Clinical and Experimental Allergy, 1998, Volume 28, pages 1104–1112

Direct measurements of temperature and humidity in dust mite microhabitats

M. J. CUNNINGHAM

Building Research Association of New Zealand, Porirua, New Zealand

Summary

Background Up to 70% of atopic asthmatics have a positive skin test to the dust mite allergen Der p 1. Reduction of dust mite numbers by lowering room humidity control is one suggested technique for reducing dust mite allergen levels to clinically acceptable levels. Trials of this technique in temperate climates have reported mixed results. It has been speculated that one reason for this is that humidity changes in room ambient air are not tightly linked to humidity changes in the dust mite microenvironment (in the base of carpets, bedding, furniture etc.).

Objective To directly measure humidities and temperatures in dust mite microenvironments and compare these to ambient conditions, and so gather data on how the microclimates are influenced by room conditions and moisture and heat sources, such as an occupant in a bed.

Methods A special small humidity device has been developed which can discriminate humidity changes over distances of millimetres. With these devices microclimates have been measured in the base of carpets, in layers through bedding, and in furniture.

Results Measured base-of-carpet humidities were significantly higher than room humidities. Bedding relative humidities show complex behaviour according to the distance separation between the measuring point and the occupant. Immediately below the occupant, bed relative humidities fall when the person enters the bed. Similar behaviour is observed in a sofa.

Conclusion Some dust mite microclimates have been shown to be very different from room conditions. Consequently, reduction of dust mite numbers and allergen levels cannot be guaranteed by the controlling of room humidities.

Keywords: microclimate, indoor climate, asthma, dust mites, relative humidity sensors, allergens, carpets, bedding, soft furniture

Clinical and Experimental Allergy, Vol. 28, pp. 1104–1112. Submitted 16 June 1997; revised 12 October 1997; accepted 9 April 1998.

Introduction

Dust mite allergens (Der p 1 to 7 and others, [1]), are one of the prime initiators and provokers of asthma. Up to 70% of atopic asthmatics show a positive skin test to the dust mites allergen Der p 1, [2]. Much effort has been put into the trialing of various methods of dust mite population control and assessing their effectiveness as measured by reduction in dust mite numbers, Der p 1 levels, or clinical symptoms [3].

Correspondence: M.. J. Cunningham, Building Research Association of New Zealand (BRANZ), Private Bag, Porirua, New Zealand.

One technique for dust mite control and allergen level reduction that has been studied is to reduce indoor relative humidities to utilise the fact that dust mites have a critical equilibrium humidity (CEH) below which they desiccate and die. However, although humidity control has shown some success in reducing Der p 1 levels in cold climates (e.g. [4,5]), outcomes have been mixed when temperate or sub-tropical climates are examined (e.g. [6–8]).

In attempting relative humidity control of dust mites almost invariably room-humidity is measured and room-humidity is taken as the variable to control. However, dust mites live in microenvironments such as bedding, carpets

© 1998 Blackwell Science Ltd

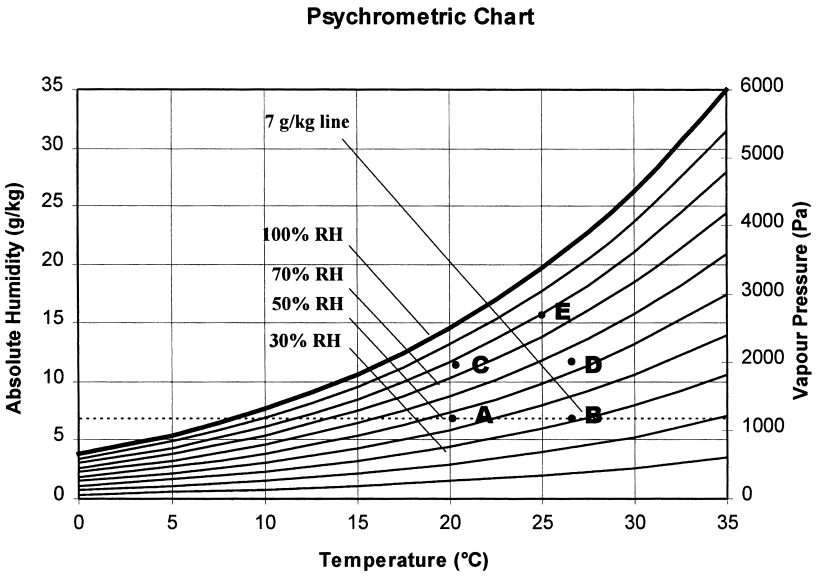

Fig. 1. Psychrometric chart showing the connection between temperature, relative humidity, absolute humidity and vapour pressure. Point A and point B both have the same absolute humidity of 7 g/kg. Point C and E have the same relative humidity, 79%, but different absolute humidities. Mites can be cultured at point C, 20°C,79% RH, but not at point D, 27°C, 56% RH, even though they have the same absolute humidity of 11.7 g/kg [19].

and furniture where the psychrometric conditions (temperature and humidity) are only indirectly controlled by room air conditions. Until now it has not been possible to measure humidities in the mite microenvironment because existing relative humidity devices have sensor heads of typically 10 mm dimension. However, dust mite microenvironments have dimensions in the order of millimetres, e.g. the distance between the top and bottom of a carpet pile will be a few millimetres, as will be the distance through layers of bedding; yet these small distances may give rise to differences in temperature and humidity such that survival is unlikely, for example, at the surface of a carpet but perfectly possible at the base.

The work reported in this paper addresses the issue of measuring psychrometric conditions in the dust mites' microenvironment. This has been made possible by the development of a relative humidity device that can discriminate relative humidity differences over distances of only a few millimetres. These devices have been used to measure microclimates in carpet, bedding and furniture.

Koekkoek and van Bronswijk [9], de Boer and van der Geest [10], and Yellen [11] report humidities in mattresses but they are limited by the size of their sensors to distances centimetres away from the bed occupant. This work reports marked differences in bedding and mattress relative humidity not detectable by larger sensors as one moves down through the bedding and mattress layers away from the occupant.

The connections between the psychrometric variables

As this work is concerned with the psychrometric variables of temperature, relative humidity, absolute humidity, and vapour pressure, the connection between them will be reviewed here. Figure 1 shows a psychrometric chart with temperature on the horizontal axis and absolute humidity or vapour pressure on the vertical axis. Absolute humidity measures the mass of water vapour per mass of air. Vapour pressure and absolute humidity are nearly proportional with 1000 Pa of water vapour pressure being 6.235 g/kg absolute humidity. The terms 'vapour pressure' and 'absolute humidity' will be used interchangeably in this work.

Relative humidity measures the degree of water vapour saturation of air. As temperature increases the maximum amount of water vapour air can hold rises approximately exponentially. This maximum amount of moisture is measured as grams of water vapour per kilogram of air (absolute humidity), or vapour pressure in Pa. Relative humidity is 100% if the air is fully saturated, while the relative humidity of unsaturated air is defined as:

$$\text{relative humidity (\%)} = 100 \times \frac{\text{vapour pressure}}{\text{saturated vapour pressure}}$$

The points A and B in Fig. 1 have the same absolute humidity of 7 g/kg, but different relative humidities, 48% and 31% relative humidity respectively, while points C and E have the same relative humidity, 79%, but different absolute humidities, 11.7 g/kg (1850 Pa) and 15.9 g/kg (2510 Pa) respectively.

Materials and methods

Details of the small relative humidity device

The key to obtaining the results reported in this work has been the development of a small relative humidity device

allowing discrimination between relative humidities measured at sites just millimetres apart.

The relative humidity device developed is based around a commercial sensor which has a dimensions of $3.8 \times 8.2 \times 0.6$ mm. All necessary driving and reading electronics are contained within this sensor but the author has added other components (a voltage regulator and capacitance) to stabilise its output. The commercial sensor is contained within in a flexible plastic surrounding with a slit of less than a millimetre width cut in the side. The sensor saturates if light falls on it — the plastic surround shields the sensor from light while the narrow slit defines the point of measurement. The device is connected to a data-logger, with a 5 V regulator placed in the connecting plug, to provide the necessary voltage reference level. Further details are reported elsewhere [Cunningham MJ. Development and performance of a small relative humidity sensor for indoor microclimate measurements. Accepted for publication].

The devices are low cost making it realistic to undertake experiments with dozens or even hundreds of relative humidity measurement sites.

Calibration

Since relative humidities were to be measured over short distances and therefore might differ only by small amounts, accurate calibration was essential. Calibration was carried out using a two-pressure relative humidity generator [12], a well known laboratory device. This generator creates an atmosphere of any chosen humidity and temperature, and has been shown to be accurate to better than $\pm$ 1% humidity and $\pm$ 0.2°C in temperature [13]. Extensive tests of the performance of these relative humidity devices, using this humidity generator, were carried out, allowing us to claim that the devices, once calibrated, have an accuracy of $\pm$ 1% humidity and a drift of less than ½% humidity per month. During data analysis the manufacturer's small temperature correction was applied – never much more than $\pm$ 1 or 2% relative humidity.

Temperature sensors (bead-type NTC thermistor with 0.1°C accuracy) were calibrated in an oil bath with accuracy better than 0.05°C, the oil bath being traceable to New Zealand National Standards.

Description of experiment

The study was undertaken in a 120 m^2 single-storey house of wooden construction with a carpeted uninsulated suspended timber floor over a crawl space. The bedroom studied was unheated and had a carpet with a pile depth of about 5 mm.

In the bedroom sensor pairs, the relative humidity device described here and a thermistor (see above) were placed: in the bedroom air; on top of the bedroom carpet; and in the base of the carpet pile.

The bed had bedding layers below the occupant consisting of a sheet, a piece of foam, an electric blanket (never switched on) and an inner-spring mattress. Sensor pairs were placed at various levels in the bedding, viz. immediately below the occupant under the bottom sheet, on the electric blanket, on top of the mattress, in the middle of the mattress, on the bottom of the mattress and on the floor under the bed. In the living room sensors were placed in the room air, and in the living room sofa, immediately underneath the furniture fabric. Sensors were connected to a datalogger taking readings every 15 min. Once a week results were extracted from the logger, converted to physical units and archived.

Dust samples were collected at each site and Der p 1 and dust mite numbers extracted. These results are not reported here as they are instantaneous values that will not change over the few days of the psychrometric data shown here.

Results

This paper reports results over time periods of a few days.

Bedroom carpet

Results shown in Fig. 2 are for 48 h from midnight. Significantly, it can be seen that the carpet is, on average, about 7% humidity above the room value. The difference between the room air and carpet humidity values is important; although the room-air humidity is possibly too low for mite survival, the value in the base of the carpet is not. On psychrometric grounds, a viable dust mite population could be maintained in the base of the carpet. This could be only guessed at if the air humidity value alone was all that was available.

The explanation for the carpet humidity values is straightforward — the absolute humidity (vapour pressure) in the carpet is almost the same as the room air value as would be expected from moisture flow considerations, but the temperature is some 1.7°C degrees lower, hence the relative humidities are higher.

Bedding

Results shown in Fig. 3 are for 24 h from midnight. The most significant feature visible in this data is that the relative humidity falls in the layers of bedding nearest to the occupant — only below the middle of the mattress does the humidity rise when the bed is occupied.

Again, examination of temperatures explains these results. Temperature rises when a person enters the bed, see Fig. 3. Indeed, temperatures immediately under the occupant rise to a level close to skin temperature. So although relative humidities fall immediately beneath the occupant, the measure of the absolute amount of water

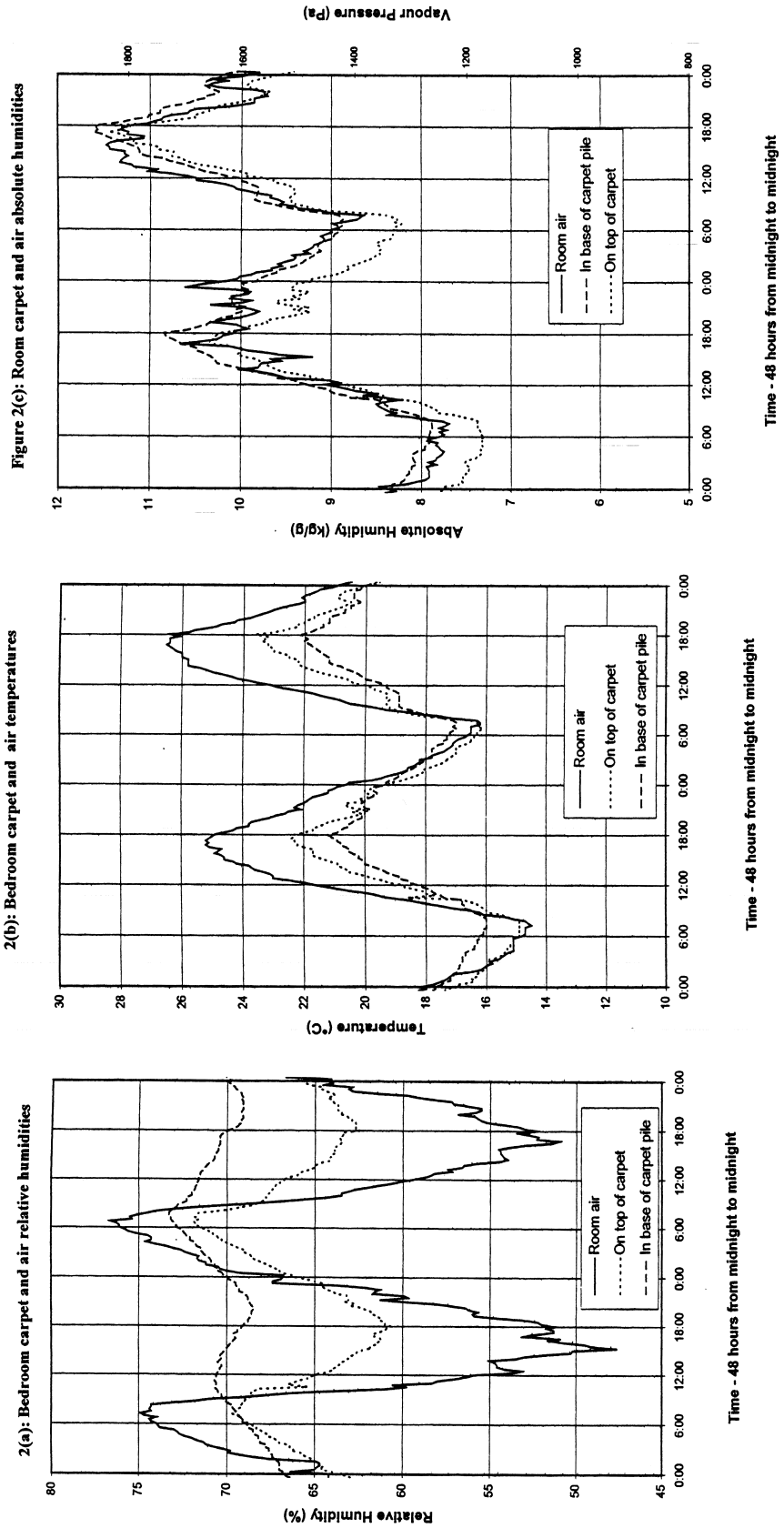

Fig. 2. Bedroom carpet and air psychrometric data. Relative humidity in the base of the carpet pile has a higher mean than the relative humidity of the room air.

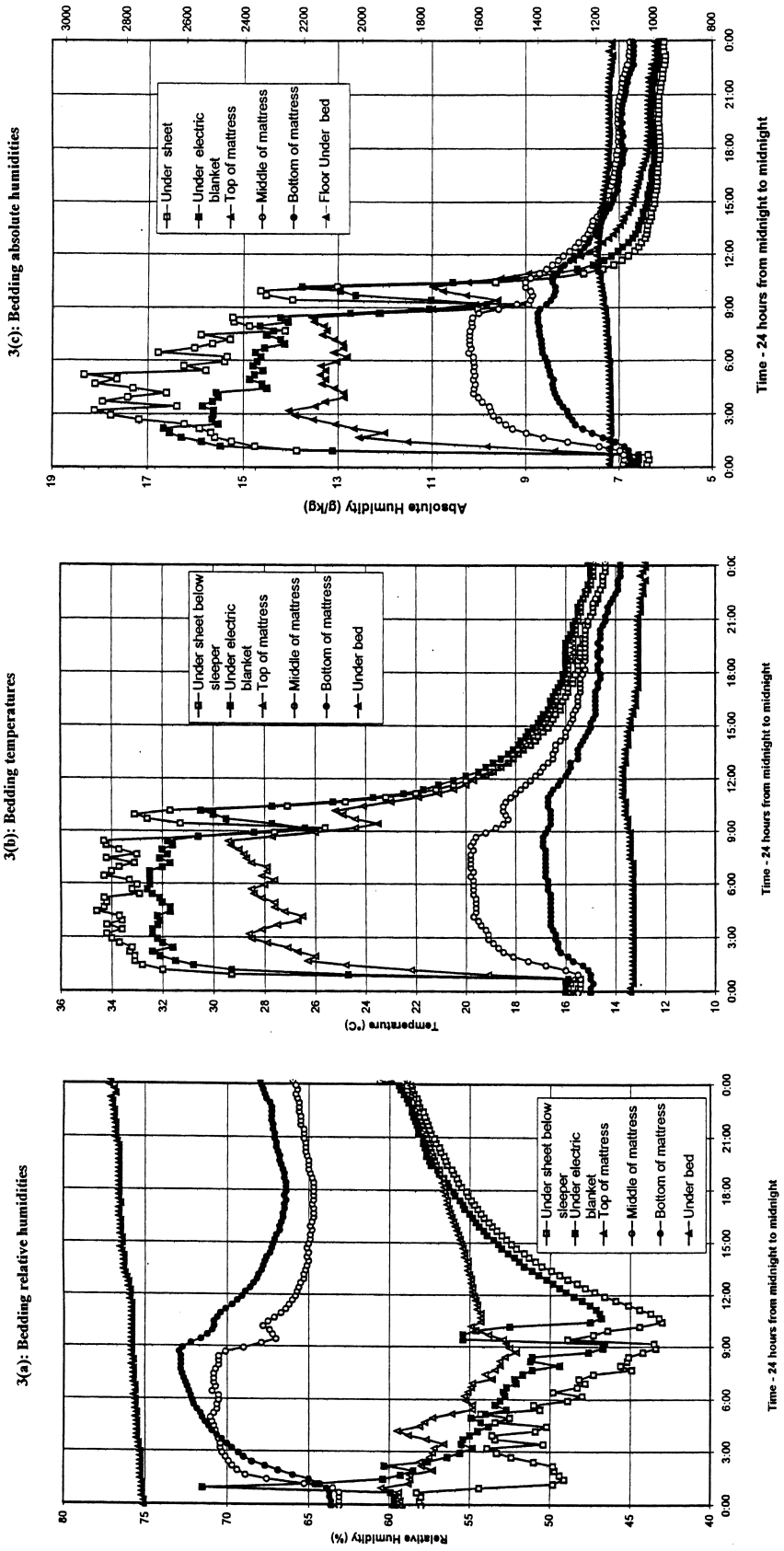

Fig. 3. Bedding psychrometric data. Relative humidity falls immediately beneath the occupant when the bed is occupied.

vapour in the air, viz. vapour pressures, or absolute humidities, are seen to rise.

Sofa

Results shown in Fig. 4 are for 72 h from midnight. The humidities and temperatures just under the fabric of the sofa show similar behaviour to those in bedding, i.e. when a person sits on the sofa relative humidities fall, because the temperature rise contributes more to the relative humidity level than the absolute humidity rise.

Discussion

Where there is no immediate moisture source, as in the case of carpets, the moisture content of the air should not change according to position, i.e. the absolute humidity (or synonymously, vapour pressure) should not vary from location to location. Figure 2(c) shows that this is approximately so, with absolute humidities in the ambient air, on top of the carpet, and in the base of the carpet all approximately equal. In this case the essential physical parameters are temperature and absolute humidity, from which relative humidity appears only as a derived variable.

On the other hand if there is a moisture source, then air moisture contents i.e. absolute humidities, will be higher near the source. In the case of bedding and furniture the occupant is a substantial moisture and heat source; this is reflected in the rise of temperature and absolute humidity (vapour pressure) under the occupant, Fig. 3(b) and 3(c), but not necessarily in a rise of relative humidity, Fig. 3(a). Given the temperature and absolute humidity rise under the occupant, the psychrometric chart, Fig. 1, can be used to find the change in relative humidity. *A priori*, it will be difficult to predict whether relative humidities will rise or fall when a bed is occupied, and indeed both happen according to distance from the occupant, Fig. 3(a).

It is worth stressing that fluxes of heat and moisture are determined by temperature and vapour pressure (absolute humidity) [14] gradients, but moisture contents of materials such as bedding, carpets etc are determined by relative humidity [15].

Conditions for dust mite viability

Neither absolute humidity or relative humidity alone determine conditions for the viability of mites. The critical equilibrium humidity (CEH) for *Dermatophagoides farinae*, below which this mite species cannot survive, is shown in Table 1, taken from Arlian and Veselica [16,17]. It can be seen that the CEH measured either as a relative humidity or an absolute humidity is not a constant independent of temperature. Arlian stresses this point [18] by drawing attention to the fact that *Dermatophagoides farinae* mites can be cultured at 20°C, 79% RH, (point C on the psychrometric chart, Fig. 1) but not at 27°C, 56% RH (point D, Fig. 1), even though they have the same absolute humidity of 11.7 g/kg (1850 Pa). Data for *Dermatophagoides pteronyssinus* [19] is more scattered but it too shows that the species' CEH is not a constant independent of temperature.

Performance of other floor types

Different studies, as referenced above, have reported differing effectiveness of humidity modification for dust mite control. Although many factors may explain these differences, differing microclimates will certainly be a major contributor.

In particular, other floor types should show quite different performances from that studied here. Floors in upstairs bedrooms and concrete slab-on-ground floors will be exposed to very different conditions underneath the carpet, and different heat and moisture diffusion rates than those met with in this study, which will reflect into quite different carpet microclimates from those measured here. Indeed, results obtained by Wickens *et al*. [20] showed an association of higher dust mite populations in suspended floors than concrete slab-on-ground floors, which is consistent with different base-of-carpet-pile microclimates as suggested here.

Implications for mite mobility

It has been speculated that mites, in searching out optimum psychrometric conditions, might move towards the

Table 1. Critical equilibrium humidity and corresponding absolute humidity for *Dermatophagoides farinae* as a function of temperature [20]

Temperature	15°C	25°C	30°C	35°C
Critical equilibrium humidity (CEH)	52%	58%	63%	69%
Corresponding absolute humidity	5.56 g/kg	11.7 g/kg	17.4 g/kg	25.3 g/kg

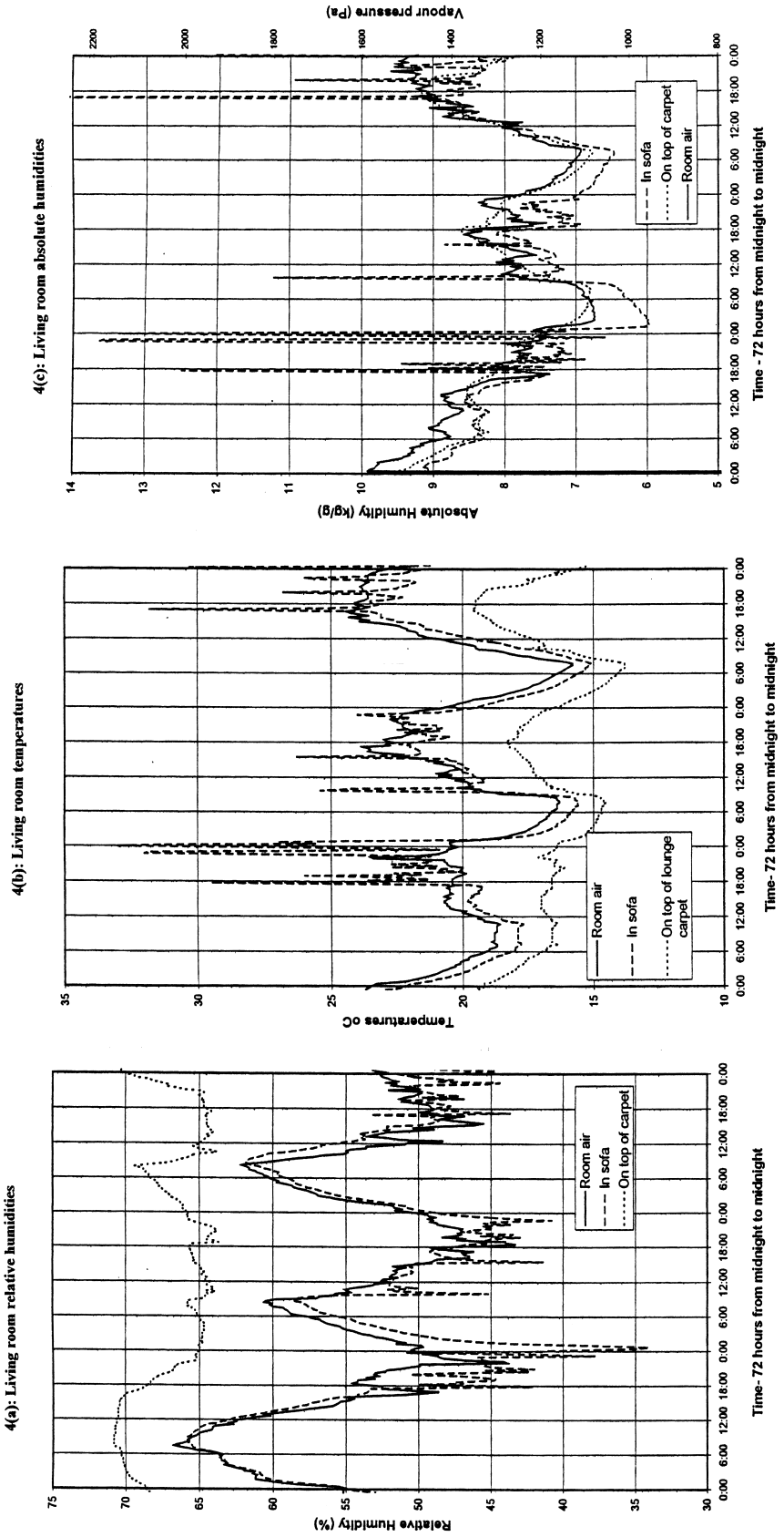

Fig. 4. Living room psychrometric data. Negative spikes of relative humidity are seen when the sofa is occupied. Carpet relative humidities show a higher mean than other relative humidities.

occupant when the bed is occupied and away when the bed is empty. Examination of the temperatures found in this study shows that conditions are too hot near the occupant, but improve to be nearly ideal when the bed is unoccupied. If mite population dynamics derived from laboratory experiments using constant psychrometric conditions can be carried over to field conditions which vary on a 24 h basis, one would be forced to conclude that, if mites move at all, they would move away and not towards the occupant of the bed. There is some evidence which might suggest that this may be so [10].

Implications for further research

Little work has yet been done on the response of dust mites to fluctuating conditions, yet it is clear that this knowledge is needed if the potential for controlling mites psychrometrically is to be properly assessed.

The work reported in this paper suggests that microbiologists might subject laboratory populations to a fluctuating climate imitating psychrometric conditions now known to be found in the domestic microhabitats. Significantly, these conditions have both temperature and relative humidity changing on a 24 h basis. It is not enough to vary humidity alone, as has been done to date [21].

There is a suggestion, from work to date, that providing mites have a period of around three hours per day of high humidity, they can survive at quite low humidities for the remaining 21 h or so per day [21]. However, these results are found using constant temperature throughout the duration of the experiment; it is unclear whether they would still hold if temperature was also allowed to change.

A key question that needs answering is ‘how much do room conditions affect bedding microclimates?’. As room conditions change, either because of seasonal effects or because of heating or dehumidifying, do conditions in bedding change significantly, or are bedding conditions so strongly coupled to the presence of a person in the bed that room psychrometric changes cannot make a significant difference to bedding microclimates, and hence bed mite dust population dynamics?

Some of these results obtained here may, at first sight, appear counter-intuitive but *a posteriori* allow easy interpretation. These results have significant implications for dust mite viability, explaining for example why it might be necessary for room air relative humidity to be below 45% for dust mite control, when laboratory experiments suggest critical equilibrium humidity at around 60% or higher.

Put differently, controlling ambient air to say 45% relative humidity may or may not force conditions in the microenvironment to be low enough kill dust mites. Without measurement and control directly in the microenvironment, it should come as no surprise that mixed results on reduction of allergen levels are reported when humidity control of dust mites is attempted, especially in temperate and sub-tropical climates.

Acknowledgements

The author wishes to thank Professor G. Tsongas, Portland State University, for directing him to the source of the humidity transducer that forms the basis of the device used in this work.

The author thanks Dr J. Crane, Wellington Asthma Research Group, Wellington, for comments on this paper. Professor C. A. C. Pickering is also thanked for encouraging the author to submit these results to a medical journal.

This research was funded by the New Zealand Building Research Levy and the Foundation for Research, Science and Technology’s Public Good Science Fund (New Zealand).

References

1 Stewart G. Proceedings of the 2nd Conference Mites Asthma and Domestic Design held at Sydney, November 1994:9.
2 Ford A. & Platts-Mills T. Standardised extracts, dust mites, and other arthropods (inhalants). Clin Rev Allergy 1987; 5:49.
3 Colloff M, Ayres J, Carswell F et al. The control of allergens of dust mites and domestic pets: a position paper. Clin Exp Allergy 1992; 22: Suppl 2, 1.
4 Korsgaard J. Preventive measures in mite asthma. A controlled trial. Allergy 1983; 38:93–102.
5 Harving H, Korsgaard J, Dahl R. Mechanical ventilation in dwellings as preventive measures in mite asthma. Allergy Proc 1988; 9:283.
6 Crane J, Grimmett D, Wickens K, Kennedy J. House dust mite allergen in Wellington homes - a preliminary report. Proceedings of the 2nd Conference Mites Asthma and Domestic Design, held at Sydney, November 1994; 107.
7 Fletcher A, Custovic A, Kennaugh J, Taggart S, Pickering A, Woodcock A. Dehumidification as a method of mite avoidance in the United Kingdom: Can it work? Proceedings of the 2nd Conference Mites Asthma and Domestic Design held at Sydney, November 1994; 101.
8 Cabrera P, Julià-Serdà G, Rodriguez de Castro F, Caminero J, Barber D, Carrillo T. Reduction of house dust mite allergens after dehumidifier use. J Allergy & Clin Immunol 1995; 635.
9 Koekkoek H, van Bronswijk J. Temperature requirements of a house-dust mite Dermatophagoides pteronyssinus compared with the climate in different habitats of houses. Ent Exp App 1972; 15:438.
10 De Boer R, and van der Geest L. House dust mite (Pyroglyphidae) populations in mattresses, and their control by electric blankets. Exp App Acarol 1990; 9:113.
11 Yellen D. The determination of micro-climates within occupied beds. Proceedings of Indoor Air Quality, Ventilation and Energy Conservation in Buildings, May 9-12, 1995; 1:215.

12 Wexler A. Calibration of humidity-measuring instruments at the National Bureau of Standards. ISA Transactions 1968; 7:365.
13 Cunningham M. BRANZ two pressure relative humidity generator. BRANZ unpublished report, UP 225. 1985.
14 ASHRAE Handbook, Fundamentals. Publisher American Society of Heating, Refrigerating and Air Conditioning, Inc. 1791 Tullie Circle, N.E., Atlanta, GA, 30329, USA. 1989.
15 Walker I, Jackson F. Equilibrium vapour pressure of wool. New Zealand J. Science 1973; 16:481.
16 Arlian L.G & Veselica M.M. Effect of temperature on the equilibrium body water mass in the mite Dermatophagoides farinae. Physiol. Zool 1981; 54:93.
17 Arlian L.G & Veselica M.M. Re-evaluation of the humidity requirements of the house-dust mites Dermatophagoides farinae (Acari: Pyroglyphidae). J. Med. Entomol 1981; 18:351.
18 Arlian L. Water balance and humidity requirements of house dust mites. Exp App Acarol 1992; 16:15.
19 Cunningham M.J. Controlling dust mites psychrometrically - a review for scientists and engineers. Indoor Air 1996; 6:249.
20 Wickens K, Siebers R, Ellis S, Sawyer G, Tohill S, Stone L, Kent R, Kennedy J, Slater T, Crothall A, Trethowen H, Pearce N, Fitzharris P, Crane J. Determinants of dust mite allergen in homes in Wellington, New Zealand. Submitted for publication. 1996.
21 De Boer R & Kuller K. Water balance of Dermatophagoides pteronyssinus in circumstances with only a few hours of moist air (above CEH) every day. Proceedings of the 2nd Conference Mites Asthma and Domestic Design 1994;22