

A pilot study of the effect of mechanical ventilation and heat exchange on house-dust mites and Der p 1 in New Zealand homes

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We have examined the effect of reducing relative humidity (RH), with inbuilt mechanical ventilation and heat-exchange (MVHE) units, on house-dust-mite (HDM) counts and allergen levels, in a pilot study of 10 Wellington dwellings. Recent international prevalence studies in adults and children have confirmed a high prevalence of asthma in New Zealand. Sensitivity to HDM is common among the general population, and HDM is the major allergen associated with asthma. Recent studies of allergen levels have confirmed high concentrations of Der p 1 in the domestic environment. While humidity was significantly reduced in those dwellings fitted with ventilation units, no systematic effect on mites or Der p 1 was observed during the study period. When the reductions in humidity were examined in the context of the time spent below the critical equilibrium humidity (CEH), the intervention led to RH values below the CEH for only 39% of the total of 24-h periods for which measurements were made. Reducing RH by means of MVHE in New Zealand domestic dwellings does not lower humidity sufficiently, or long enough, to have any measurable effect on HDM populations.

Key words: allergen avoidance; domestic environment; house-dust mites; humidity control.

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Recent international prevalence studies in adults and children have confirmed a high prevalence of self-reported asthma symptoms in New Zealand, with a 12-month period prevalence of wheezing of 26% in adults aged 20–44 years and 32% in children aged 13–14 years (1, 2). The predominant sensitizing environmental allergens in New Zealand are from house-dust mites (HDM), domestic cats, and grasses. Atopy defined by skin prick tests to these three allergen sources show population frequencies of 32%, 13%, and 30%, respectively, among 13-year-olds. Analysis of allergen-specific relative risks of asthma symptoms, airway hyperresponsiveness (AHR), or a combination, for these allergens showed only HDM and cat entailing a significantly increased risk; for the combination of symptoms and AHR, the risks were six- and four-fold respectively (3).

In those with asthma sensitive to HDM allergens, a dose-response relationship has been observed

between the risk of current symptoms and reservoir levels of the major allergen Der p 1 in the domestic environment (4). Recent studies in New Zealand have shown *Dermatophagoides pteronyssinus* to be the predominant mite species, with high levels of Der p 1 in the domestic environment. Geometric mean levels of Der p 1 of 46 µg/g fine dust in bedding and 26 µg/g fine dust on living-room floors have been found in Wellington homes (5). These findings suggest that HDM allergens probably play an important role in the development and maintenance of asthma in New Zealand. Attempts to reduce exposure to HDM allergens by the general population and sensitized symptomatic asthmatic patients may reduce asthma prevalence and morbidity.

One method to control HDM growth and proliferation has been to exploit the dependence of mites on high ambient relative humidity (RH) (6). In the laboratory, at RH below 58% at 25°C or

below 52% at 15°C, *D. farinae* starts to lose water to the surrounding environment (7). The humidity at which this water loss begins is temperature dependent, and has been termed the critical equilibrium humidity (CEH). This laboratory observation is supported by the failure to find either species of mite in naturally arid or alpine (>1200 m) environments (4, 8).

A series of studies in Denmark by Korsgaard and colleagues showed a significant reduction in mites in dwellings where humidity was reduced by inbuilt heat-exchange and ventilation units (9). Their studies showed significant improvements in clinical asthma among asthmatic occupants of these dwellings. The Danish climate with warm, dry summers and very cold, dry winters appears ideally suited to this type of intervention. In winter, most of the indoor moisture comes from the occupants and their daily activities. Increased exchange of air from inside with dry outdoor air warmed by heat exchange will significantly lower indoor humidity. However, the climatic conditions in New Zealand are very different from Denmark, with high year-round humidities and a narrow temperature range. This pilot study was designed to examine whether inbuilt mechanical ventilation with heat exchange (MVHE), in combination with increased space heating, could sufficiently lower RH to reduce HDM populations in Wellington homes.

Material and methods

The study was a joint undertaking of the Wellington Asthma Research Group; the Electricity Corporation of New Zealand (ECNZ), the national bulk electricity producer; Wellington City Council (WCC), who provided the dwellings; and Capital Power, the local electricity retailer.

WCC identified a number of dwellings in a single suburb that were due for upgrading and insulating. The council undertook the upgrading and installation work in conjunction with Capital Power, who oversaw the installation and commissioning of the MVHE units.

Study outline

Thirty similar dwellings and their occupants were enrolled for a period of 21 months. Dwellings were randomly assigned to three groups, each comprising 10 dwellings.

- group A – installation of MVHE units, increased space heating in the form of electric night store heaters, plus insulation and draught-proofing
- group B – identical insulation and draught-proofing only

- group C – control properties with no intervention during the study period (these dwellings were upgraded at the end of the study).

Outcome measures included continuous recording of humidity and temperature, regular measurement of Der p 1, and standardized counts of dead mites from the main bedroom floor. These measurements were made for a period of approximately 6 months before and 12 months after the intervention. For group C dwellings, an arbitrary date for the intervention was assigned as midway between the beginning and end of the interventions in groups A and B dwellings.

It was recognized that a larger number of dwellings would have been more appropriate to provide greater power in determining the effect of the intervention. However, due to the costs of the study, no more than 10 dwellings could be retrofitted and monitored. Power calculations suggested that if we had observed reductions similar to those found in Denmark we would have had sufficient dwellings to reach a valid statistical conclusion.

Study dwellings and tenants

WCC provided a complete list of its housing stock, comprising 92 dwellings, on the Miramar peninsula. These dwellings were all built between 1952 and 1960 with an approximate average floor area of 80 m². Foundations were of reinforced concrete, and framing was of light timber with a weather-board external covering. Internal linings were either Gibraltar board or hardboard with timber joinery and roofs of corrugated iron or tiles. Dwellings were required to have mites present with concentrations exceeding 100 mites/g fine dust or 2 µg/g of Der p 1 antigen, in mattresses or on floors in the principal bedroom.

The dwellings were randomly assigned to one of the three groups outlined above. For two dwellings, random assignment was not possible due to the low pitch of the two roofs, which prevented the installation of the ventilation units.

Tenants in these dwellings were approached, the details of the study were discussed, and each household was invited to participate. To minimize dropouts from the study, tenants were included only if they thought they would remain in the accommodation for at least a year. The extra electricity cost for the period of the study was met by Capital Power and ECNZ, and each participating household received a rent subsidy while the study was in progress. Thirty dwellings were eventually selected after 51 households had been approached out of the total of 92 eligible to participate. Householders were advised to continue

their normal cleaning and washing regimen throughout the study period. Group A householders were also advised to keep windows and doors closed, and external doors were fitted with closing devices.

Heating and ventilation units. These units were supplied locally by Avon Electric Ltd. The units were sized to provide 0.75 air changes per hour (ac/h), and were set to increase to 1.9 ac/h when thermostats indicated bathroom or kitchen use. Each unit was fitted with a three-stage 2.4-kW duct heater and a summer bypass damper, to prevent heat from being added to the home on hot days. When outdoor ambient temperatures exceeded the thermostat setting of 21°C, fresh air bypassed the heat exchanger core.

In addition, a single night store heater of 3.4 kW capacity was installed in a central location in each of the group A dwellings to increase indoor temperatures. The heat-exchange ventilation units and the space heating were designed and set to maintain a temperature of 21°C throughout the dwelling.

Insulation. Insulation for groups A and B dwellings consisted of adding Thermofleece™ to ceilings and walls. External walls were insulated to an *R* value of 1.2 and ceilings to an *R* value of 3. Floors were insulated to an *R* value of 0.9. In addition, external doors and windows were draught-proofed.

Measurements

Temperature and RH. During the course of the study, temperature and RH were measured continuously by small electronic data loggers (Smart-Readers™, ACR Systems, Inc). Data loggers were able to record temperatures in the -40° to +70° range with a resolution of 0.4° at 25°C. A separate RH module, RH-001, was incorporated in the logging devices. This had a resolution of 0.4% RH and an accuracy of ±4% RH. Loggers were placed in each dwelling in the living area, and were positioned out of the reach of children on a suitable elevated surface close to an internal wall. The loggers recorded temperature and RH every 8 s. Values were averaged for each 30-min period. During dust-sample collection, these data was downloaded onto a laptop computer and stored in a central file.

Air exchange. To ensure adequacy of the retrofitting, air-exchange measurements by the standard negative pressure method were made in a sample of 15 of the group A and group B dwellings before and after the ventilation units or the insulation had been fitted.

Dust sample collection. The samples of dust were collected approximately every 3 months between November 1993 and September 1995, with two or three collections before the modifications of the group A and group B dwellings.

A portable vacuum cleaner (Medivac™, airflow 45 l/s) with a modified prefilter was used to collect samples from three sites, the living-room floor, the mattress (in the main bedroom), and the bedroom floor. The living-room-floor samples were taken from a central area with no furniture and the bedroom-floor samples from a space of 1 m² beside the bed. All samples were taken from the same site on each occasion. One square metre of the floor or mattress was vacuumed for 1 min. After collection, the dust was sieved in a 425-µm sieve and weighed, and 0.1 g of this fine dust was frozen at -18°C until analysis.

Der p 1 assay. Der p 1 was determined by two-site monoclonal antibody ELISA (10). The dust samples were extracted with 1 ml of phosphate-buffered saline containing 1% bovine-serum albumin for 30 min at room temperature and assayed in duplicate at 1:20 to 1:640 dilution. A standard curve (from Der p 1 standard supplied with assay kit) was included on each microtitre plate. The plates were read on an Anthos ht II plate reader, and allergen levels were determined by the software package Delta Soft II. Allergen concentrations lying off the linear part of the curve were repeated at an appropriate dilution ranging from undiluted to 1:2560. The between-batch coefficient of variation was 10%. Results are expressed as µg per m².

Mite density estimation. After collection and sieving, 0.2–0.5 g of fine dust was mixed in a saturated solution of NaCl with 30% sucrose. After centrifuging at 2000 rpm, the supernatant was poured off and mixed with 5–10 ml of 0.1% crystal violet. This mixture was filtered through a Buchner funnel onto filter paper. Dead mites were counted and expressed as mites per gram of fine dust.

Critical equilibrium humidity. The CEH was calculated for the changing ambient temperature and humidity from a simple linear regression equation. The CEH values were based on the four measurements made by Arlian (7). From these equations, we calculated for each 30-min period whether the RH was above or below the CEH for the mean temperature during that period. These 30-min periods were then summed to provide the total number of continuous 24-h periods for which temperature and humidity were below CEH in each house. The number of periods and the length of periods below the CEH were calculated for all dwellings in each group.

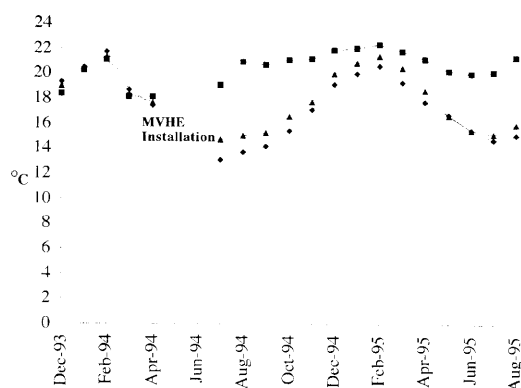


Fig. 1. Mean monthly ambient temperatures in group A ■, group B ▲, and group C ◆ dwellings measured in living room for study period. (Sensors were removed during MVHE and insulation refurbishment.)

These original CEH measurements were for *D. farinae* rather than *D. pteronyssinus* and were for ambient rather than microhabitat RH. The CEH for *D. pteronyssinus* is approximately 3% higher than for *D. farinae* (11).

Data analysis. All data were entered and separately checked against the original record. The distribution of Der p 1 and mite counts was found to be log normal. All mean values for allergen levels and mite counts are presented as geometric means. Allergen levels in different sites were compared by Student's *t*-test. Statistical significance was set at $P < 0.05$. Statistical analysis was done with PC SAS (SAS, Cary, NC, USA) software.

The study was approved by the Central Regional Health Authority ethics committee.

Results

The data collection commenced at the beginning of December 1993 and finished in August 1995. For the purposes of this report, the study period was divided into a summer and winter period before the intervention (summer or winter 1994) and a summer and winter period after the intervention (summer or winter 1995). Each of these periods was 6 months long except summer 1994, which comprised 3 summer months. Seasons are not as clearly defined in New Zealand as in temperate northern hemisphere locations. In total, 30 dwellings were enrolled in the study. Householders were included only if they were likely to stay for the study period; inevitably, a number left or moved during the study period. The following analysis is restricted to those dwellings with at least one collection in each summer and winter period. This includes 10 dwellings in group A, 10 in group B, and eight in group C. Two families in group C

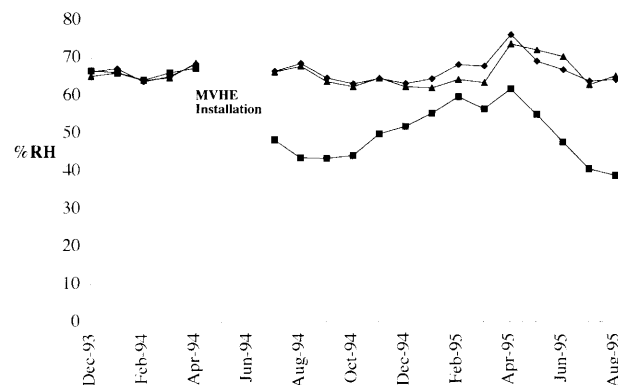


Fig. 2. Mean monthly ambient relative humidity (RH) in group A ■, group B ▲, and group C ◆ dwellings measured in living room for study period. (Sensors were removed during MVHE and insulation refurbishment.)

dwellings left the study for personal reasons after the first summer period and were not replaced.

Air-tightness measurements. Fifteen dwellings, eight in group A and seven in group B, were studied before and after the retrofit. Mean air-exchange per hour (ac/h) at a pressure of 50 Pa reduced from 18.5 to 9.0 ac/h. The major reduction came from improving window and door fittings. Further reduction was obtained by improving interior linings in cupboard areas where lining materials were often absent or inadequate.

Temperature and humidity

Figs. 1 and 2 show monthly averaged temperatures and humidity from thermohygrographic sensors placed in each living room for the three groups of dwellings. Measurements were taken before the intervention for 5 months, and then continuously for just over 1 year after the intervention. The sensors were removed during the period of refurbishment and retrofitting because of concern that they would be lost during this work. The sensors were removed to be read and then replaced. Occasionally, sensors were found not to be working, and from time to time they had been taken out of the living room by the occupants. These data were removed from the dataset. Temperature and humidity were measured constantly for an average of 478 days in each house.

For dwellings in groups B and C, the high year-round humidities were maintained at around 65% RH, rising during autumn to 75% RH and then returning to 65% RH during winter. Low winter temperatures were recorded in these dwellings with mean temperatures of 13–15°C in July and August. In the group A dwellings with the MVHE and increased space heating, a significant reduction in

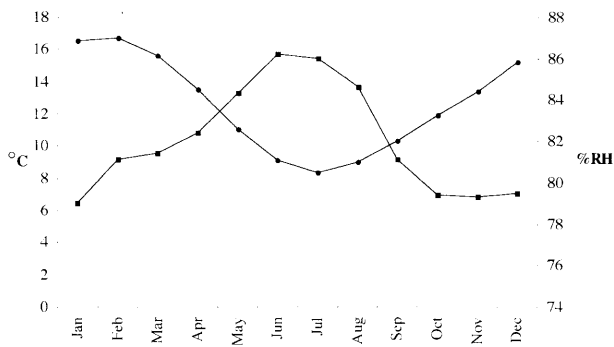


Fig. 3. Mean monthly outdoor temperature (●) and relative humidity (■) at 0900 (1961–95).

RH and rise in temperature was recorded, with mean ambient living-room RH decreasing for about 3 months to below 45%. However, humidity was maintained at a lower level for group A dwellings throughout the summer period, due to the mechanical ventilation. Both temperature and humidity rose during spring and summer, with temperature reaching a maximum in February and RH a maximum in April. The ventilation units were run continuously during the summer months, and heating was discontinued at the householder's discretion.

Seasonal variation

Fig. 3 shows mean monthly air temperature and RH recorded at 0900 for Wellington City (1961–95) (data supplied by National Institute of Water and Atmospheric Research – NIWA). These values show only a 6% variation in mean RH and an 8°C change in mean temperature throughout the year. Examination of allergen levels or mite counts (Figs. 4–6) in mattresses and on bedroom or living-room floors in group C dwellings showed no consistent seasonal trend.

Der p 1 ($\mu\text{g}/\text{m}^2$) and mite counts

Figs. 4–6 show Der p 1 at the three sites, mattresses, main bedroom floor, and living-room floor, for the summer and winter before the intervention and for the summer and winter period after the intervention. For group C, the mid-point of the groups A and B intervention dates was used as the intervention date. The data are shown as geometric mean values for Der p 1 per unit area. Concentrations of Der p 1 are not shown for reasons of brevity, but they were similar in pattern to those for the unit area measurements. As can be seen from these graphs, there was no significant change in Der p 1, after the intervention in group A dwellings, on the bedroom or living-room floors or on the mattress.

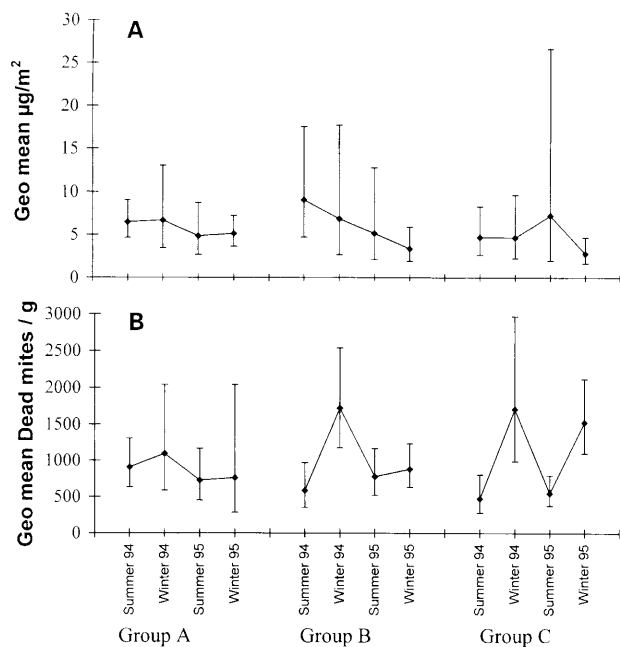


Fig. 4. A) Geometric mean Der p 1 per m^2 on bedroom floors for summer and winter period before installation of MVHE (summer and winter 1994) and after installation (summer and winter 1995) for groups A, B, and C dwellings. B) Geometric mean dead mites per gram fine dust on bedroom floors for summer and winter period before installation of MVHE (summer and winter 1994) and after installation (summer and winter 1995) for groups A, B, and C dwellings.

Fig. 4B shows dead mites per gram dust on the bedroom floor for the three groups of dwellings. Mites were counted only during the two winter periods for the living room and mattress, but this again showed no significant changes in group A dwellings (data not shown).

When allergen levels at the three sites or mite counts from the bedroom floor were compared before and after the intervention in group A dwellings, there were no statistically significant differences between them. Similarly, there were no significant differences between the three groups of dwellings at each time point.

Critical equilibrium humidity

Fig. 7 shows for each group of dwellings, the number of 24-h periods, 2–3-, 4–5-, 6–10-, and ≥ 11 -day periods that temperature and RH were below CEH. Thus, for all group A dwellings, there were 89 single-day periods below CEH and 34 periods of 11 days or more. This compared with very few sustained periods below CEH in group B or C dwellings. For group A dwellings, 39% of the total 24-h periods were below CEH compared with 2.1% for group B and 0.91% for group C. The total

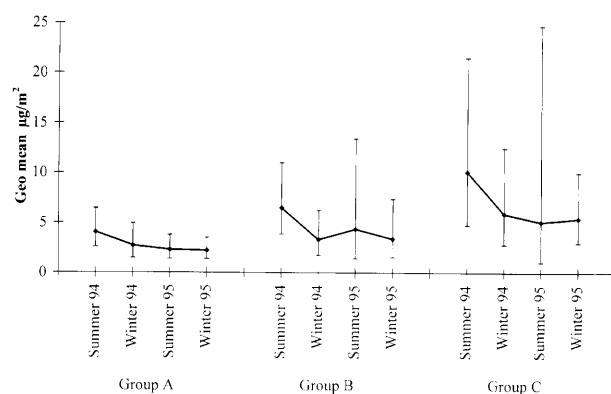


Fig. 5. Geometric mean Der p 1 per m² on living-room floors for summer and winter period before installation of MVHE (summer and winter 1994) and after installation (summer and winter 1995) for groups A, B, and C dwellings.

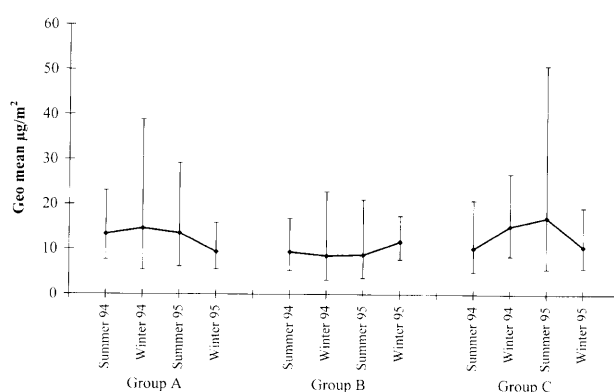


Fig. 6. Geometric mean Der p 1 per m² on mattresses for summer and winter period before installation of MVHE (summer and winter 1994) and after installation (summer and winter 1995) for groups A, B, and C dwellings.

number of 24-h periods for which temperature and humidity were recorded was 13389.

Discussion

The insulation and draught-proofing caused an average 50% reduction in air-exchange rates. The MVHE units were designed to operate with 7 ac/h; thus, these dwellings were just below those specifications (mean 9 ac/h). However, this improvement in insulation was considered sufficient to allow the ventilation units to operate effectively.

The recordings of temperature and humidity in these dwellings over 21 months reveal a high level of year-round humidity and of cold internal temperatures during winter in the control groups B and C dwellings. The increased space heating and mechanical ventilation in group A dwellings reduced indoor RH, but not sufficiently to have a

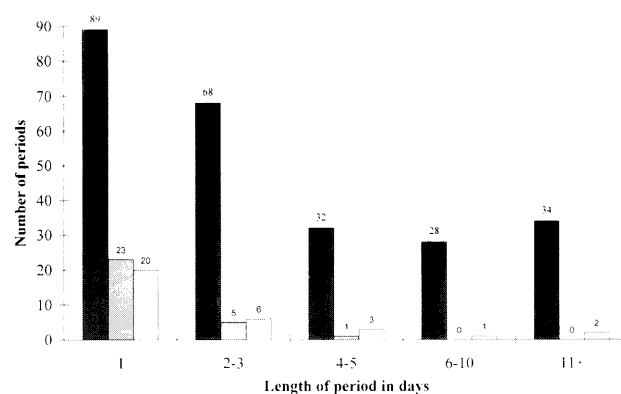


Fig. 7. Number of periods below critical equilibrium humidity in groups A, B, and C dwellings.

major impact on HDM. This was despite the fact that average monthly RH fell below 50% for a total of 7 months during the intervention. However, when the decrease in RH was expressed in relation to the percentage of time below CEH, this amounted to only one-third of the total time, and clearly was insufficient to influence mite growth. Humidity is likely to be higher and temperature lower in microhabitats such as carpets; thus, the time below CEH was likely to be even less in these environments.

No major seasonal variation was observed in HDM counts or allergen levels. However, this study was not designed to examine seasonal variation specifically, and further studies will examine this factor. Certainly, seasonal climate variation is not extreme in New Zealand, where there is little variation in RH, as can be seen from the mean outdoor RH and temperature values.

This pilot study has confirmed that in humid temperate climates such as New Zealand, where HDM allergen levels are very high, MVHE systems alone will not result in significant reductions in HDM populations (11), despite a significant reduction in mean ambient RH.

In this study, we observed reductions in mean ambient RH and increases in temperature during the winter after installation of MVHE units and additional heating. An extensive education campaign was undertaken before households were enrolled and during the study, including mailed information and personal visits. Households were encouraged to keep outside doors and windows shut during the winter and allow the mechanical ventilation to ventilate the house. Outside doors were fitted with automatic closing devices. However, on many occasions, visits to the dwellings revealed both doors and windows kept open. It is likely that this lowered the internal temperature

and increased RH, although it seems unlikely that this difference would have been sufficient to have altered the effect on HDM.

Previous studies aimed at reducing HDM by reducing humidity have been undertaken in Denmark, where reducing humidity was found to have a major effect on HDM levels (12), and, more recently, in the UK, where no reduction in allergen levels was observed (13). In Scandinavia, the cold and dry winter climate is ideal for reducing indoor humidity with heat exchange and ventilation, in New Zealand and the UK, the climate renders this type of intervention ineffective.

It would be of interest to know in more detail what reduction in ambient humidity would be required in the home to have a significant impact on mite feeding and breeding in their microhabitats. To date, these studies have been conducted only under controlled laboratory conditions, and the situation within the complex and rapidly changing domestic environment is likely to be very different. Ambient humidity would clearly need to be low enough to reduce and maintain RH in the microclimate below the CEH for prolonged periods to counteract the increased humidity in bedding from perspiration, and sufficient to counteract local factors such as cooler floors from suspended wooden flooring, which are used extensively in New Zealand. In laboratory studies, de Boer & Kuller have shown that 3 h of high humidity in 24 are sufficient to allow mites to take in enough water to survive and proliferate (14).

It is possible that changes would have been observed if we had been able to continue the study for a longer period. The effect of greater space heating and ventilation may have gradually dried out these dwellings and lowered humidity still further. However, it seems unlikely that this would have been sufficient to cause large-scale reductions in mite populations. A similar intervention with added dehumidification centrally might lower humidity sufficiently to have an impact on HDM, although the energy expended in dehumidification would make this form of control very expensive in a humid environment. One study of dehumidifiers in bedrooms in a humid climate has shown reductions in allergen concentrations, although the extent of the reduction in RH is not recorded (15).

We conclude from this pilot study that simple heat exchange and ventilation alone in New Zealand domestic dwellings are unlikely to have a significant impact on HDM and are not a worthwhile strategy for reducing HDM exposure. It is possible that intensive cleaning or other avoidance strategies might be enhanced by MVHE, particularly if built into new homes.

A more detailed knowledge of microclimates and their ability to support mites in the domestic environment is required in order to predict more precisely under exactly what internal temperature and humidity conditions this form of intervention will prove effective.

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