in some reported habits. Heating was sometimes considered a "last resort" and would only be used if it felt "really cold", with a reported tendency to maintain comfort through other measures instead (such as wrapping up in blankets).

> "We just button up, put on more clothes, we've always got blankets here in the lounge. We only light [the fire] if we really need to if it was really, really cold. I would say last month was the most we really cracked in with the fire, nearly every day, because it was … horrendous." [AK3.4]

Cost was often quoted as the reason for restricting heating. Whilst some participants expressed relatively low concern with heating costs, instead preferring to maintain comfort in the home, for others, the cost of heating was prohibitively high, resulting in restricted heating use.

> "Usually it would be OK, but those colder nights took ages [to warm up] … we had to just stay in [the living room] just to keep warm. I even thought of putting on the oven to get that extra heat. But I couldn't afford to top up the gas heater. Because that was $40 just to top up that bottle, and you can't do $20, you have to top it right up." [AK1.3]

This highlights not only the impact of cost on heating habits and comfort but the importance of heating type and thermal performance of the property. Where one or more of these were suboptimal, participants often reported difficulty in achieving an adequate level of warmth, even with the heating on. As a result, occupants still felt cold and/or the benefits of heating were short-lived, with temperatures rapidly declining once the heating went off. This experience could create a negative feedback loop. Householders experiencing little benefit from using a heat source, combined with an awareness of the cost of doing so and/or income constraints, may feel less inclined to heat at all.

> "No, [it's] a smaller house, but the energy bills are higher. But there's no insulation in the roof, on the ground, no carpets … once that heater goes off, the temperature drops. It's wasted energy really, eh?" [CH2.3]

> "It was cold. We used the gas heater, but it was not very effective at all. [Didn't use it as much as we wanted] because of the cost." [CH2.3]

Conversely, when the benefits of heating were felt, this could encourage heating behaviour. Participants living in a well-insulated property with an efficient heat source commented on their ability to heat more than in other places they had lived.

> "We would have [the heat pump] on probably every day if the weather's really cold. We have it on low, very low, because it throws out a lot of heat … it's very efficient. And because the place is insulated and everything, it really minimises the amount of heat you have to use." [WN3.3]

> "[We] heated more than what we would have if we had electric heaters because we found the power bill was good with the heat pump – better than with oil heaters." [CH2.1]

These experiences highlight the importance of a well-insulated thermal envelope and an efficient, appropriate heating source to ensure that, when householders do heat, they feel the benefit. This is particularly pertinent for households on a constrained income for whom energy bills represent a significant financial burden.

5.2 Whole-house heating

While heating the living area was common amongst study participants, the challenge of maintaining adequate warmth in all areas of the home was often noted. Rather than heating areas of the home separately, participants frequently reported only heating the living area and often relied on – or expected – this to heat the whole of the house. This behaviour saw some participants heat the living area to higher temperatures than they would like, before allowing the heat to flow through to the rest of the house. Whilst a not uncommon habit amongst study households, there was little evidence that it actually worked and achieved the effect they desired – to adequately heat other areas of the home.

> "The living area was warm with the heater on, but out here [in the kitchen], it was cold." [DN1.5]

> "So, [the living room gas heater] would heat this room, but the bedrooms would be cold." [CH2.3]

> "What we have to do is we've got to lock all the doors, the windows, heat up in here before we can get it hot enough for us so we can't bear it, then open the doors, so the heat goes out … but when that happens, the heat goes straight downstairs, it's lost." [AK3.4]

5.3 How warm is 'warm enough'?

Occupant perceptions of 'warm' did not necessarily equate with what is considered warm from a healthy home perspective. WHO recommends a minimum indoor temperature of at least 18°C in any occupied areas of the home.

> "I turn the heater on about lunch time, until about 6 … then when anyone gets home, it's warm." [DN 1.5]

As this quote and Figure 25 illustrate, this participant heated the living area from lunchtime through to the evening, to ensure it was "warm" for when other occupants arrived home, but the achieved temperature was still below the recommended 18°C. Participants in this household also all slept in the living area in winter due to bedrooms being too cold, which means they (including a young child) were sleeping in conditions with an average temperature at times during the night below 14°C.

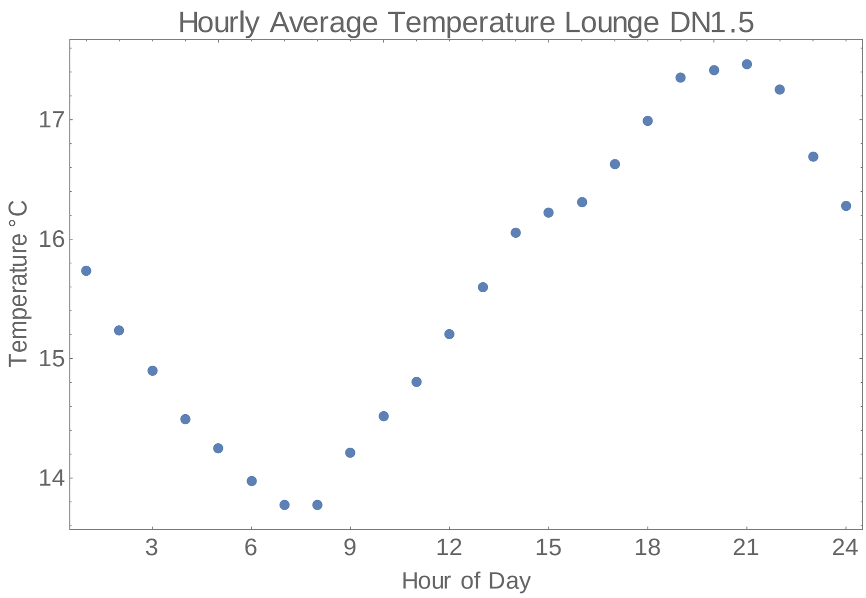

Figure 25. Average hourly temperature in the main living area where occupants slept (DN1.5, 2017).

Similarly, another participant reported heating their living area and bedroom for several hours to make it "nice and cosy and warm", but the average temperature recorded remained below 18°C in the living area and below 16°C in the bedroom (Figure 26). This property was small – just one kitchen/living area and one bedroom. The only heat source was a single portable electric heater, and the property had three external walls. With no mechanical extract ventilation, the occupant relied on opening windows and doors to air out the house, which they did frequently. Contrary to the perception of it being "cosy and warm" and despite heating (at some considerable cost, with "sky-high" power bills), this participant still observed how cold it could be in the home in winter and the extra measures they had to take to keep warm.

> "When it gets really cold, it'll just heat the kitchen, and then I've got to take it into the bedroom, to heat the bedroom, and that takes a while to warm up. So, maybe about 3 hours in here, and then I take it in there, and by the time I get to bed, maybe a couple hours later, it's nice and cosy and warm." [CH1.2]

> "You wear your socks, and you wear your hat, you wear your jersey to bed, and then I have my duvets. I have my mink blankets. It's very cold in the winter here." [CH1.2]

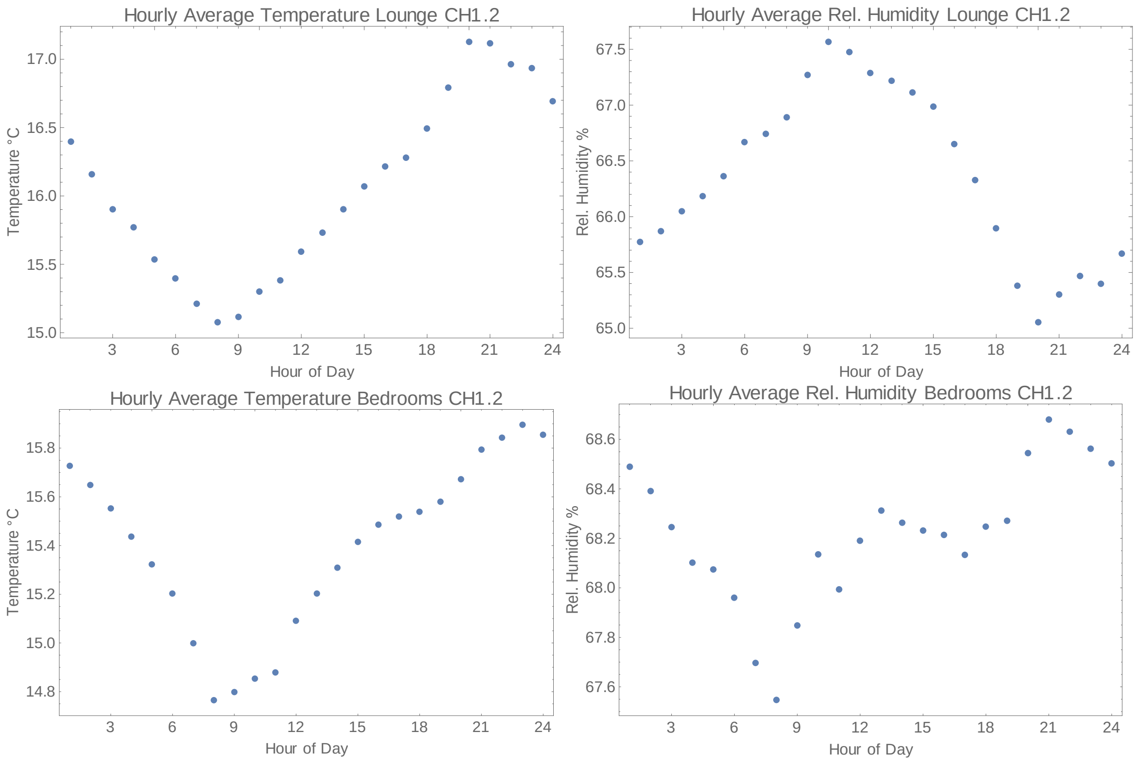

Figure 26. Average hourly temperature and relative humidity in the living area and bedroom (CH1.2, 2017).

5.4 Heating bedrooms

Whilst all participants in the 2017 study heated the living area at least some of the time in winter, there was less tendency to heat bedrooms. Only seven participants reported heating their bedroom every day or most days over winter, while 11 (48%) never usually heated their bedroom in winter. As observed above, instead of direct heating of bedrooms, there was a high reliance on heating the living area as a source of heat for the whole house. Householders would heat the living area then open doors to the rest of the house to allow heat to flow to bedrooms. This reported behaviour was evident in the temperature readings (Table 5 and Figure 3).

This approach had varying levels of success for household occupants. Whilst for some, it provided what they considered adequate warmth in the bedroom, for others, the bedroom was considered cold. The extent of cold did prompt some participants to heat the bedroom directly on occasions, while others reported other measures to help keep warm, such as using extra blankets, electric blankets and hot water bottles. These measures were key to maintaining comfort for study participants. However, while such strategies may ensure the occupant feels warm, they are still at risk of potential adverse effects of breathing in cold, damp air.

> "It's cold as. We actually had a column heater in [the bedroom] quite a bit … [With the heater on,] it's not too bad, it took away that crispiness in there, but you knew when the heater was off." [AK3.4]

> "Nah, I've got an electric blanket, that's my heater! It's nice with my electric blanket on … but it does get really … what do you call it when it gets cold? … real damp, musty. Like on the walls, it starts building that grey, you know, when it gets all the mould and then the windows, it gets that thing over it … the water [condensation?], yeah, that's it." [AK1.1]

Five study households (one-fifth) reported sleeping together in one room to help keep warm and/or avoid the cost of having to heat another room. This behaviour is known as 'functional overcrowding'.

> "Nah [don't heat the bedrooms], in the winter, we sleep in the sitting room … most nights, because the [bed]rooms are too cold." [DN1.5]

> "We didn't hardly use [my young daughter's] room because she could come into my room. On colder nights, we'd just stay in the lounge just to keep warm." [AK1.3]

In addition to functional crowding, at least one household was overcrowded according to the Canadian National Occupancy Standard, the definition used and reported by Statistics New Zealand (Baker, Goodyear & Howden-Chapman, 2003). This 3-bedroom house had 11 occupants at the time of study, including babies and young children. Multiple occupants of varying ages and genders shared a bedroom, and some family members slept in the living room by necessity. Household overcrowding has been linked with increased risk of health problems (Baker, McDonald, Zhang & Howden-Chapman 2013). This overcrowded house reported problems with damp and mould, and high rates of sickness amongst family members.

Another study household reported such extreme problems with the conditions in the son's bedroom and poor health that he was encouraged to sleep in the living room. This property had a hole in the ceiling and leak in the roof. The occupants relied on a wood burner in the living area to heat the house, although they often lacked an adequate wood supply, and frequently used a dehumidifier.

> "My biggest boy throughout the years has always complained that he's got a cold, that he's always snivelling, so I made him sleep out in the lounge. It's that *** ceiling, the condensation and the *** that's coming through the hole. They still tried to sleep in it, but they bear with it as best they can. But I don't want them to bear with it, I'd rather them be in here, keeping warm." [AK3.4]

5.5 Ventilation practices in the bathroom

The 2016 occupant ventilation behaviour questionnaire asked participants about ventilation habits in the bathroom and kitchen. While this report is mainly concerned with the indoor environment in living areas and bedrooms, the bathroom and kitchen can be two major sources of moisture in the home. Without adequate ventilation in these areas and without containment of moisture to these areas, this could become a source of moisture and therefore a potential trigger for damp and mould elsewhere in the house.

The questionnaire results show that householders were more likely to use an extractor fan than to open windows whilst taking a bath or shower (Figure 27). Over half (54%) of households surveyed 'always' used an extractor fan whilst taking a bath/shower, and only 30% 'always' opened the windows. Over one-quarter (27%, shown as N/A in Figure 27) of participants did not have an extractor fan in the bathroom. Excluding these households from the analysis of frequency of use of an extractor shows a very high use rate (74%).

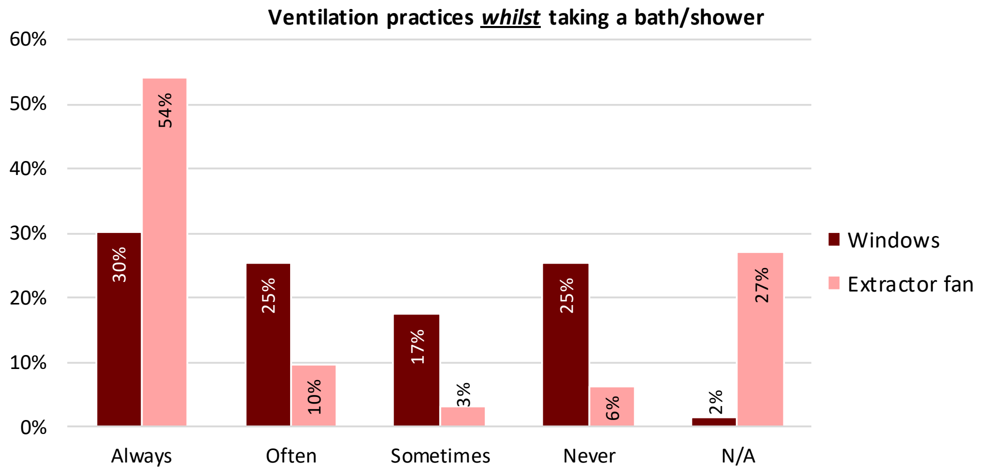

Figure 27. Ventilation practices whilst taking a bath/shower.

While use of extractor fans whilst bathing/showering was more common than opening windows, the reverse was true of ventilation practices after taking a bath/shower (Figure 28).

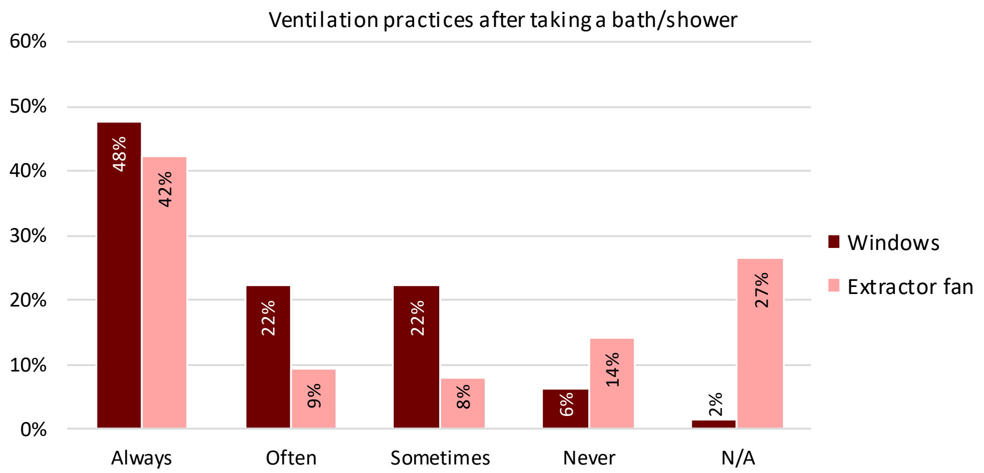

Figure 28. Ventilation practices after taking a bath/shower.

Nearly half (48%) of all respondents said they 'always' opened a window after showering, 18 percentage points higher than the rate of 'always' opening windows whilst showering/bathing. This behavioural pattern could be related to a desire to maintain a comfortable temperature in the bathroom whilst bathing (hence not opening windows until afterwards).

Overall, the 2016 study questionnaire responses show most households ventilated the bathroom by some means (windows or extractor fan) before and after showering. Table 11 shows that:

- 73% always ventilated the bathroom whilst taking a bath/shower
- 70% always ventilated the bathroom after taking a bath/shower
- 61% always ventilated the bathroom both before and after showering.

Table 11. Ventilation of the bathroom during and after taking a bath/shower.

Whilst taking bath/shower	After taking bath/shower			
	Always	Often/sometimes	Never	Total
Always	61%	13%	0%	73%
Often/sometimes	8%	9%	2%	19%
Never	2%	5%	2%	8%
Total	71%	27%	4%	100%

Only one household said they never ventilated the bathroom during or after showering or bathing. This house did not have any mechanical ventilation but did have a window in the bathroom. The household did not report any problems with damp or mould. These findings broadly align with those from the 2017 study householder interviews. More than half of households had an extractor in the main bathroom (14 out of the 23 participants) and over half of these (eight) said the always used it when taking a bath or shower. Those that never used it said the reason for this was that it didn't work or was ineffective (one knew it extracted to the roof space), and others noted that, whilst they did use it, it seemed to do little. This highlights the importance of ensuring mechanical extract ventilation is correctly sized, installed and functioning.

Similar numbers reported always opening windows in the bathroom.[4] No participants said they never open windows in the bathroom. Whilst some reported actively opening and closing windows to manage moisture generated when taking a bath or shower, there was an overall high tendency to leave a window open all the time. This practice seemed to stem from habit ("too lazy to close it") and/or preference for having a constant source of fresh air in the bathroom. For some, this included throughout winter, despite cold outdoor temperatures. Leaving the window open constantly and resulting in a lower indoor temperature can exacerbate problems of condensation, damp and mould. Research has also shown it is more effective to 'purge' and remove damp air by opening the window wide for 10–15 minutes, rather than having a constant trickle ventilation (McDowall, 2017).

> "Our bathroom and toilet windows are always open. We've got draught stoppers we can use, or we just chuck a towel down sometimes. Otherwise, it would just be the odd occasion when we want to close it, even during winter." [AK4.3]

[4] The interview did not differentiate between before, during and after, but this was discussed.

Heating the bathroom would also help, but this was almost non-existent amongst study participants (only one reported ever heating the bathroom). Whilst use of extractor fans (where present) and frequently or even constantly opening windows was common behaviour, these practices had varying levels of success in managing moisture in the bathroom. Ineffective extractor fans and leaving a window open a small amount all the time could also lead householders to perceive they were taking good measures to manage moisture, but their practices were not having the desired or required effect.

> "I don't think [the extractor fan] usually works that much … it's all the steam … so I have the window open, cos it doesn't really thin it that much. And the water's always dropping off the ceiling when you're having a shower." [AK1.1]

5.6 Ventilation practices in the kitchen

The 2016 householder questionnaire also asked respondents about ventilation practices whilst cooking. Results show that ventilating the kitchen whilst cooking either through the use of rangehood/extractor fans or opening windows was less common than ventilation of the bathroom.

One third (33%) of respondents reported not having a mechanical extract in the kitchen, and of those that did have an extractor fan/rangehood, less than half would always use it (Figure 29). Opening windows whilst cooking was even less common, with only 19% of respondents reporting this behaviour all the time, and 43% 'sometimes' did this.

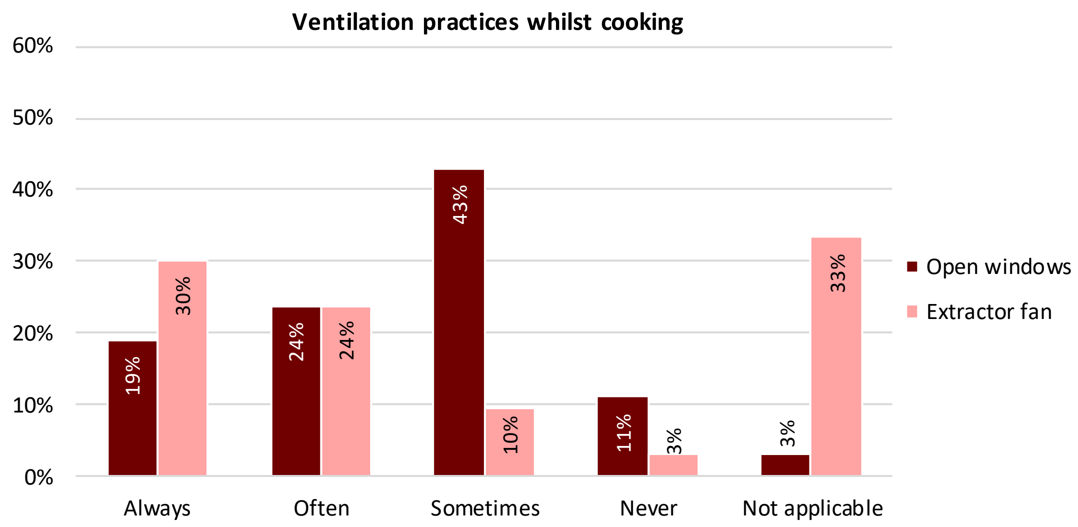

Figure 29. Ventilation practices whilst cooking hot meals.

A higher proportion of 2017 study participants – half of those interviewed (12) – did not have an extractor or rangehood in the kitchen. Of those that did, all reported using it every day or most days when cooking. Just over half (13) reported opening windows in winter every day or most days when cooking. Getting rid of cooking smells was the main motivation for this, followed by removing steam. As with the experience in managing moisture in the bathroom, participants reported a wide range of experiences, from those that had no problem to those that, despite using mechanical extraction and/or opening windows, were still aware of moisture build-up – for example, seeing condensation on windows or walls.

5.6.1 Ventilation habits around the house

The 2017 study interviews explored ventilation habits in more depth and extended this to other areas of the home beyond the bathroom and kitchen. Respondents reported a high tendency to open windows and strong preferences for "fresh air".

> "Mine goes open as soon as I wake up about 6 o'clock in the morning to thin that condensation … so it circulates around. And it's nice, fresh air." [AK1.1]

> "Fresh air. Air circulation. I don't like stale air. Even if I'm not in the room, I'd go in and open it up." [AK3.3]

Some participants reported opening bedroom windows when they woke up to help with problems of condensation on the windows and refresh the air in the room. Others left windows open all the time, even in bedrooms throughout winter when it was cold, due to a preference for fresh air. As noted above, this behaviour can result in a colder indoor air temperature, particularly in unheated areas of the home such as the bedrooms, which can increase the risk of moisture problems. This was evident in the temperature and humidity data in the bedrooms of several houses where the indoor air temperature was low and relative humidity notably high for a non-high moisture environment (Figure 30).

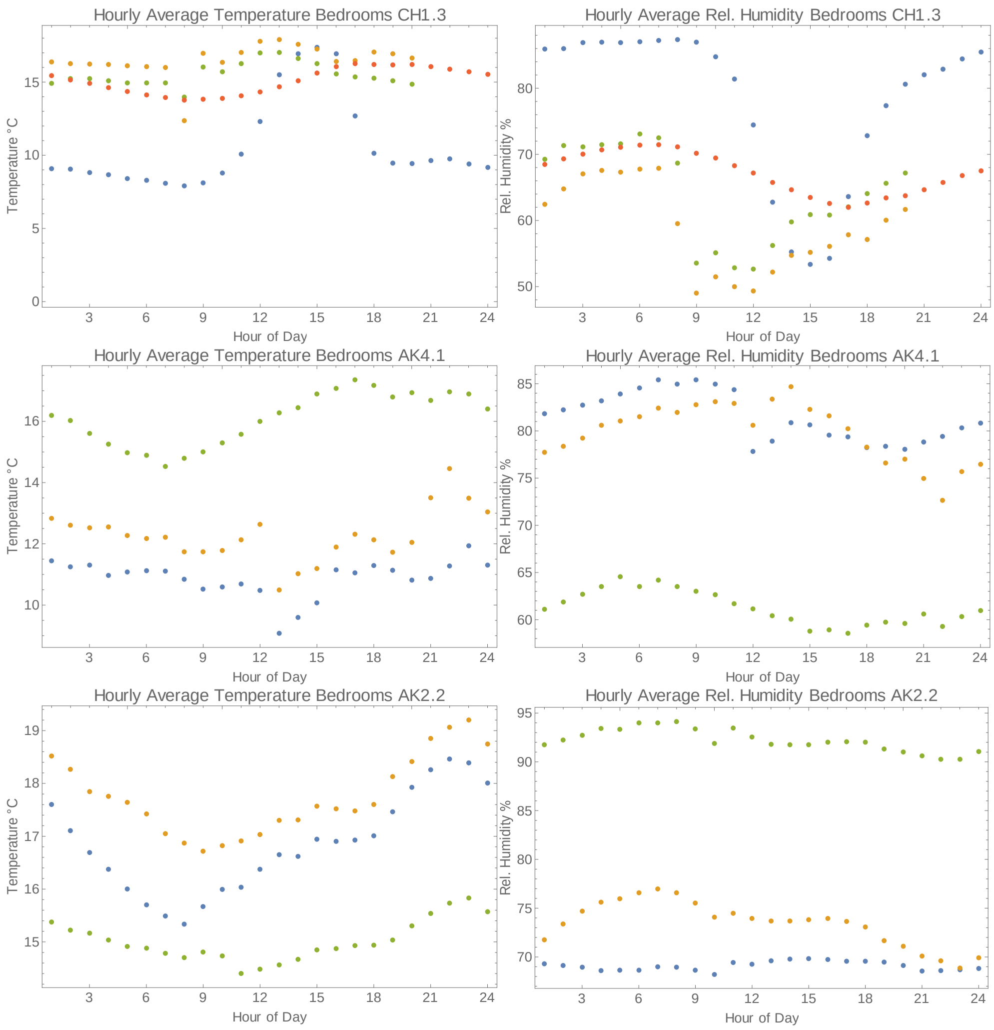

Figure 30. Average hourly temperature and relative humidity over all days in all the bedrooms of three study households (2017).

The interview accounts from occupants of the properties shown in Figure 30 suggest there are a number of different factors at play that are impacting on indoor environmental quality. The first two highlight behavioural factors:

- Using an unvented clothes dryer, uncontrolled ventilation (draughts from poorly fitted windows and curtains and a hole in the backdoor) and lack of adequate heating in bedrooms [CH1.3].
- Broken/ineffective mechanical ventilation in the bathroom ("when you turn it off, it drips. I think it must be blocked or something"), inadequate heating of bedrooms, overventilating creating a cold environment and drying clothes indoors [AK4.1].

> "I noticed there was mould in that room. It must have been from the bathroom. It was in the roof, in the corner by the window, and then just above the bed. We cleaned the roof off, and then, when I pulled everything away from the walls, it was down the walls and in the drawers and even behind the door … I think it was coming from the bathroom because we were only using the extractor, not opening the windows then." [AK4.1]

The occupants of house AK2.2 had taken several measures to help improve their home and reported positive behaviours, including:

- insulating the subfloor prior to winter
- installing a new heat pump
- fitting secondary glazing
- heating the living area most days for 4–5 hours throughout the day
- heating one bedroom (occupied by an adult and baby) with a portable heater, sometimes through the night
- heating other bedrooms with panel heaters sometimes in the evenings
- always using the mechanical extract ventilation in the kitchen and bathroom and often opening windows.

However, they still experienced significant problems with condensation on windows and severe damp in one bedroom despite heating and using a dehumidifier. Given these largely positive reported behaviours and evidence of heating observed in the temperature data, the location of the house could be a key factor here. It is located in a valley, backing on to bush with little direct sunlight.

> "Probably if the condensation got really bad, then I'd open the windows. Otherwise, I'd just wipe the windows and leave it closed, because it's too cold." [AK2.2]

> "Yeah, especially my sister's room down the end, that's real damp. Her walls had moisture on them. She said her bed even felt damp." [AK2.2]

5.7 Damp and mould

In the 2016 household questionnaire, participants were asked about the extent of any problems with damp or mould in the home on a three-point qualitative scale. While no householders considered their home to have a 'major problem' with damp or mould, nearly two-fifths (39%) considered damp/mould to be a 'minor problem' (Figure 31).

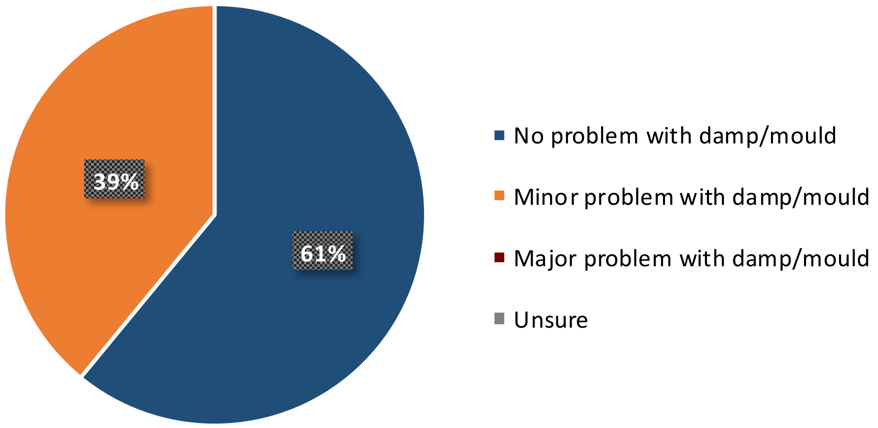

Figure 31. Householders' assessment of mould and damp in their home.

In addition, 44% noted condensation as a problem in their home (Figure 32). Other problems commonly noted by 2016 study participants included feeling cold, experiencing draughts and problems with heating (including difficulty controlling heating, faulty heating and heating insufficient).

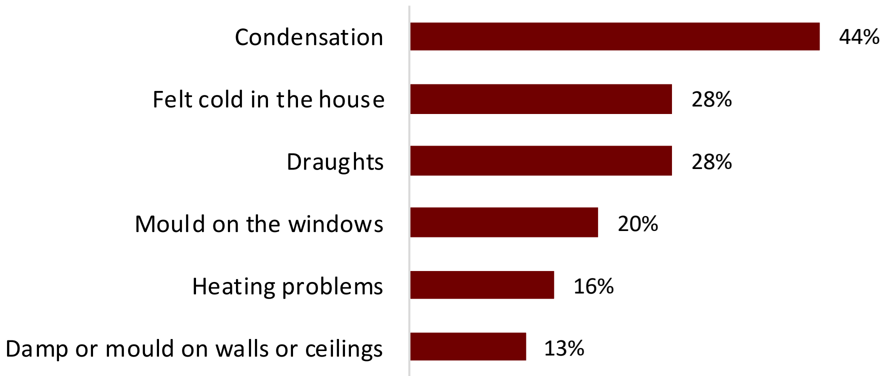

Figure 32. Problems experienced by householders in their home.

In the 2017 study, whilst householders frequently reported good habits in ventilating the home and using extractor fans (where present), there was also evidence and an awareness of problems with damp and mould.

> "Major problem [with damp and mould]. Especially major down in my boy's room. And my room. Mainly the roof, the wall. If you haven't done regular cleaning around the drawers and stuff, you can see the build-up from the mould, dust and all that. Constant ongoing problem, doesn't go away. If you clean it, it just comes back. So now where my room, the main room is, the little patches that are happening you can see now, there used to only be one patch. Now there's visible patches all around. And I know in time it is just going to be like the boy's room." [AK3.4]

Participants demonstrated varying degrees of concern about the problem and actions to address it. This included having to move furniture, being unable to sleep in the bedroom due to the severity of the problem and an awareness that if affected the health of household occupants.

It is worth noting that studies have shown that householder perceptions of problems in the home do not necessarily align with or provide a true, accurate reflection of reality.

For example, findings from the BRANZ House Condition Survey have shown householders typically consider their property to be in better condition than an independent assessor (White, Jones, Cowan & Chun, 2017). There was some evidence of this in the 2017 study when comparing occupant reports of problems in the home with the measured conditions, spore sampling and researcher assessment of visible mould.

5.8 Occupant health

The householder interviews in the 2017 study asked about occupant health over the previous 12 months. In addition to this – and unprompted – several participants referred to the impact of their indoor environment on the health of household occupants. The impacts on occupant health of living in cold, damp, mouldy homes has been well researched and evidenced, both in New Zealand and internationally (Fisk, Lei-Gomez & Mendell, 2007; Afshari et al., 2009; Mendell at al., 2011; Weinmayr et al., 2013; Shorter et al., 2018, Ingham et al., 2019).

> "I think [damp and mould] is a major problem because it affects our health. For the breathing. My mokos get all coughy, chesty at night. And I get sick, all chesty and coughy." [AK1.1]

Poor health did prompt some participants to heat bedrooms and/or ensure younger family members were warm, sometimes at their own expense. "

> Mine is the worst one because it's got mould on the walls. Mine is the coldest, everyone else has got a bit warmer rooms. I want to give them to my kids." [AK1.1]

However, despite an awareness of the impact on and consequences for household occupants' health and despite efforts to keep warm, maintaining adequate warmth and a healthy indoor environment remained unachievable for some.

> "It's still cold. That's why I have my heat pump on and tell them to heat their room up. Close the curtains, try to keep it a bit warmer … But we all end up getting sick. Coughing because it's cold. Lots of runny noses, going to the doctors, lots of appointments in the winter." [AK1.1]

As noted above, study participants reported a tendency to heat only the living area, which resulted in a large temperature difference between that room and other areas of the home. This was observed in the temperature data for some households and reported by study participants.

> "It was only this area that was warm all the time, but when you walked down the hallway, whoah!" [AK3.4]

Transitioning between warm and cold temperatures can exacerbate health problems, as observed by the lived experience of one participant.

> "I mean, even when I was in [the living room], it was getting too hot. You know, when everyone starts coughing and stuff … and then when you open the door to let the heat out, they start coughing again, because the cold air goes in." [DN1.5]

6. Discussion

As described above, the 2016 study used a subset of the 2015 BRANZ House Condition Survey sample. While the House Condition Survey aims to represent a cross-section of the New Zealand housing stock, the subset of the recruited homes used for the 2016 study is not necessarily representative. This is also the case for the 2017 study, which was conducted in the Wellington region only.

The temperature variability in the bedrooms is rather large, and the lowest temperatures are reached, as expected, in the early morning hours as most bedrooms are not heated during the night. The temperature histograms show that, apart from solar gains during the day, heating of bedrooms occurs in the evening. Results from the 2017 householder interviews and House Condition Survey (White & Jones, 2017) suggest heating of bedrooms is more likely from heat transport from other parts of the building rather than direct heat input.

The 2017 study showed a more prominent temperature shift in bedrooms towards warmer temperatures in the evening compared to the 2016 data. More than 90% of bedrooms experienced a temperature of less than 18°C for up to 57% of the time in the 2016 study, compared to 52% of the time in the 2017 study.

The median relative humidity recorded in bedrooms over night-time was 65%. This means that, for 50% of the time, bedrooms had a moisture load high enough to warrant ventilation or heating to reduce the elevated moisture level.

If temperatures had been increased to above the 18°C thresholds, the relative humidity levels would have reduced in many of these bedrooms. This suggests that those bedrooms are experiencing high relative humidity due to the low temperature. Conversely, bedrooms that are already at a temperature above that threshold would not experience a decrease in relative humidity but instead need to increase their ventilation to reduce the moisture load in the room.

The 2016 householder questionnaire and 2017 householder interviews showed relatively high reported tendency to ventilate the home by using mechanical extract ventilation where present and/or opening windows. However, reported ventilation habits were not always aligned with best practice – for example, participants were relying on constant ventilation (the window open a small amount all the time) rather than actively and effectively airing out the house. These reported window-opening habits will be further explored by looking at data from motion sensors that were affixed to the windows as part of parallel study.

In the 2017 study, householders also reported a tendency to heat the living area, which appears to align with the results seen in the temperature data. However, there was very little evidence reported or in the measurements of directly heating bedrooms. This 'spot' heating behaviour may ensure the living area is at a healthy temperature, but bedrooms were often much colder than recommended levels, based on measurements and occupant accounts.

The fungal exposure in many homes and in particular in bedrooms was found to be very high. This could be caused by high moisture loads in the rooms, in many cases due to a lack of heating and/or ventilation. Given that occupants spend many hours in the bedroom, the levels found are of concern and could have some health implications. This study used four techniques to determine the mould exposure – direct observation of visible fungi, airborne sampling onto a microscope slide, viable spore count onto an agar plate and fungi/bacteria metabolite analysis from the floor dust samples. The latter technique was employed to pilot/test this potentially very sensitive method and see if it can quantify the exposure to mycotoxins. The results were promising, and this technique will be used in a much larger study involving 200 homes (commencing in 2021). The mycotoxin method was able to identify the presence of toxins indicating a certain mould is/was present, while the spore sample found these moulds only in one sample. However, quantitative data of these toxins is not yet available as pure toxins for calibration purposes were not available.

7. Conclusion

New Zealand homes are still lacking heating and ventilation to provide a healthy indoor environment. A contributing reason is the relatively poor state of insulation in older homes and hence the high cost of heating these to or above the recommended 18°C. The higher temperature would also help reduce moisture-related problems observed in homes. The excess moisture causes many homes to have mould growth not only in bathrooms but also in bedrooms where occupants spend a substantial amount of time.

The homes of the 2017 study showed higher temperature profiles and reported tendency to heat and open windows to refresh the indoor air. These 'good' habits may be attributed to the education these occupants have received in the past. However, there was still evidence of damp and mould in many houses – in some cases, to severe/extensive levels in bedrooms – and occupants still reported bedrooms that were too cold to sleep in. Further analysis is needed to explore in more depth whether householder-reported behaviours align with the results from the mould assessment and temperature and humidity data.

References

Afshari, A. et al. (2009). *WHO guidelines for indoor air quality: Dampness and mould*. Copenhagen, Denmark: World Health Organization.

Baker, M., Goodyear, R. & Howden-Chapman, P. (2003). Household crowding and health. In Statistics New Zealand, *What is the extent of crowding in New Zealand? An analysis of crowding in New Zealand households 1986–2001* (pp. 58–87). Wellington, New Zealand: Statistics New Zealand. Available at: http://archive.stats.govt.nz/browse_for_stats/people_and_communities/housing/crowding-analytical-report.aspx#report

Baker, M., McDonald, A., Zhang, J. & Howden-Chapman, P. (2013). *Infectious diseases attributable to household crowding in New Zealand: A systematic review and burden of disease estimate*. Wellington, New Zealand: He Kainga Oranga/Housing and Health Research Programme, University of Otago.

Fisk, W. J., Lei-Gomez, Q. & Mendell, M. J. (2007). Meta-analyses of the associations of respiratory health effects with dampness and mold in homes. *Indoor Air*, *17*(4), 284–296.

Hess-Kosa, K. (2010). *Indoor air quality: Sampling methodologies*. Boca Raton, FL: CRC Press.

Ingham, T., Keall, M., Jones, B., Aldridge, D., Dowell, A., Davies, C., Crane, J., Draper, J., Bailey, L., Viggers, H., Stanley, T., Leadbitter, P., Latimer, M. & Howden-Chapman, P. (2019). Damp mouldy housing and early childhood hospital admissions for acute respiratory infection: A case control study. *Thorax*, *74*(9), 849–857.

McDowall, P. (2017). Open windows for dry home. *Build*, *158*, 84–85.

Mendell, M. J., Mirer, A. G., Cheung, K., Tong, M. & Douwes, J. (2011). Respiratory and allergic health effects of dampness, mold, and dampness-related agents: A review of the epidemiologic evidence. *Environmental Health Perspectives*, *119*(6), 748–756.

Pollard, A. R. (2001). *Investigating the characterisation of temperatures within New Zealand buildings* (Master's thesis). Massey University, Palmerston North, New Zealand.

Shorter, C., Crane, J., Pierse, N., Barnes, P., Kang, J., Wickens, K., Douwes, J., Stanley, T., Taubel, M., Hyvarinen, A. & Howden-Chapman, P. (2018). Indoor visible mold and mold odor are associated with new-onset childhood wheeze in a dose-dependent manner. *Indoor Air, 28*(1), 6–15. https://doi.org/10.1111/ina.12413

Shorter, C. (2013). *Fungi in New Zealand homes: Measurement, aerosolisation and association with children's health* (PhD thesis). University of Otago, Dunedin, New Zealand.

Weinmayr, G., Gehring, U., Genuneit, J., Buchele, G., Kleiner, A., Siebers, R., Wickens, K., Crane, J., Brunekreef, B. & Strachan, D. (2013). Dampness and moulds in relation to respiratory and allergic symptoms in children: Results from Phase Two of the International Study of Asthma and Allergies in Childhood (ISAAC Phase Two). *Clinical & Experimental Allergy*, *43*(7), 762–774.

White, V. & Jones, M. (2017). *Warm, dry, healthy? Insights from the 2015 House Condition Survey on insulation, ventilation, heating and mould in New Zealand houses.* BRANZ Study Report SR372. Judgeford, New Zealand: BRANZ Ltd.

White, V., Jones, M., Cowan, V. & Chun, S. (2017). *BRANZ 2015 House Condition Survey: Comparison of house condition by tenure*. BRANZ Study Report SR372. Judgeford, New Zealand: BRANZ Ltd.

Appendix A: Results from fungal spore air samples

Table 12. Results from the fungal spore air samples.

Location	Pollen Grains	*Cladosporium*	*Penicillium/ Aspergillus* type	*Alternaria/ Ulocladium/ Pithomyces*	*Drechslera/ Bipolaris*	*Curvularia*	*Stachybotrys*	*Chaetomium*	*Epicoccum*	*Phoma* type	*Fusarium*	Basidio-mycete	Spore Clusters	Hyphal Fragments	Other Spore Types	**SPORE TOTAL /m^3**
AK4.1a Bedroom	0	573	2387	0	0	0	0	0	0	0	0	193	133	33	11067	**14253**
AK4.1b Bathroom	7	127	753	0	0	0	0	0	0	0	7	60	33	13	5400	**6360**
AK4.1c Living room	0	13	100	0	0	0	0	0	0	0	0	7	7	13	260	**393**
DN1.2a Bedroom	27	333	180	0	0	0	0	0	0	0	7	153	60	127	8333	**9133**
DN1.2b Bathroom	0	87	53	7	0	0	0	7	0	0	0	80	0	47	3200	**3481**
DN1.2c Living room	13	393	127	27	0	0	0	0	0	0	0	140	53	120	7567	**8374**
CH1.3a Living room	33	400	560	0	0	0	0	13	0	0	7	333	233	20	15700	**17033**
CH1.3b Bathroom	13	353	1213	7	0	0	0	0	0	0	7	220	160	20	11267	**13087**
CH1.3c Bedroom	7	167	107	7	0	0	0	0	0	0	13	260	13	20	9000	**9574**
DN1.5a Bedroom 1	7	367	22833	27	0	0	0	0	0	0	0	107	627	133	5767	**29234**
DN1.5b Bathroom	0	40	3600	13	0	0	0	0	0	0	7	33	200	47	3500	**7240**
DN1.5c Living room	7	5367	17667	0	0	0	0	0	0	0	0	47	967	87	11967	**35135**
AK1.1a Bedroom 1	0	22400	15400	0	0	0	0	0	0	0	7	300	1267	33	19367	**57507**
AK1.1b Bathroom	0	453	2120	0	0	0	0	20	0	0	0	333	133	60	9533	**12519**
AK1.1c Lounge	0	373	2967	0	0	0	0	0	0	0	0	460	133	13	16467	**20280**
CH2.1a Bedroom 1	67	73	20	0	0	0	0	0	0	0	0	87	0	27	3433	**3640**
CH2.3a Bedroom 1	0	7000	6933	0	7	0	0	0	0	0	0	167	467	633	5967	**20707**
WN2.1a Bedroom 3	0	13767	27600	13	0	0	0	0	0	0	0	67	1067	800	8533	**50780**
AK3.4a	0	1633	44100	0	0	0	0	0	0	0	0	73	3500	73	30800	**76679**
AK2.2a Bedroom 2	0	40	30633	0	0	0	0	0	0	0	7	7	633	13	4100	**34800**
AK1.2a Bedroom 2	0	133	933	0	0	0	0	0	0	0	0	93	13	120	3200	**4479**
WN3.3 Bedroom 2	13	33	247	13	0	0	0	0	0	0	0	33	27	13	1100	**1439**
AK1.5a Bedroom 1	0	247	93	0	0	0	0	0	0	0	0	107	53	27	4033	**4507**
AK4.3a Bedroom 1	13	700	660	0	0	0	7	0	7	0	7	100	53	47	3667	**5195**
WN3.2a Bedroom 1	0	107	780	0	0	0	0	0	0	0	0	53	20	33	2900	**3873**
WN2.4a Bedroom 3	0	507	840	0	0	0	0	0	0	0	7	53	87	53	4700	**6160**
WN3.1a Bedroom 3	0	22700	87267	0	0	0	0	0	0	0	0	67	7467	0	1933	**111967**
AK1.3a	160	3767	4233	0	0	0	0	0	0	0	0	13	633	127	10800	**18940**
WN2.10a	7	347	727	0	0	0	0	0	0	0	0	33	73	60	2100	**3267**
AK2.3a	147	120	253	0	0	0	0	0	0	0	7	267	40	13	6500	**7160**

Numbers in red are considered unusual or unacceptable.