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Date: June 2001			

THE RESOURCE CENTRE FOR BUILDING EXCELLENCE

CONFERENCE PAPER

No. 86 (2001)

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Malcolm Cunningham, Paul Roberts and Mark Hearfield

Presented at the CIB World Building Congress,
Wellington, New Zealand, 8-11 April 2001

Funding for the work reported here was provided by the Foundation for Research Science and the Building Research Levy.

SUPPORTED BY THE BUILDING RESEARCH LEVY

ISSN: 0111-7505

CHANGES IN INDOOR CLIMATE AND MICROCLIMATE OF A NEW ZEALAND BUNGALOW AFTER A TWO STAGE INSULATION RETROFIT

Malcolm CUNNINGHAM[1], Paul ROBERTS[1] & Mark HEARFIELD[1]

ABSTRACT

There has been speculation that passive means of humidity control effected by changes in house design might be sufficient to control dust-mites.

To test this possibility a New Zealand three bedroom timber frame house has been retrofitted in two stages, with ceiling and floor insulation in June 1998, and wall insulation in June 1999. It has been monitored continuously from June 1997 to June 2000 for indoor temperature and relative humidity, heating energy use, building envelope heat flows, and temperatures and humidities in the dust-mite microhabitats of the base of carpets and in bedding.

Heating energy changes in the study house after each of the 2-stage retrofits was much as was expected. Humidity changed from 65% to 60% after the first retrofit, and then from 60% to 59% after the second retrofit. Base of carpet humidities did not change even though there were increases in base of carpet temperature differences above outdoor temperatures from a yearly average of 0.5 ^{o}C to 2.1 ^{o}C after the first retrofit, and from a yearly average of 2.1 ^{o}C to 2.9 ^{o}C after the second retrofit. The yearly average relative humidity in bedding, below the bottom sheet, fell from 54% to 53% after the first retrofit, and from 53% to 50% after the second retrofit

None of these changes are large enough to affect dust-mite viability, with the results suggesting that passive techniques might not be adequate to control dust-mites in many New Zealand houses.

Key words: insulation, retrofit, indoor climate, indoor microclimate, relative humidity, carpets

BACKGROUND

Biocontaminants such as dust-mites and mould live in microenvironments such as bedding, furniture and bases of carpets in the case of dust-mites, and in cold spots on building linings in the case of mould. Since these biocontaminants require high humidities to survive it has been suggested that by altering building design details it might be possible to lower microenvironment humidities and in this way control biocontaminant proliferation.

The effect of retrofitting insulation, providing lower heating energy bills and a warmer indoor climate, is well known. What has not been studied closely is how indoor humidity and indoor microclimates might change when a house has been retrofitted with insulation, and in particular whether it is possible to effect changes large enough to control biocontaminants. It is the purpose of this work to investigate this possibility.

[1] Building Research Association of New Zealand (BRANZ)
Private Bag 50908
Porirua City
New Zealand

EXPERIMENTAL DETAILS

The House. Experimentation was carried out on a house in Plimmerton, New Zealand, built in 1929, with two bedrooms, of timber framed rustic weatherboard construction with a hip roof. The floor was suspended with piles above a crawl space. In 1996 a timber framed skillion roof extension was added to the east side of the original house, consisting of a living room/kitchen and a third bedroom. The house, including the extension, was deliberately left totally uninsulated. Two adults and two teenagers occupied the house.

All heating used was electrical.

The instrumentation and experimental regime. Beginning in June 1997 (beginning of New Zealand's winter) the house was monitored in its unmodified form for temperature, humidity, envelope heat flows, and electrical energy use. In June 1998 the ceiling and floor were fitted with insulation and monitoring continued. In June 1999 the walls were fitted with insulation and monitoring continued until June 2000.

Temperature and humidities were measured quarter hourly in the air of each room, in the base of carpets and in bedding. Measuring humidities in these microenvironments required special very small humidity sensors [1]. Envelope heat flows were measured by use of heat flux transducers, approximate a metre square. These were placed on the ceiling, under the floor, and inside the walls. Energy consumption transducers were used to measure heating, hot water and other energy use.

The retrofits. For the first retrofit the skillion roof of the new extension was fitted with R2.6 110 mm glassfibre batts, and the ceiling of the original house was fitted with R3.6 155 mm fibreglass-batts. The floor was fitted with 50 mm of foil-faced glassfibre blanket under an extra 50 mm batts for a nominal extra floor R-value of 2.6 m^2 $^{o}C/W$.

For the second retrofit the external cladding was taken off the walls, the cavity fitted with R2.6 110 mm batts, and new cladding, in the same style as the old, installed.

RESULTS AND DISCUSSION

How People Heat Houses in New Zealand. New Zealand's climate is mild, see for instance data in Table 3 and Table 4, with the result that New Zealanders heat their houses intermittently, tolerate indoor temperatures that would be regarded cool or cold indoors, and usually heat only the living areas leaving bedrooms quite cold in winter. Central heating or air conditioning is very rare. These remarks need bearing in mind in examining results below.

Energy Use. Table 1 show the annual (June to May) energy use for heating, hot water and other, while Table 2 shows the energy use over the winters of 1997, 1998 and 1999.

The winter heating energy saved after the first retrofit was 399 kWh. After the second retrofit heating energy saved over the pre-retrofitted condition was 313 kWh. After the first retrofit the occupants chose to save 472 kWh on their annual heating bill, representing a saving of 16% in their heating energy use. 86 kWh more heating energy was used after the second retrofit.

It is worth stressing here that, alone, the amount of energy saved does not give a good idea of the effectiveness of retrofitting insulation because it is necessary also to ascertain what new temperature levels the occupants use. This is detailed below.

	June 1997 to May 1998	June 1998 to May 1999	June 1999 to May 2000
Heating	3017 kWh	2545 kWh	2631 kWh
Hot water	3913 kWh	3793 kWh	3940 kWh
Other	1946 kWh	2063 kWh	1896 kWh
TOTAL	8876 kWh	8401 kWh	8467 kWh

Table 1 Annual (June to May) Energy Use

	Winter 1997 (June/July/August)	Winter 1998 (June/July/August)	Winter 1999 (June/July/August)
Heating	941 kWh	542 kWh	628 kWh
Hot water	525 kWh	481 kWh	311 kWh
Other	319 kWh	311 kWh	306 kWh
TOTAL	1785 kWh	1336 kWh	1472 kWh

Table 2: Winter (June/July/August) Energy Use

Energy/Temperature Trade-off. Table 3 shows the yearly average and the winter (June, July and August) average indoor air temperature, averaged over all rooms, and average indoor air temperatures in excess of average outdoor temperatures. Figure 1 shows the daily average indoor temperature and Figure 2 shows the daily average indoor temperature in excess of outdoor temperature.

Significant gains in indoor temperature excesses can be seen after each retrofit.

	Temperature ^oC	Outdoor Temperature ^oC	Temperature excess over outdoor temperature ^oC
97/98	16.1	15.4	0.7
98/99	17.8	16.2	1.6
99/00	17.8	15.1	2.7
Winter 1999 (June/July/August)	12.2	10.3	1.9
Winter 1998 (June/July/August)	13.9	11.5	2.4
Winter 1999 (June/July/August)	15.3	12.0	3.3

Table 3: Average Indoor Temperatures, and Average Temperature Excesses over Outdoor Temperature.

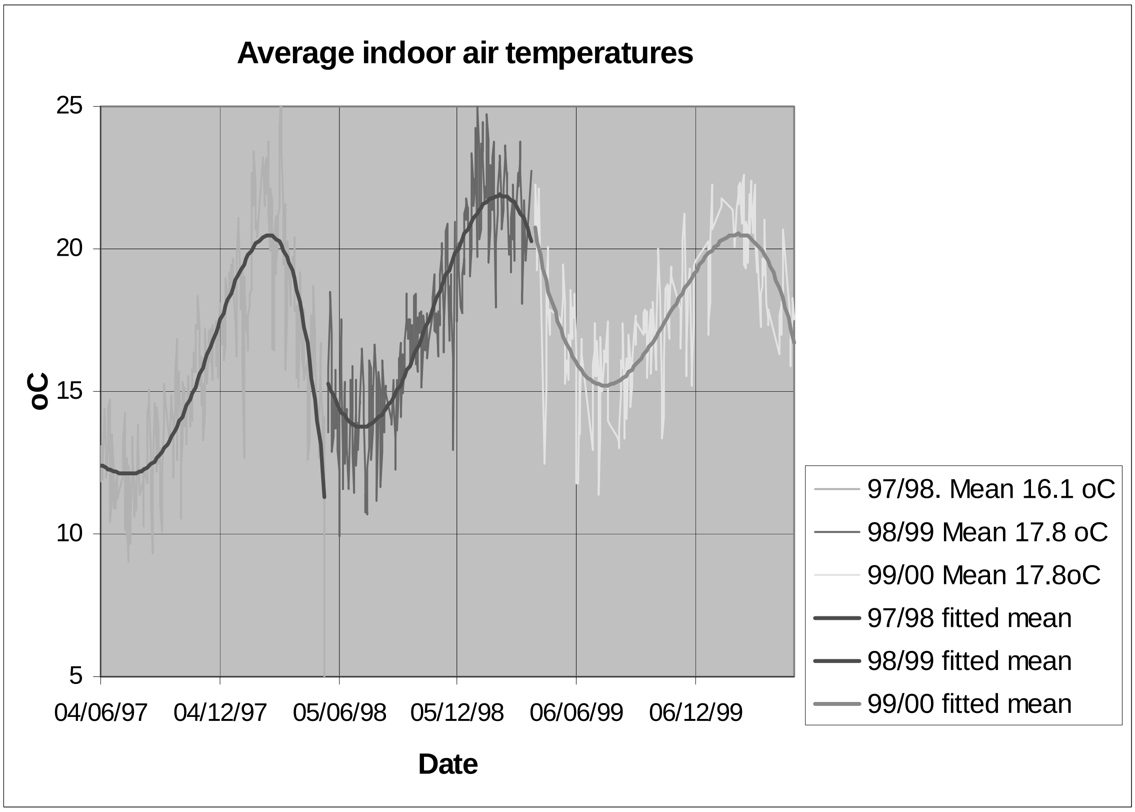

Figure 1: Daily Average House Temperatures

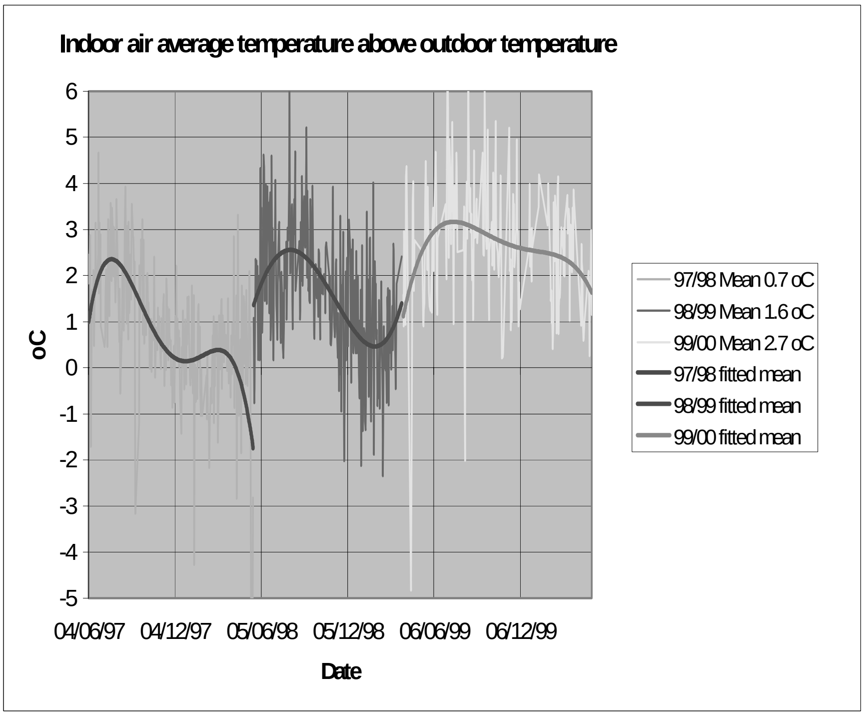

Figure 2: Daily Average House Temperature in Excess of Outdoor Temperature

Operating Point. At each stage, before retrofitting, and after the first and second retrofit, the house can be characterised by the temperature excess it produces for a given heating power. The locus of possible points will be approximately linear (reflecting the approximate fact that heat flux is proportional to temperature difference).

These graphs are shown in Figure 3 together with the actual operating point chosen by the house occupants.

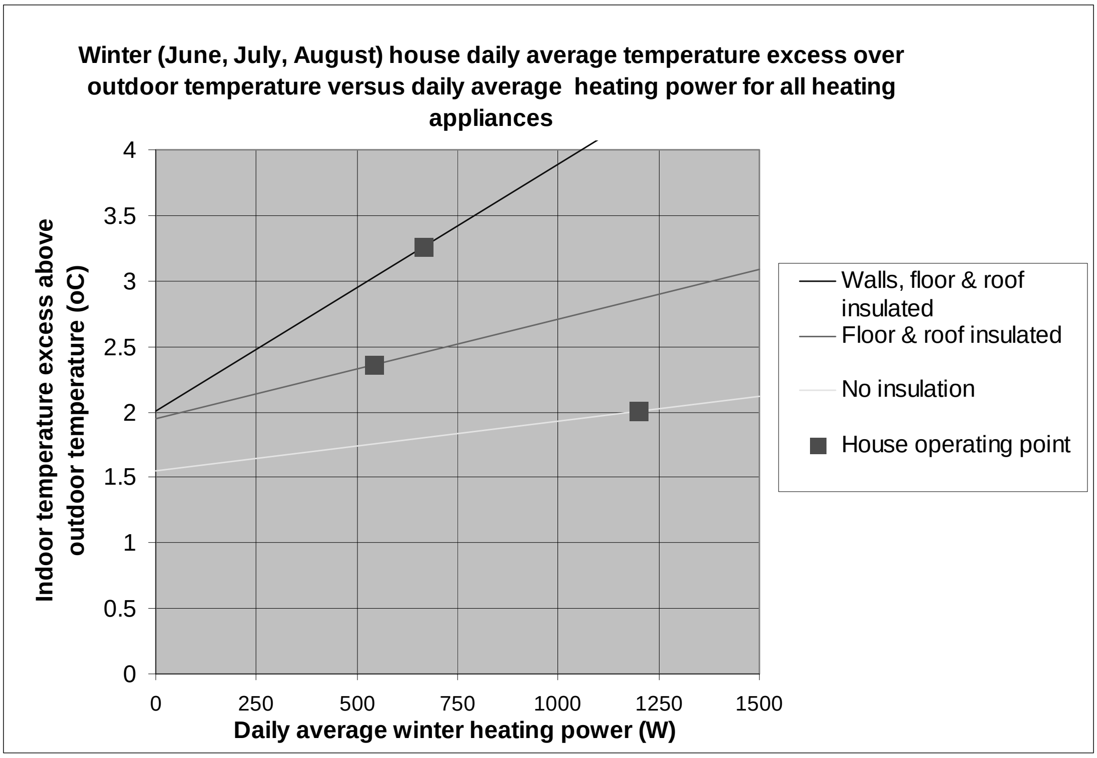

Figure 3: Operating Points for the House, Averaged over all Rooms, in Winter

As an example, after the first retrofit, the occupants could have set the winter house operating condition to any point on the middle line in Figure 3; they chose to set the average over all rooms winter indoor temperature at 2.4 ^{o}C above outdoors for a daily average power use of 543 Watts. They could have chosen to leave the average heating power constant at the pre-retrofit daily average of 1199 Watts, which would have resulted in an indoor temperature 2.9 ^{o}C above outdoors. Equally, for no heating whatsoever, they could have taken an indoor temperature excess of nearly 2.0 ^{o}C.

Heat Fluxes. Figure 4 shows the daily average total envelope heat losses through the roof, floor, and walls of the house. Heat flow through the windows is not included.

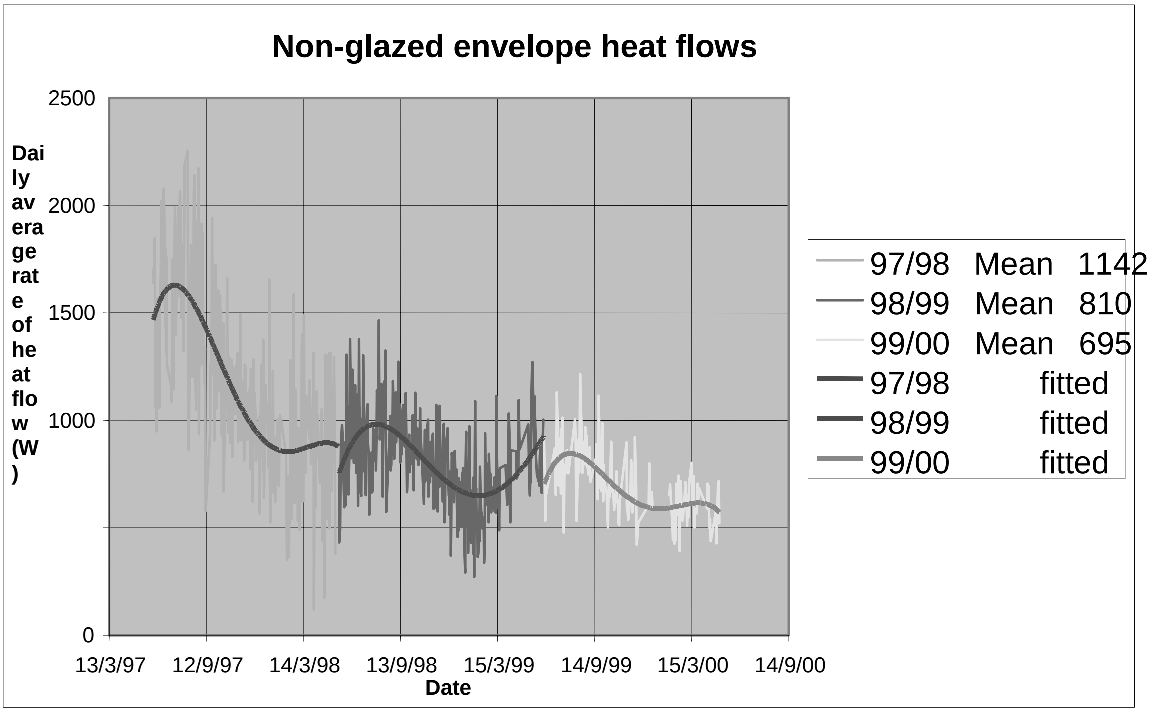

Figure 4: Daily Average Envelope Heat Flows (except Glazing)

Average yearly heat flows fell from 1142 W before retrofitting, to 810 W after the first retrofit and 695 W after the second retrofit.

Relative Humidities. Table 4 and Figure 5 show the changes in average over all rooms indoor humidity after each retrofit. After the second retrofit, indoor humidities are 6% relative humidity lower averaged over a year, and 8% relative humidity lower averaged over winter. These decreases are real in the sense that external relative humidities can be seen to have been relatively constant

Period	Indoor Relative Humidity	Outdoor Relative Humidity
97/98	65%	76%
98/99	60%	75%
99/00	59%	78%
Winter (Jun/Jul/Aug) 1997	68%	80%
Winter (July/Jul/Aug) 1998	64%	81%
Winter (July/Jul/Aug) 1999	60%	79%

Table 4: Average House Air Relative Humidities After Retrofitting

This represents a noticeable drop in indoor relative humidity, but it is nowhere near enough to aid dust-mite control. For this to happen the accepted figure for mite control is 7g/kg absolute humidity [2,3,4], which at 21^{o}C corresponds to 45% relative humidity maintained all year round.

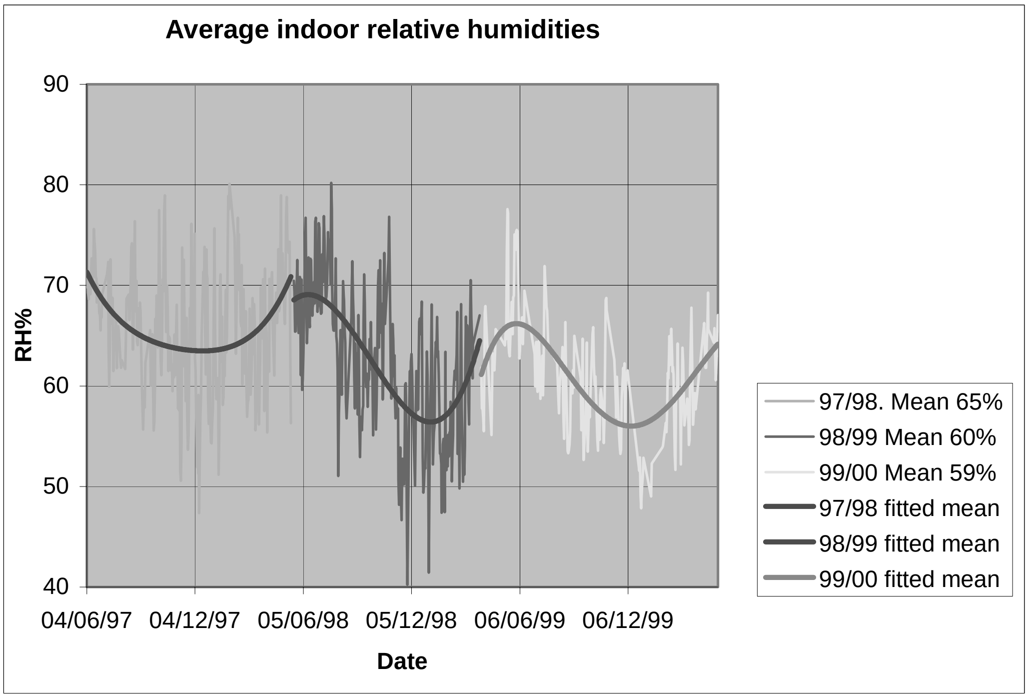

Figure 5: Daily Average House Air Relative Humidities

Microclimates – base of carpet. Figure 6, Figure 7 and Figure 8 show the changes in the carpet microclimates in bedroom 1 after each retrofit. It can be seen that, although the temperature at the base of the carpet above outdoors became larger, there was no significant change in base of carpet humidities.

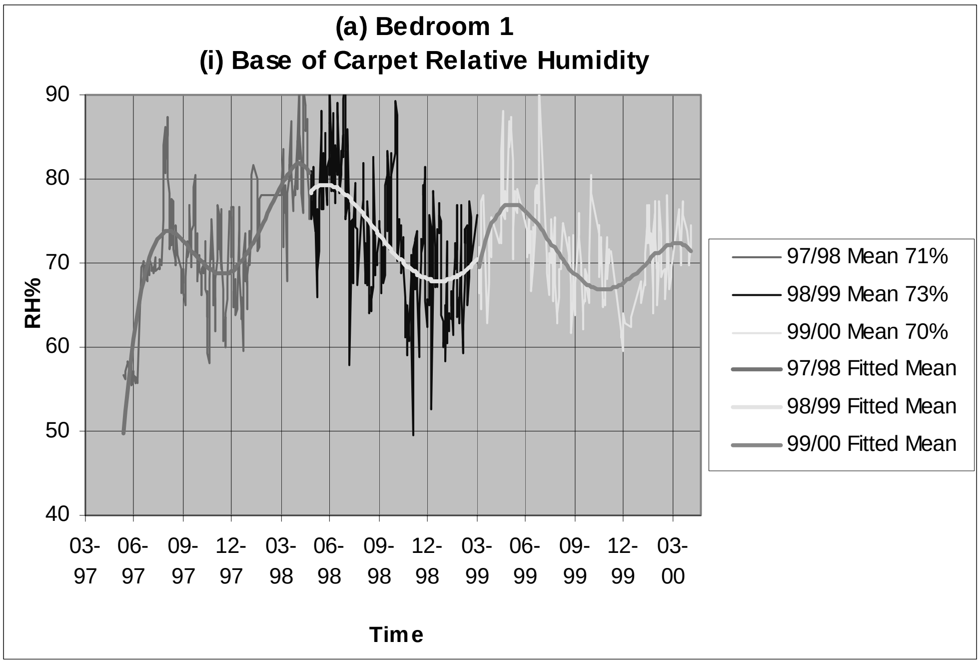

Figure 6: Base of carpet humidities in bedroom 1

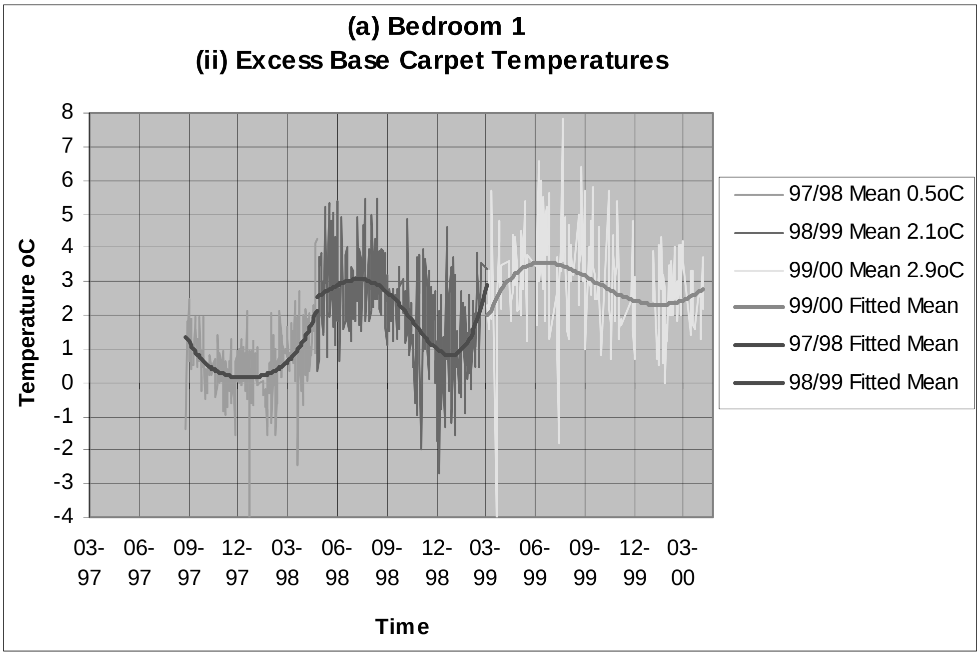

Figure 7: Base of Carpet excess temperatures for bedroom 1

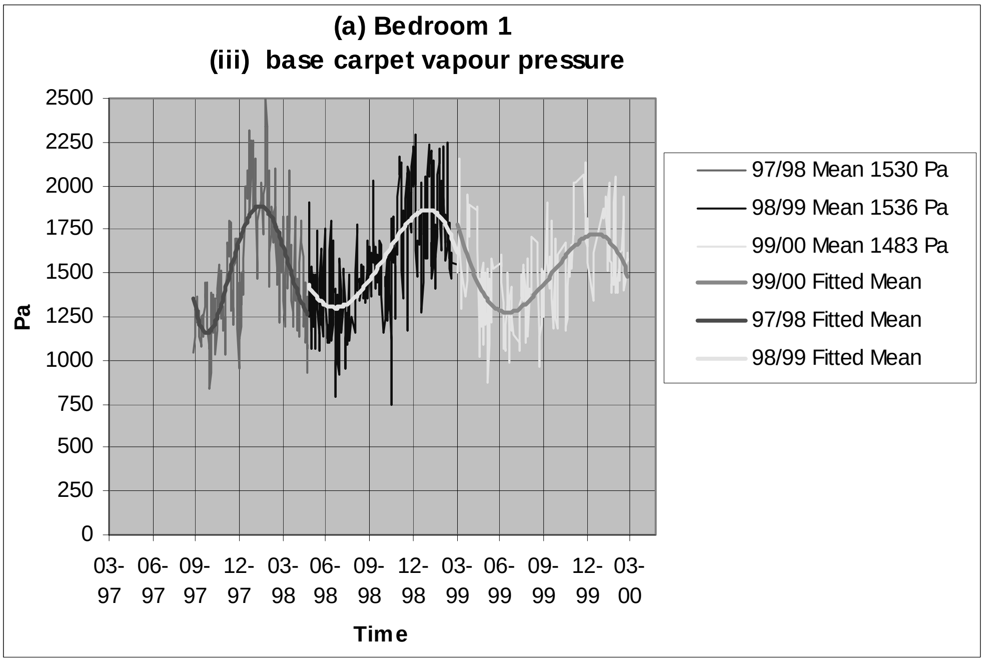

Figure 8: Base of carpet vapour pressures

That the base of carpet relative humidity has not fallen is due to the complex changes in base of carpet vapour pressures and base of carpet temperatures, see Figure 7 and Figure 8. The house is generally tighter after the first retrofit, causing indoor vapour pressures to be higher. Exactly what final relative humidity is achieved then depends upon how much higher base of carpet temperatures are. To guarantee lower base of carpet humidities it becomes clear that there must be better improvements in base of carpet temperatures than what has been achieved in this house, and the increase in indoor vapour pressures due to house tightening must not be too high, or must be reduced with better ventilation.

These changes will be difficult to achieve in New Zealand by passive means. Higher base of carpet temperatures would require more insulation, particularly more sub-floor insulation, which in this case is already far above that required by New Zealand Standards [5]. Newer houses are more air-tight than the study house so extra ventilation would need to be required, but given New Zealand's high outdoor humidities and outdoor temperatures that are always well above freezing, there is not much water vapour take-up capacity in outdoor air being used for ventilation.

Microclimates – bedding. Daily average bed microclimates are difficult to predict. While the bed is occupied the microclimate close to the occupant is dominated by the heat and moisture release from the occupant, but towards the bottom of the mattress the microclimate is strongly influenced by conditions under the bed, which in turn are influenced by conditions in the room air, see Cunningham [6]. However, during the day time the bedding conditions drift back to room conditions with a time constant of several hours [6]. Therefore one might expect the daily average bedding conditions to be influenced in part by the daily average room conditions, giving the remote possibility that if room relative humidities are lowered then bedding relative humidities will be lowered leading to the possible control of control dust-mites.

Figure 9 shows the daily average temperature and relative humidity under the bottom sheet, just millimetres from the occupant, in the bed in bedroom 3. It can be seen that the temperature remains unchanged after each retrofit but that there is a change of relative humidity, from 54% to 53% and then to 50%. If conditions were steady night and day at these levels, dust-mites would be killed [7,8] even before retrofitting. However, it is known that dust-mites need only short periods on a daily basis at higher humidities to rehydrate themselves and hence recover from dehydration [9,10]. The 24 hour cycle of humidities in bedding is complex [6], but is thought to contain sufficient periods of rehydration to allow them to survive under these conditions. This complex daily cycle is not seen of course if one is presenting with only daily information as in Figure 9.

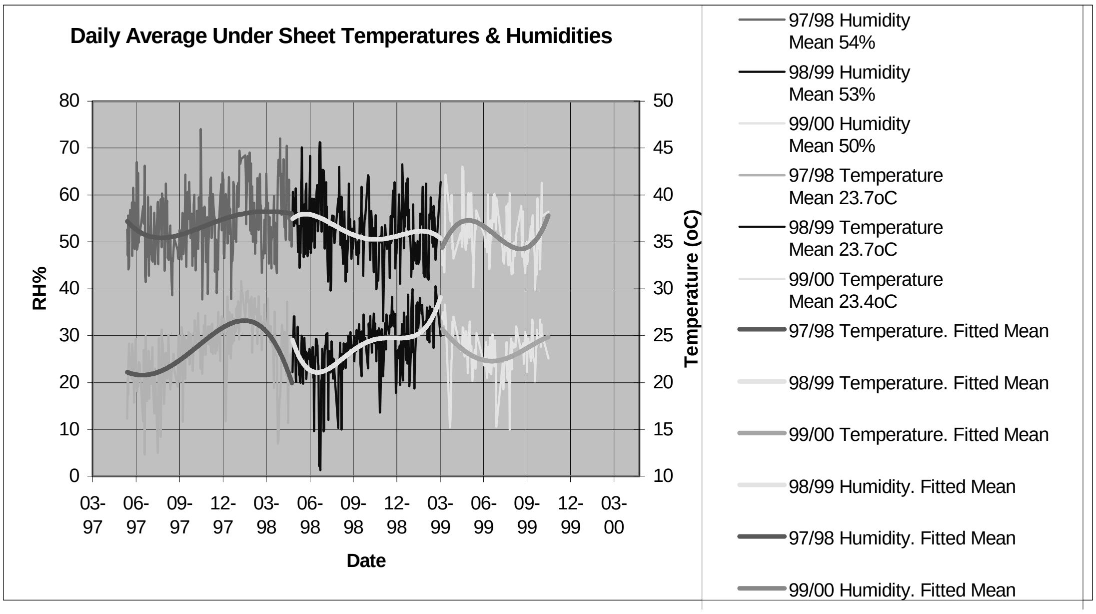

Figure 9: Daily Average Under Sheet Temperature and Humidities in Bedroom 3

CONCLUSIONS

Heating energy changes, internal temperature changes and heat flux changes in the study house after each of the 2-stage retrofits were much as they were expected to be. Humidity changed from 65% to 60% after the first retrofit, and then from 60% to 59% after the second retrofit. Base of carpet humidities did not change even though there were increases in base of carpet temperature differences above outdoor temperatures from 0.5 ^{o}C to 2.1 ^{o}C after the first retrofit, and from 2.1 ^{o}C to 2.9 ^{o}C after the second retrofit.

There has been speculation that passive means of humidity control effected by changes in house design might be sufficient to control dust-mites; however, in this house none of these changes were large enough to affect dust-mite viability.

This can reasonably be extrapolated to conclude that, in general, in New Zealand, it will be very difficult to achieve dust-mite population control by the use of passive methods. Active means such as heating and dehumidifying will be needed. This is an important negative result given the interest in changing indoor conditions for dust-mite control using these passive techniques.

ACKNOWLEDGEMENTS

This research was supported by funding from the Foundation for Research Science and Technology, PGSF fund, and the Building Research Levy.

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