# Mechanical ventilation and high-efficiency vacuum cleaning: A combined strategy of mite and mite allergen reduction in the control of mite-sensitive asthma

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**Background: The relationship between exposure to house dust mite (HDM) allergens and prevalence of sensitization to these allergens in patients with asthma has been confirmed in many studies. Mite population growth is regulated by humidity. Reducing humidity and removing allergen by efficient vacuuming should control mite allergen and reduce symptoms.**
**Objective: We sought to investigate the effect of mechanical ventilation and high-efficiency vacuuming on HDM numbers and Der p 1 concentrations in the homes of mite-sensitive asthmatic subjects and to evaluate the effect of any reductions on symptoms.**
**Methods: The homes of 40 HDM-sensitive asthmatic subjects were randomized to receive (1) mechanical ventilation and a high-efficiency vacuum cleaner (HEVC); (2) mechanical ventilation alone; (3) an HEVC alone; and (4) no intervention. Homes and patients were monitored for 12 months. Change in absolute humidity, mite numbers, Der p 1 concentrations, lung function, bronchial hyperresponsiveness, and symptom scores were analyzed.**
**Results: Homes with mechanical ventilation achieved significantly lower humidity levels than those without ($P < .001$), with an associated reduction of mite numbers ($P < .05$) and Der p 1 concentrations ($P < .001$ [in nanograms per gram], $P = .006$ [in milligrams per square meter]) in bedroom carpets and some other mite sources in the ventilated areas of the homes. The addition of a vacuum cleaner enhanced this effect. There was a trend for an improvement in histamine $PC_{20}$ ($P = .085$) in the patients whose homes were ventilated.**
**Conclusion: The use of a mechanical ventilation system in suitable homes resulted in some reduction in numbers of HDM and Der p 1 concentrations. The addition of an HEVC slightly enhanced the effect but not sufficiently to see an improvement in symptoms. (J Allergy Clin Immunol 2000;75-82.)**

***Key words:*** *Humidity, mechanical ventilation, asthma, allergy, house dust mites, Der p 1*

Sensitization to house dust mites (HDMs) is a major independent risk factor for asthma.[1] In the United Kingdom 50% to 80% of patients with asthma demonstrate skin test reactivity, RAST reactivity, or both to mites.[2-4] The most common species of mite found in homes in the United Kingdom is *Dermatophagoides pteronyssinus*, which grows optimally at a relative humidity (RH) of 75% to 80% at 25°C to 30°C.[5] The critical humidity for mite survival has been stated as 7 g/kg absolute humidity (AH), which is equivalent to about 40% to 45% RH.[6] It is well known that when asthmatic patients with HDM sensitivity are sent to institutions at high altitudes, where the humidity is low and therefore the mite numbers are reduced, they show highly significant improvements in asthma symptoms, bronchial hyperresponsiveness, and need for medication.[7] Therefore installing systems in homes to reduce indoor humidity has been suggested as a method of controlling mite numbers. Results from Scandinavia[8,9] suggest that installing whole-house mechanical ventilation with heat recovery (MVHR) will not only cause a significant reduction in dust mite populations but also bring about a clinically relevant reduction in asthma symptoms and reduced need for medication. However, there are doubts about the likely effect of MVHR on mites in UK homes; in fact one study from the Northwest of England[10] failed to demonstrate any reduction in mite numbers or mite allergen concentrations over a period of 12 months in homes in which MVHR systems had been installed. It must be stated that in these homes the mean RH was never reduced below 50% and for the majority of the time was above 60%, and therefore the lack of success was not surprising, but this nevertheless raises the question of whether the critical humidity can be achieved in the United Kingdom for a period of time long enough to affect the mite populations.

If the intervention affects only the mites and not the allergen, then any resultant reduction in allergen concentration will take many months to accomplish. We there-

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*Abbreviations used*
AH: Absolute humidity
EPX: Eosinophil protein X
HDM: House dust mite
HEVC: High-efficiency vacuum cleaner
MVHR: Mechanical ventilation with heat recovery
RH: Relative humidity

fore investigated the combined effect of MVHR with use of a high-efficiency vacuum cleaner (HEVC) in an attempt to reduce mite numbers and to more rapidly affect the allergen reservoirs and thereby achieve clinical improvement in HDM-sensitive asthmatic subjects.

## METHODS

Subjects were selected from patients attending either the pediatric or adult asthma clinics at Southampton University Trust Hospitals. The clinical inclusion criteria were as follows: ability to perform peak flow measurements, flow-volume loop, and histamine bronchial challenge; a skin prick test wheal response of at least 5 mm in diameter for *D pteronyssinus*; moderate-to-severe asthma requiring prophylactic medications; and no pets in the home if skin tests identified a sensitivity to the pets in question. One hundred fifty-eight patients who fulfilled these criteria were then asked to complete a housing questionnaire to assess the suitability of their homes for installation of an MVHR unit. These questionnaires were assessed by Building Research Establishment and Electricity Association Technology Group, and 40 households were selected for inclusion in the study. Inclusion criteria that were considered included: solid floor, wet plastered walls (as opposed to plasterboard on dabs), no open fireplaces, no extractor fans, draft-proofed or double-glazed windows, and cavity-filled walls. Ideally, definite exclusion criteria would have been as follows: old drafty homes, pre-existing ventilation system, open fires, more than one chimney, open-flue boilers, structural dampness, severe condensation, or fungal growth. Because of the limited number of homes available from the clinical inclusion criteria, the final criteria for the home to be included in the study were as follows: an uninhabited roof space above all rooms, electric or balanced flue gas boiler heating systems and no bottled gas or liquid fuel as the main or supplementary heating fuel, no existing ventilation system, and no solid fuel fires or open chimneys.

Each home was visited to confirm the suitability of the dwelling. In 6 homes, where it was clear that a MVHR system could not be installed because of, for example, duct runs being too complicated or the house having a flat roof, patients were designated to be assigned to a group without MVHR. Four homes had unreported open fires, and residents of these homes were also placed in the non-MVHR groups. Baseline housing characteristics (eg, type of house, double glazing, and central heating) were not different between the groups.

The 40 patients finally selected consisted of 27 children (age range, 4-16 years; mean age, 9.7 years; 17 boys and 10 girls) and 13 adults (age range, 20-67 years; mean age, 40.1 years; 9 men and 4 women). Twenty-five of the children were receiving inhaled steroids, and 2 were receiving sodium cromolyn. All the adults were receiving inhaled steroids.

Ethical approval for the study was obtained from The Southampton University Hospitals NHS Trust Joint Ethics Committee.

### Temperature and humidity recording

Temperature and humidity data were collected from the patients' bedrooms between March and May 1994 by using an Amcon Smart logger mounted in a perforated aluminum case, which was placed on the carpet and made recordings at 10-minute intervals, and this information was used to place the homes into 4 humidity bands: greater than 7.9 g/kg, 7 g/kg to 7.9 g/kg, 6.4 g/kg to 6.9 g/kg, and less than 6.4 g/kg. The humidity bands were used to stratify for allocating the homes to the 4 intervention groups to ensure the baseline humidity was comparable before intervention.

The 4 groups were as follows: (1) MVHR plus HEVC, (2) MVHR only, (3) HEVC only, and (4) no intervention (control).

We attempted to randomize all 40 homes (taking into account the stratification for humidity) to achieve 10 homes in each group; however, because of the 10 homes that were eventually considered to be unsuitable for the installation of MVHR, 30 homes were randomized between all 4 groups, and 10 homes were only randomized between groups 3 and 4. The final groupings resulted in group 1 containing 5 adults, group 2 containing 4 adults, group 3 containing 2 adults, and group 4 containing 2 adults. The baseline temperature and humidity readings were not significantly different among the 4 groups.

The loggers remained in place throughout the study, with data being retrieved at every home visit. Two loggers were used to record outdoor conditions. The loggers were mounted on the north side of 2 dwellings within the survey area protected from rain and were downloaded at the same time intervals as the internal loggers.

### The ventilation system

To provide the benefits of ventilation but minimize disruption, an upstairs system was chosen (ADM Indux, Bradford, UK). The MVHR units consisted of a heat exchanger and 2 fans with a manually operated boost switch for the bathroom and an EU4 filter on the supply. This was a pleated filter, which had a greater than 90% efficiency of trapping particles of greater than 5 μm and was aimed at trapping pollen grains and larger inhalable particulates. The heat exchanger and fans were mounted in the loft space supplying tempered fresh air to bedrooms and extracting moist air from the bathroom. An additional extract point was fitted on the landing to intercept moist air moving up the stairwell. The MVHR units were purchased by EA Technology and installed by ADM Indux. It was aimed to achieve between 0.4 and 0.5 air changes per hour in the upstairs area. A separate extractor fan (Indux/Vent-Axia) was fitted in the kitchen by Dimplex (Southampton, UK).

### The vacuum cleaner

The vacuum cleaner was a cylinder model and contained an S-class filter (Miele, Abingdon, UK), which filtered particles down to 0.3 μm with an efficiency of 99.985%. Each vacuum cleaner was fitted with an internal timer to enable the number of hours the cleaner was in use to be monitored during the study. The householders were instructed to use the vacuum cleaner every day in the patients' bedrooms and the living room and at least once per week in the rest of the house.

### Clinical assessment

The 40 patients completed daily symptom diary cards and twice daily peak expiratory flow rate monitoring with a Wright peak flowmeter during October 1994, before the start of the study, and for 1 month before each visit to the home to collect samples. Symptoms were scored as follows: wheeze last night (0-3), cough last night (0-3), wheeze today (0-3), and activity today (0-3). Consumption of inhaled or oral bronchodilators, corticosteroids, sodium cromolyn, and other medications was also recorded. Mean morning and evening peak expiratory flow rates, symptom scores, and medication use were calculated for each period for each subject.

### Lung function

Lung function tests were performed before the start of the study and at 1, 2, 3, 6, 9, and 12 months into the study by using a Micro-

lab portable spirometer. When the patients had optimized their technique, the best of 3 flow-volume loops was taken for calculation of baseline $FEV_1$ as a percentage of predicted value for age-, height-, and sex-matched control subjects. The tests were performed after withholding all $\beta_2$-agonist medication for 12 hours. Reference values for lung function tests were taken from the data of Polgar and Promadhat[11] for children and Quanjer[12] for adults.

At the start of the study and at 12 months, the patients performed an inhalation provocation test with histamine acid phosphate by using a standard modification of Cockcroft's method. A 2-minute tidal volume breathing technique was used for inhalation followed by spirometry at 0.5, 1.5, and 3 minutes. Calibrated Intersurgical Cirrus nebulizers (Berkshire, UK) were used and filled with 4 mL of histamine solution in doubling dilutions. $PC_{20}$ values were calculated and log transformed.

Symptom scores and lung function measurements were not significantly different between groups at the start of the study.

## Home visits

Visits were made to each home to collect dust samples, download logger information, perform lung function assessments, and collect diary cards during the month before the activation of the interventions and at 1, 2, 3, 6, 9, and 12 months after activating the systems. The householders were instructed to switch on their MVHR systems and begin using their vacuum cleaners on November 9, 1994.

## Dust sampling

Dust samples were collected in 2 ways: (1) for mite counting and (2) for allergen assessment. Both methods used a Goblin R100 vacuum cleaner. For mite counting, the cleaner was fitted with a modified Cutler sampling head, and dust was collected onto a Kleenex tissue filter (code no. 4472, Kimberley-Clark Ltd). For allergen assessment, a standard ALK dust collecting device was used (ALK, Laboratories, Denmark). In each home there were 4 sampling locations: living room carpet, soft furnishings (chair and sofa seats) in the living room, bedroom carpet in the patient's bedroom, and the patient's mattress. Two adjacent areas of 1 $m^2$ were marked out on the living room and bedroom carpets, and 2 adjacent areas of $35 \times 35$ cm were marked out on the soft furnishings and mattress. At each of the 4 locations, one area was sampled with the Cutler head, and the other was sampled with the ALK head. The 1-$m^2$ areas were sampled for 3 minutes, and the $35 \times 35$–cm areas were sampled for 1 minute. The samples for mite counting were sent to The Scottish Agricultural Science Agency for analysis.[13] The samples for allergen assay were analyzed as detailed below.

## Dust Der p 1 analysis

For antigen determination, dust samples were extracted in PBS containing 0.5% Tween-20 and 0.2% BSA overnight (1:5 wt/vol). Samples were filtered (Anotop 10 plus, 0.2F; Whatman, Maidstone, UK) and analyzed by using an ELISA system for Der p 1 performed according to the manufacturer's instructions (ALK).

The mite numbers and Der p 1 concentrations were not significantly different among groups at the start of the study.

## Urine analyses

Morning urine samples were collected from each patient at baseline, 6 months, and 12 months of the study as spot samples and immediately frozen at –80°C.

Urinary eosinophil protein X (EPX) was measured by using a specific competitive RIA according to the manufacturer's instructions (Pharmacia Diagnostics, Uppsala, Sweden). The sensitivity of the assay was less than 3 μg/L. Immediately before assessment of EPX, the urine was diluted 5 times in standard diluent provided with the assay.

Urinary cotinine was kindly analyzed by Drs T. and J. Merrett at The Allergy Analysis Centre (Gwynedd, Wales, UK).

The extent of dilution of urine in the kidneys was determined by measuring the concentration of creatinine in urine by using the Synchron CX Systems creatinine reagent kit (Beckman, High Wycombe, UK). The EPX and cotinine results are expressed as micrograms of EPX and nanograms of cotinine per millimole of creatinine.

## Statistical analysis

Data were analyzed by using the summary measures approach suggested by Matthews et al.[14] Analysis of covariance was used to test for the difference between intervention groups at 12 months, with the reading at the start of the intervention treated as a covariate. Adjusted geometric means were used because they provide better estimates of the true treatment effects compared with the uncorrected treatment geometric means.[15] The adjustment takes into account the different starting values of each variable at month 0. The association between mite numbers and allergen levels was calculated by using the Pearson correlation coefficient on log-transformed data. The statistical analysis was performed by using SPSS for Windows version 7.0 (SPSS Inc, Chicago, Ill). Statistical significance was declared at a $P$ value of less than .05.

# RESULTS

## Temperature and humidity

The study period was characterized by a relatively mild winter, with the coldest week having a mean temperature of 2.8°C, and an unusually warm summer, with the warmest week having a mean temperature of 25°C. There was no significant difference in bedroom temperature between the groups at the start of the study. Both MVHR and control groups showed a similar behavior over the study period. Above 15°C outdoor temperature, the bedroom temperature rose in line with increasing outdoor temperature, with a slope of 0.67°C per degree Celsius. Below 15°C, bedroom temperature fell only slowly with decreasing outdoor temperature with a slope of 0.28°C per degree Celsius. Analysis of covariance showed a significant difference between the MVHR and non-MVHR groups ($P < .001$ below 15°C and $P < .05$ above 15°C), with the MVHR groups being warmer by about 0.5°C than the non-MVHR groups.

All humidity analyses were performed by using AH values rather than RH values because this permitted a direct comparison between indoor and outdoor conditions. Fig 1 shows a sequential plot for AH throughout the study period. Throughout the winter, groups 1 and 2, but not groups 3 and 4, achieved values of less than 7 g/kg for sustained periods of time. Analysis of covariance showed a highly significant difference ($P < .001$) between the MVHR and non-MVHR groups. The houses with MVHR had a lower bedroom humidity than the non-MVHR houses over the whole test period, both winter and summer. The difference was greater in winter, being 0.73 g/kg at an outdoor humidity of 5 g/kg and 0.38 at an outdoor humidity of 10 g/kg. A full description of the ventilation equipment and humidity analysis is given by Stephen et al.[16]

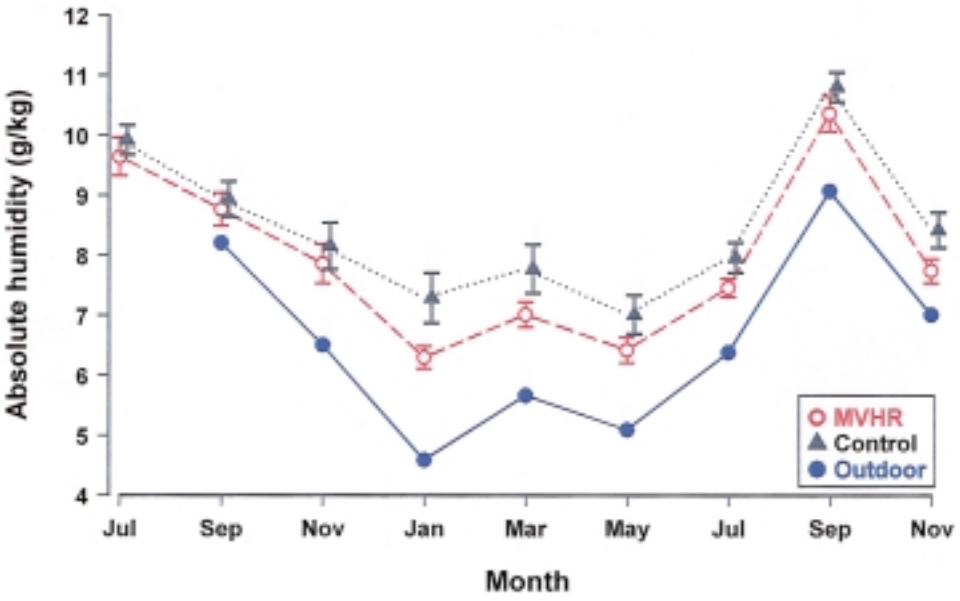


**FIG 1.** Graph showing group AH averages plotted sequentially every 8 weeks over the whole measurement period. Ninety-five percent confidence intervals are shown for the indoor measurements but not for the outdoor measurements because these were only monitored at 2 locations in the study area. There was a significant difference between the MVHR and non-MVHR groups ($P < .001$).

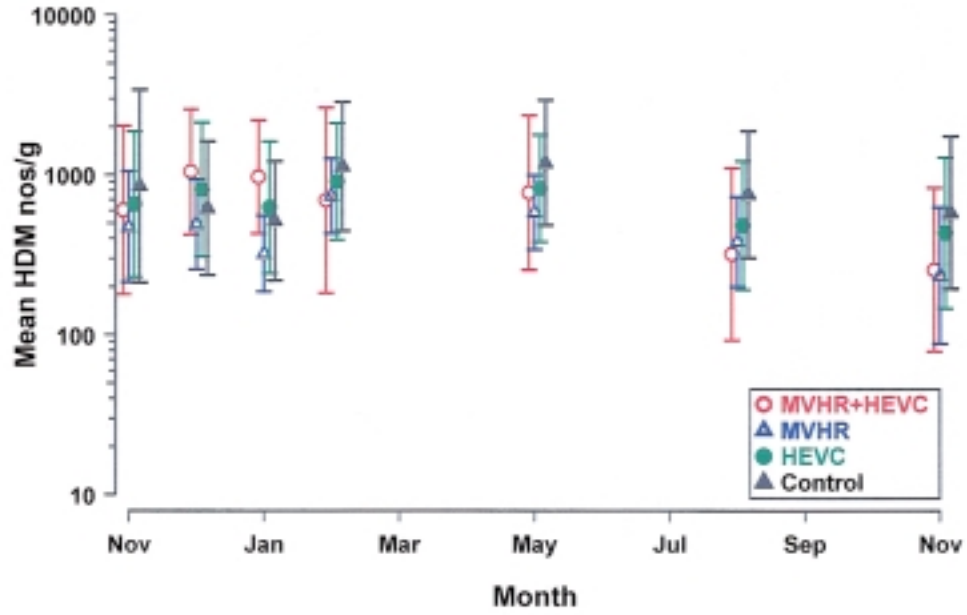


**FIG 2.** Log number of HDMs per gram of dust in the bedroom carpet in the 4 groups over the 12-month intervention period. Ninety-five percent confidence intervals are shown.

## HDM counts

The numbers of mites in the bedroom carpet were significantly correlated with AH at the start and end of the intervention period ($r = 0.4$, $P = .02$ and $r = 0.4$, $P = .01$, respectively). In the mattress, living room carpet, and sofa the numbers of HDMs per gram of dust did not correlate with the AH either at baseline or at 12 months, although at 12 months there was a trend for the numbers in the mattress to correlate with AH ($r = 0.3$, $P = .08$). This is most likely reflecting the position of the logger recording the humidity, which was placed on the floor in the bedroom. The change in mite numbers in the bedroom carpet in the 4 groups over the 12-month intervention period is shown in Fig 2. There were no significant changes in mite numbers when the 4 groups were analyzed individually; however, analysis of covariance showed the fall in mite numbers per gram of dust to be just significant in the homes with MVHR units ($P < .05$)

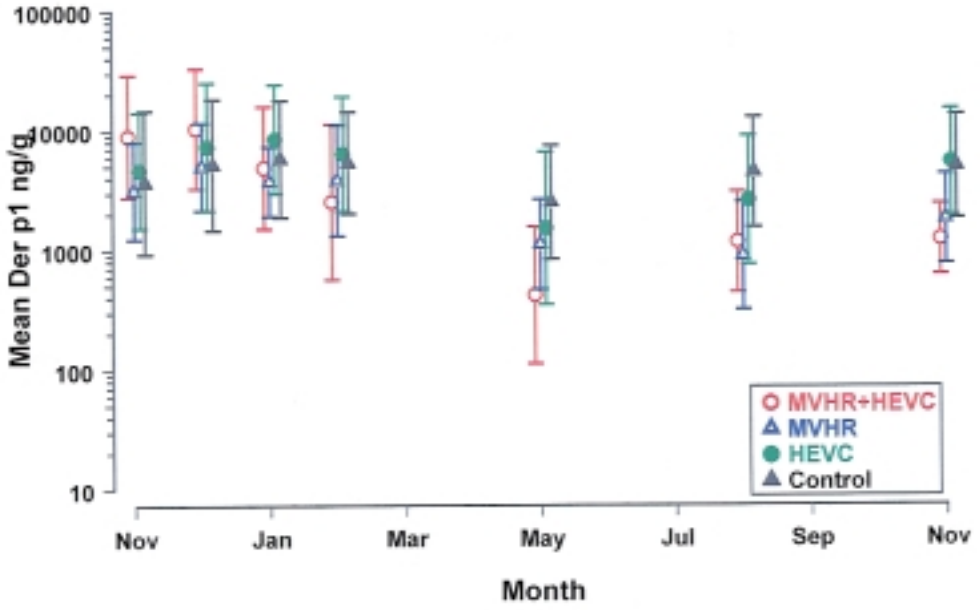


**FIG 3.** Log Der p 1 (in nanograms per gram of dust) in the bedroom carpet in the 4 groups over the 12-month intervention period. Ninety-five percent confidence intervals are shown.

**TABLE I.** Adjusted geometric means for Der p 1 after 12 months of intervention showing the concentrations in nanograms per gram and nanograms per square meter for each of the 4 groups

| | Bedroom carpet | | Mattress | | Living room carpet | | Living room sofa | |
|---|---|---|---|---|---|---|---|---|
| Intervention | ng/g | ng/m² | ng/g | ng/m² | ng/g | ng/m² | ng/g | ng/m² |
| MVHR + HEVC | 914.5 | 275.7 | 5343.2 | 1206.1 | 3829.1 | 1024.5 | 1445.1 | 572.8 |
| MVHR | 2046.4 | 695.2 | 4017.9 | 1839.5 | 8334.9 | 2545.7 | 1079.7 | 884.1 |
| HEVC | 5226.4 | 958.1 | 6998.4 | 3703.4 | 3370.5 | 772.9 | 8976.4 | 3706.8 |
| None | 5818.4 | 2103.8 | 8213.0 | 4914.7 | 6516.3 | 1692.8 | 4597.3 | 4637.7 |

but not significant in the homes with HEVCs. There were no significant reductions in mite numbers in the mattress, living room carpet, or sofa.

## Der p 1 concentrations

The change in Der p 1 concentrations in the bedroom carpet in nanograms per gram of dust over the 12-month intervention period for the 4 groups is shown in Fig 3. There were no significant changes in Der p 1 concentrations over the 12-month period when each group was analyzed individually; however, when all the homes with MVHR and all those with HEVCs were combined to make 2 groups, some interesting changes were seen. Interactions between MVHR and HEVCs were investigated, but none were found. Table I shows the adjusted geometric means of Der p 1 per square meter and Der p 1 per gram of dust in all sampling sites after 12 months. Although significant differences were not seen, there is a clear trend for MVHR units plus HEVCs to be more effective than MVHR alone, which in turn is more effective than use of an HEVC alone. Table II shows the analysis of covariance for the effect of MVHR and use of an HEVC in the different locations. A significant effect was observed for MVHR on Der p 1 per square meter in the bedroom carpet, mattress, and sofa ($P = .006$, $P = .03$, and $P = .03$, respectively) but not for the living room carpet. MVHR also showed a significant effect on Der p 1 per gram of dust in the bedroom carpet and sofa ($P < .001$ and $P = .04$, respectively) but not the mattress or living room carpet. Use of an HEVC had a significant effect on Der p 1 per square meter in the bedroom carpet ($P = .04$) but not in any other locations.

## Clinical symptoms

Fig 4 shows the effect of MVHR, use of an HEVC, or both on histamine $PC_{20}$ after 12 months of intervention. There was a trend for the patients with MVHR to have higher $PC_{20}$ values than those without MVHR, but it did not reach significance ($P = .085$). Some patients were not considered to have $FEV_1$ results compatible with performing a histamine challenge at baseline or after 12 months because their $FEV_1$ was below 80% predicted value. The number of valid cases was only 27, and therefore a Fisher exact test was carried out to assess whether the challenge status of patients improved, remained the same, or decreased during the study period. This allowed

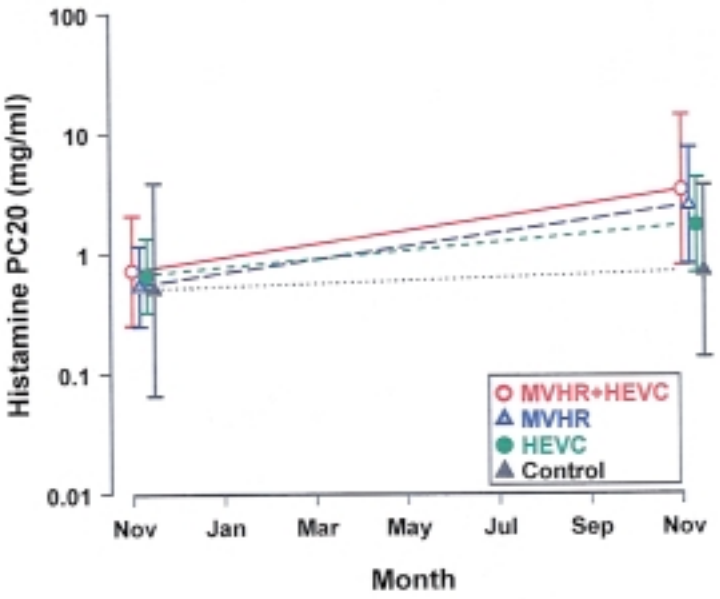


**FIG 4.** Change in histamine $PC_{20}$ between baseline and 12 months in the 4 groups. Ninety-five percent confidence intervals are shown.

**TABLE II.** The effect of MVHR and use of an HEVC in different locations

| Sample site | Intervention | Adjusted geometric mean (ng/m²) | Ratio of adjusted means from analysis of covariance | 95% confidence intervals for ratio of means |
|---|---|---|---|---|
| Bedroom carpet | | | | |
| MVHR | Yes | 437.8 | | |
| | No | 1419.7 | 3.24 | 1.43-7.36 |
| HEVC | Yes | 514.0 | | |
| | No | 1209.2 | 2.35 | 1.02-5.41 |
| Mattress | | | | |
| MVHR | Yes | 1489.4 | | |
| | No | 4265.8 | 2.86 | 1.01-7.40 |
| HEVC | Yes | 2113.5 | | |
| | No | 3006.8 | 1.42 | 0.54-3.73 |
| Living room carpet | | | | |
| MVHR | Yes | 1615.1 | | |
| | No | 1143.9 | 0.70 | 0.26-1.91 |
| HEVC | Yes | 889.8 | | |
| | No | 2075.9 | 2.33 | 0.99-6.30 |
| Sofa | | | | |
| MVHR | Yes | 711.5 | | |
| | No | 4145.7 | 5.82 | 1.02-28.71 |
| HEVC | Yes | 1457.1 | | |
| | No | 2024.9 | 1.38 | 0.28-6.86 |

Shown are adjusted geometric means for Der p 1 levels after 12 months by an analysis of covariance adjusting for baseline measurements of Der p 1. The ratio is that by which the intervention reduced the Der p 1 concentration compared with the concentration with no intervention.

a further 6 patients to be included in the analysis; however, although a trend was indicated, there was no significant difference ($P$ = .08) between the MVHR and non-MVHR groups. There was no such trend for the HEVC versus the non-HEVC groups.

There were no demonstrable differences in lung function over the 12-month period in any group. Symptom scores were assessed by calculating the area under the curve for months 1 through 12. Although the geometric means for MVHR and non-MVHR groups showed a difference for episodes of "asthma last night," this was not significant ($P$ = 0.4); however, not all the subjects in the study completed diary cards. Peak flow readings and other symptoms showed no significant differences between baseline and end-of-study measurements.

### EPX

No significant differences were seen in EPX-creatinine ratios at the end of the study period either between groups or within groups compared with baseline.

### Cotinine

There were no significant differences in the cotinine/creatinine ratios between groups at either baseline or the end of the study, indicating that tobacco smoke exposure did not act as a confounder in this study.

## DISCUSSION

Because MVHR has the potential to affect all the mite sources in the areas in which it is installed, it is a very attractive intervention, even more so because it does not require large amounts of patient time to put it into practice. It can be hypothesized that the most successful long-term intervention measures are likely to be those that are the least time consuming for the household. Nevertheless, MVHR does not affect allergen directly (other than perhaps removing small airborne quantities), and until the mite populations are significantly reduced, there is unlikely to be much change in allergen concentrations and, as a consequence, in symptoms. Therefore we investigated the effect of MVHR with the additional intervention of an HEVC to reduce the allergen more quickly and thereby potentially increase the time during the study period when exposure would be reduced and any change in symptoms could be assessed. Also because of the much more humid climate experienced in the United Kingdom compared with that at high altitude or in Scandinavian winters, it was believed that a further allergen reduction measure may be necessary.

The reduction in humidity was much larger than that reported in a previous study of mechanical ventilation.[10] However, the 2 studies were not directly comparable because of Fletcher et al[10] reporting their results as RH rather than AH and the fact that their temperature and humidity data were not continuously logged throughout the test period but related to 2 selected weeks before and after the winter period. As expected, in the current study the MVHR was most effective during the winter period, with 15 of the MVHR homes having a mean bedroom humidity of less than 7 g/kg compared with 3 of the non-MVHR homes, but nevertheless, groups 1 and 2 maintained humidity levels that were lower than those of groups 3 and 4 throughout the intervention period. The type of housing did not appear to affect these findings, although this is likely to be because of the selection criteria for entry into the study. It should be noted that these systems did not include a dehumidification step. Our own studies (article in preparation) have shown portable dehumidifiers to be effective in significantly reducing Der p 1 levels, and therefore its inclusion in the ventilation systems could be beneficial.

The reduction of mite numbers in the bedroom carpet in homes with MVHR was encouraging but only just significant. This reduction has previously only been reported in countries with cold dry climates[8,9,17] and has been suggested to be unattainable in the warmer, more humid climate of the United Kingdom.[10] The careful selection and group allocation of the homes in this study was probably an important factor in achieving even the small reduction because it would be much more difficult to reduce the humidity in very leaky houses. The vacuum cleaners were added to expedite the removal of allergen; few live mites are removed by vacuuming, and therefore the lack of reduction in mite numbers because of the use of the HEVC was not unexpected.

At baseline, the mite numbers correlated well with allergen concentration in all samples. At 12 months there appeared to be some disturbance of this relationship, demonstrating that the interventions changed the living conditions for the mites and thus altered their behavior. Certainly in the mechanically ventilated groups the mites in the bedroom carpet appeared to produce less Der p 1 at 12 months than they did at baseline, indicating that not only were there fewer mites, but they also produced less allergen. This would be consistent with the finding that lower humidity is associated with reduced feeding, and therefore although all the mites were not killed, their allergen production was curtailed.[18] This change in distribution was not apparent with HEVCs, which might have been expected to reduce allergen to a greater extent than mite numbers.

The geometric means for both Der p 1 per gram and Der p 1 per square meter in the bedroom carpet at the end of the study were highly suggestive of an additive effect of the 2 techniques. Group 1 had lower Der p 1 concentrations than either groups 2 and 3, which were, in turn, lower than the concentrations of group 4. However, it was not possible to distinguish between these groups statistically. A similar effect for Der p 1 per square meter was seen in the mattress, which was also exposed to both interventions. The 2 sources in the living room, which were more distant from the MVHR systems, were less consistent in their order of magnitude; however, the sofa, which did show a significant reduction in Der p 1 concentration in the MVHR groups compared with the non-MVHR groups, gave an indication of a similar effect for Der p 1 per square meter. Therefore although the MVHR had the major effect on reducing levels of Der p 1 in the bedroom, the use of an HEVC also had some effect. The use of both intervention methods produced the best reduction in Der p 1 levels.

It was disappointing that the reductions in allergen concentrations (most notable in the bedroom carpet) were not translated into a significant clinical improvement. However, the power of this study was low to detect clinical changes. This was a weakness dictated by the cost of the MVHR, which itself could be translated into a practical difficulty in real-life situations. Indeed, 75 patients with MVHR compared with 75 patients without MVHR would be required to detect a 20% improvement in asthma symptoms at a power of 80%. The histamine $PC_{20}$ values showed a similar order effect to the Der p 1 concentrations across the 4 groups, but because of only 4

patients in the no intervention group being able to perform the challenge at 12 months, no statistical significance was observed.

Since this study was performed, smaller and cheaper systems have been introduced, which can be installed individually in various rooms within a house. This might improve the possibility that a larger study could be undertaken.

The lack of any significant differences in EPX concentrations in any of the groups suggests that there was no change in eosinophil activation during the study. The reason for including these measurements was because high-altitude studies have demonstrated significant changes related to clinical improvements.[19] However, because eosinophil activation proteins have been shown to correlate with lung function,[20] this result was consistent with the inability to demonstrate any change in airway function.

Therefore in conclusion, the installation of an MVHR system in a suitable home resulted in significant reductions in humidity, leading to some associated reductions in HDM and Der p 1 concentrations in the ventilated areas of the home. Addition of an HEVC increased the effect of the MVHR; however, the reductions were not sufficient to show a significant change in bronchial hyperresponsiveness. The likelihood of being able to show a change in clinical symptoms could be improved by performing a larger study and ventilating more areas of the houses, possibly with the inclusion of active dehumidification within the systems.

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