

Original article

Effect of improved home ventilation on asthma control and house dust mite allergen levels

Background: The warm, humid environment in modern homes favours the dust mite population, but the effect of improved home ventilation on asthma control has not been established. We tested the hypothesis that a domestic mechanical heat recovery ventilation system (MHRV), in addition to allergen avoidance measures, can improve asthma control by attenuating re-colonization rates.

Methods: We conducted a randomized double-blind placebo-controlled parallel group trial of the installation of MHRV activated in half the homes of 120 adults with asthma, allergic to *Dermatophagoides pteronyssinus*. All homes had carpets steam cleaned and new bedding and mattress covers at baseline. The primary outcome was morning peak expiratory flow (PEF) at 12 months.

Results: At 12 months, the primary end-point; change in mean morning PEF as compared with baseline, did not differ between the MHRV group and the control group (mean difference 13.5 l/min, 95% CI: -2.6 to 29.8, $P = 0.10$).

However, a secondary end-point; evening mean PEF, was significantly improved in the MHRV group (mean difference 24.5 l/min, 95% CI: 8.9–40.1, $P = 0.002$). Indoor relative humidity was reduced in MHRV homes, but there was no difference between the groups in Der p 1 levels, compared with baseline.

Conclusions: The addition of MHRV to house dust mite eradication strategies did not achieve a reduction in mite allergen levels, but did improve evening PEF.

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The prevalence of asthma in the western world has increased over the last generation (1), in parallel with a warmer indoor microclimate (2). Increased insulation, double glazing and modern building construction have improved standards of heating and energy efficiency in homes, but with reduced ventilation (3). A warm, humid indoor environment favours the growth of the

house dust mite population (4). Sensitivity to the house dust mite is the most common allergy associated with asthma in the UK (5).

Studies of occupational asthma (6) and altitude (7) infer that the environment may directly affect symptoms of asthma. Accordingly, allergen avoidance has been advocated as an important aspect of asthma manage-

ment, yet the evidence for its efficacy is limited (8). Large studies of conventional measures to eradicate dust mites, such as mite-impermeable mattress covers, have not shown a benefit for asthma symptoms (9). However, Morgan et al. (10) found significant improvement in asthma when a number of allergens were targeted in combination with an educational intervention and smoking cessation advice. This study was not blinded and some positive results were subjective, nevertheless it addressed the concept of environmental control of allergens that has repeatedly been emphasized in statements from the Global Initiative for Asthma and the National Asthma Education and Prevention Program. Recent meta-analyses recommended that repeating common interventions is unlikely to be informative (9); however, more comprehensive interventional studies on house dust mite control are required (11), and more specifically, there is a need for studying the health benefits of dehumidification by a double-blind, randomized, controlled trial with adequate sample size measuring clinical outcomes in patients with asthma (12).

As house dust mites thrive in moist conditions, an additional eradication strategy would be to reduce indoor air humidity by improving ventilation. Mechanical heat recovery ventilation (MHRV) is a method of active ventilation using both an extract and a supply fan. Outdoor air is supplied at ambient humidity into the living room and bedroom, and extracted from the kitchen and bathroom. There is evidence that mechanical ventilation reduces indoor air humidity and the house dust mite allergen burden (13). This randomized controlled study in 40 homes of HDM-sensitive asthma subjects, with mechanical ventilation, achieved significantly lower humidity levels and Der p 1 allergen (means: 2.05 vs 5.82 $\mu\text{g/g}$ dust, $P < 0.001$), with a trend for improved histamine (PC) (20) ($P = 0.085$) but no change in symptoms or lung function; therefore the clinical effects of mechanical ventilation on asthma remain unproven. We tested the hypothesis that domestic MHRV, in addition to allergen avoidance measures, can improve asthma control of subjects sensitive to house dust mite allergen, by attenuating re-colonization rates.

Methods

Participants

Participants 16–60 years of age were eligible if they had asthma for more than 1 year, were on regular inhaled corticosteroids and had daily symptoms. Participants were recruited from general practice (GP) and hospital clinics in Lanarkshire, Scotland, UK. Variable airflow obstruction of $\geq 12\%$ on spirometry (14) or $\geq 15\%$ on peak expiratory flow (PEF) readings (15) or a symptom score of ≥ 0.86 on the Asthma Control Questionnaire (ACQ) (16, 17) was required for inclusion. Participants had a minimum forced expiratory volume in 1 s (FEV_1) of $> 50\%$ predicted at baseline and had not had an exacerbation in the previous month. Spirometric measurements were recorded using an electronic

spirometer (Vitalograph, Buckingham, UK), before and after inhaled salbutamol (400 μg) (18). Peak expiratory flow measurements were taken at home using a mini-Wright peak flow meter (Clement Clarke, Harlow, UK). Allergy to *Dermatophagoides pteronyssinus* was determined by positive skin prick test, defined as a wheal diameter of ≥ 3 mm greater than that of negative control at 15 min; solutions supplied by ALK Abello (Hungerford, UK) (19). Participants were excluded if they were likely to move house or had a pet that provoked their symptoms. The Lanarkshire Research Ethics Committee approved the study. All participants gave written informed consent.

Study design

This was a randomized, double-blind, placebo-controlled, parallel group study to evaluate the effect of home installation of MHRV, in addition to conventional eradication strategies, in adults with asthma who were sensitive to *D. pteronyssinus*.

MHRV system

Homes of eligible participants were surveyed to assess suitability for installation. Homes were excluded if installation was technically difficult or if there was asbestos in ceiling materials. MHRV units (HR250 or HR800) were fitted in the roof space or hallway cupboard in 120 suitable homes by 'Vent-Axia™' (Crawley, UK). These energy efficient units extract air continuously from the kitchen and bathroom and deliver prewarmed air via insulated ducts into the bedroom and living room (Fig. 1). The system provided an additional 0.5 air exchanges per hour to the living room and bedroom.

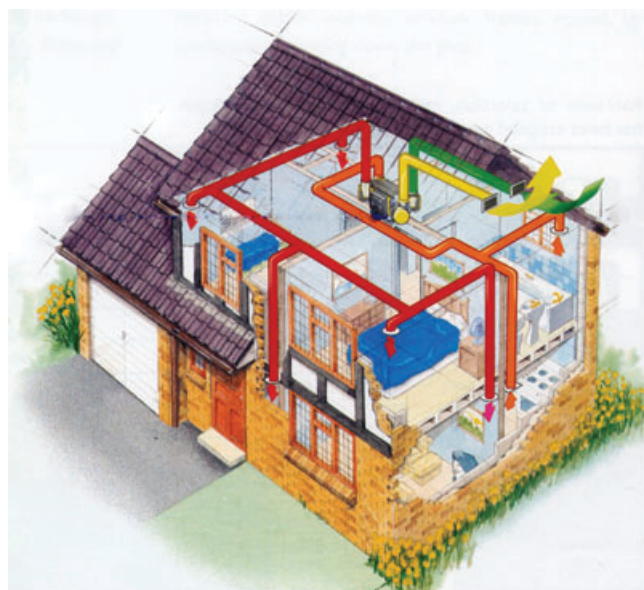


Figure 1. Mechanical heat recovery ventilation system. The mechanical heat recovery unit extracts air from the kitchen and bathroom (orange ducts) and delivers outdoor air warmed by exchanging heat with outgoing air via ducts into the bedroom and living room (red ducts). As designed and installed by 'Vent-Axia™'.

Clinical assessments

Participants attended a baseline visit where spirometry was recorded, and the ACQ (16) and St George's Respiratory Questionnaire (20) were completed. The EQ-5D questionnaire (21) was used as a standardized generic instrument for valuing health-related quality of life. Each score is categorized and 'quality of life years' (QALYs) can be calculated from the difference in health states due to an intervention. Participants compiled a 2-week PEF diary prior to the visit. Nasal symptoms were recorded on a visual analogue scale (22). Serum total IgE and *D. pteronyssinus* and pollen-specific IgE antibody were measured by commercial enzyme-immunoassay (Sweden Diagnostics Ltd, Milton Keynes, UK) (23).

House dust allergen, humidity and other environmental measurements

The architect team attended the home for a baseline visit. The bedroom, living room floor and bed surface were vacuumed at a rate of 1 m²/min to obtain complete dust samples using a Dyson model – DC14 (Dyson, London, UK). The dust samples were filtered and weighed, and a standardized soluble extract prepared. The extract concentration of allergens from house dust mite (Der p 1, Der p 2), cat dander (Fel d1) and dog dander (Can f1) was measured using fluorescent multiplex array technology (Indoor Biotechnologies, Charlottesville, VA, USA) (24). The microbial content of dust was estimated by measuring soluble extract concentrations of bacterial endotoxin and fungal β (1–3) glucan (Associates of Cape Cod Inc., East Falmouth, MA, USA).

Temperature and humidity were recorded at 90-min intervals for 12 months in the living room and bedroom using thermohygrographs, 'Gemini Tiny Tag Ultra two channel' data loggers (Gemini, Chichester, UK). The critical equilibrium humidity, at which no water is gained or lost by the house dust mite, is 73% relative humidity at 25°C (4). As maintaining relative humidity below 50% is a reasonable recommendation for reducing dust mites in the home in terms of practicability and efficacy (25), the proportion of time that relative humidity fell below 50% was calculated.

Cigarette smoking history. A volunteered smoking history was recorded and objectively confirmed by quantifying plasma cotinine, a stable nicotine metabolite and an indirect measure of individual tobacco smoking. Cotinine was measured using a microplate competitive enzyme-immunoassay (Cozart Bioscience Ltd, Abingdon, Oxford, UK).

Allergen avoidance measures. Once baseline measurements were complete, allergen eradication was carried out in all homes. Carpets were cleaned with a 'Medivac' steam cleaner at the rate of 1 m²/min (Medivac Healthcare Ltd, Cambridge, UK). New pillows, duvets and mattress covers were supplied to all participants ('Naturelle' range; Medivac Healthcare Ltd, Cambridge, UK).

Randomization and blinding

Randomization was created using a random number generator (SAS version 9 software, SAS Institute Inc. Cary, NC, USA), and performed in sequential blocks of four using an automated telephone answering system at the Robertson Centre for Biostatistics, University of Glasgow, UK, by the architect team. Accordingly, a fused electrical spur was switched in the roof space by the architect to activate half of the units. The unit activation device was concealed from the patient and the clinical research team.

To ensure blinding of intervention status, all participants were told not to expect any significant sound or air movement. All the electric switchgear were boxed into to prevent tampering. To control for any audible signs, all the low-level electric motors were switched on, but were not connected to the fans in the control group. The fans were ceiling mounted and were relatively inaccessible. Furthermore, the air coming in had been warmed, which along with the low flow rate would have been very difficult to detect. Thereafter, the topic of which group the subjects were assigned to was never brought up and the subjects were remarkably uncurious about this.

Follow-up

Participants were followed up at 3, 6, 9 and 12 months after randomization. Participants measured morning and evening PEF for 2 weeks before each visit. At each visit, spirometry was performed, ACQ score was recorded and requirements for oral corticosteroids, hospitalizations, GP or Emergency Department (ED) visits and any adverse reactions were noted. The St George's Respiratory questionnaire, the EuroQol questionnaire and nasal visual analogue scale and questionnaires were repeated at 6 and 12 months after randomization. At 12 months, blood samples for IgE serology, dust samples and humidity measurements were taken and placebo units activated.

Statistical analysis

The sample size was based upon a parallel group design, using a standard deviation of 40 l/min for mean morning PEF. The study was intended to have 64 evaluable participants per group ($n = 128$), to have 80% power (at the 5% significance level) to calculate a difference of 20 l/min.

The primary analysis was a comparison between groups of the change over baseline in morning PEF. Secondary end-points were evening PEF, ACQ scores, exacerbation and hospitalization rates, spirometry, *Der p 1* levels and humidity readings in the homes, IgE levels and economic evaluations. If 12-month data were not available, 9-month data would be used instead. The main analyses were carried out with ANCOVA models adjusted for baseline severity. The analyses were firstly carried out on an intention-to-treat basis. A list of major protocol violators, consisting of those MHRV units that were prematurely activated by the electrician and any randomization errors, was created and the remaining population was denoted per the protocol set. The primary and secondary end-points were repeated for the 'per protocol' set. Binary end-points such as hospitalizations were compared by odds ratios, the 95% confidence interval and tested by Fisher's exact test.

Results

Baseline characteristics of participants

A total of 4986 participants were invited to participate, 482 attended clinical screening. Of these, 188 did not have a positive skin test to house dust mite allergens and 78 were clinically unsuitable (35 were asymptomatic, 22 were lost to follow-up, 12 had low FEV₁, nine were symptomatic to their own pet). A total of 216 subjects fulfilled the clinical entry criteria (Fig. 2). Of these 216, 96 were excluded after a house survey which found that 53 that did not fulfil all housing criteria, and the reasons for

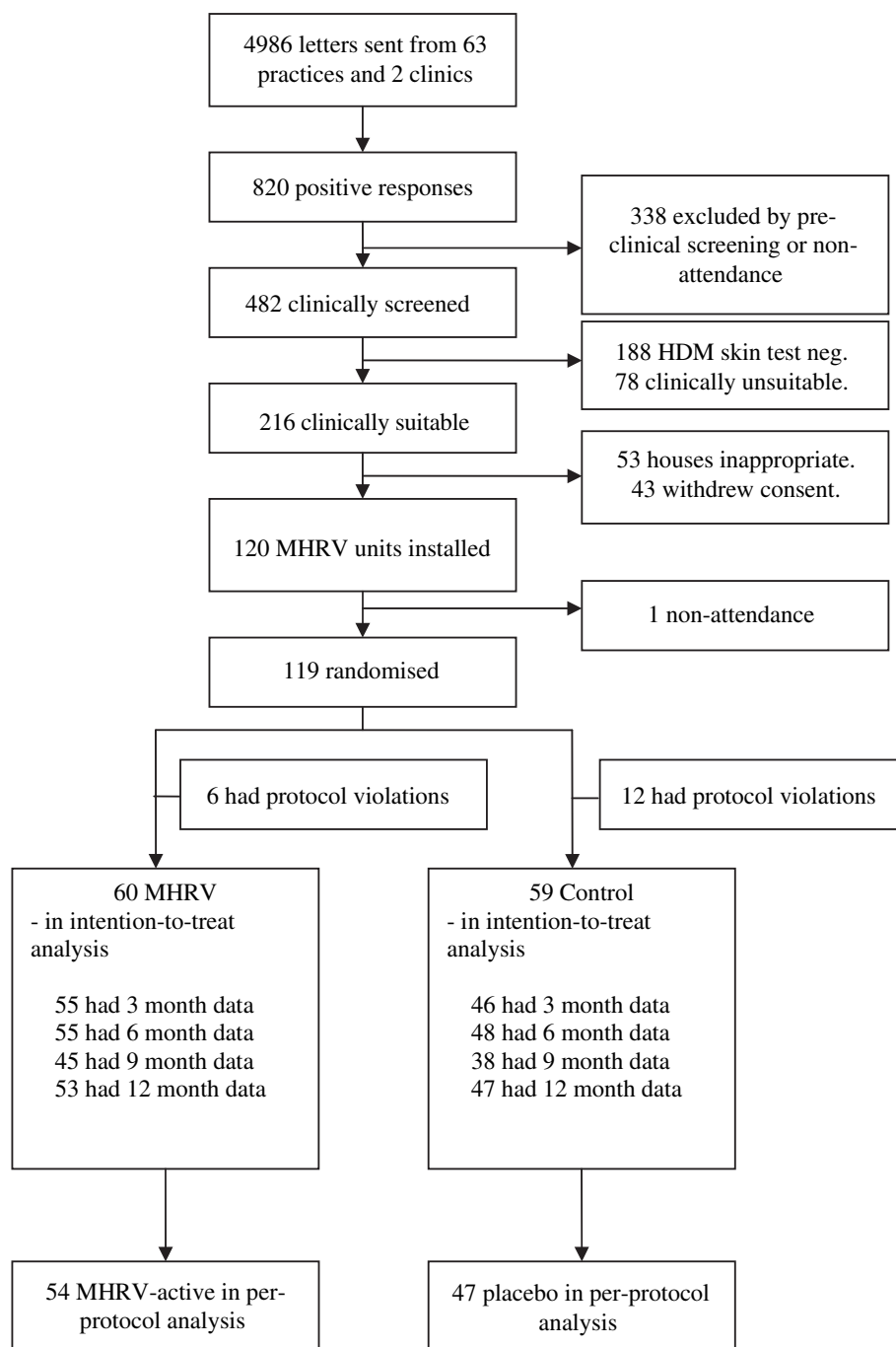


Figure 2. Consort diagram: study profile.

exclusion were firstly, possible asbestos in ceiling material and secondly, technical difficulties in installing the MHRV unit. A further 43 subjects did not wish to have the MHRV unit installed after discussing the practical details of the unit with the house surveyor. Over time, recruitment and drop-out rates settled at 120 appropriate candidates and MHRV units were installed, one subject defaulted and therefore 119 underwent randomization.

Baseline demographic characteristics of those randomized were similar (Table 1).

Eighteen major protocol violators were excluded from the per protocol analysis as the MHRV machine had been inadvertently prematurely activated by the electrician. Of these, five were further complicated, three homes had delays of 6 months in randomization and were withdrawn from follow-up. One withdrew due to ill

health. One unit appeared to have been reactivated twice prior to randomization and was withdrawn. A further three simple randomization errors were made because the MHRV system had already been activated by the electrician and the randomization was not followed appropriately. These were included in the per protocol analysis in the correct treatment arm. This was partly due to the unusual form of a randomized clinical trial within an architecture study and lack of familiarity with this procedure. In summary of loss to follow-up, 19 patients did not attend the final follow-up: three major protocol violators were excluded by the team, one withdrew due to ill health, one withdrew due to repeated reactivation, five moved house and nine failed to attend appointments.

Outcomes

Clinical outcomes. A total of 100 participants, 53 MHRV and 47 placebo, attended follow-up at 12 months. The clinical outcome measures are listed in Table 2. The primary end-point; change in mean morning PEF, did not differ between the MHRV group and the control group (mean difference: 13.5 l/min, 95% CI: -2.6 to 29.8, $P = 0.10$). However, there was a significant improvement in the MHRV group compared with the control group in mean evening PEF (mean difference: 24.5 l/min, 95% CI: 8.9–40.1, $P = 0.002$) (Fig. 3).

Values for spirometry, use of rescue medication, ACS, St George's Respiratory Questionnaire score, rhinitis scale, requirement for oral corticosteroids, GP or ED visits or hospitalizations with asthma did not differ between the two groups. In the economic analysis, there was an insignificant gain of 0.02 QALYs per MHRV patient. The 'per protocol' analysis provided similar results to the intention-to-treat analysis. No adverse event was reported relating to the installation of the MHRV unit.

Indoor relative humidity and temperature. Mechanical heat recovery ventilation system significantly reduced mean relative humidity in the bedrooms for a sustained period from October to February ($P < 0.05$ each month) and in the living room from December to February ($P < 0.05$ each month) (Fig. 4). The median (inter-quartile range) per cent of time homes achieved a reduction in the indoor relative humidity below 50% was greater in the MHRV group than in the control group in the bedroom [45.1% (30.0–55.1) vs 21.0 (8.5–49.0), $P = 0.001$], but not in the living room [51.5% (35.4–58.7) vs 40.6% (12.8–63.5), $P = 0.26$].

Concentration of allergens and microbial products in house dust, and serum IgE levels. At 12 months, the changes in mean Der p 1 and Der p 2 concentrations in the bed, bedroom and living room carpets, as compared with baseline concentrations, did not differ between the

Table 1. Baseline demographic and clinical characteristics

Characteristic	MHRV group	Control group
Subjects; no.	60	59
Age; years	41.6 (9.6)	42.3 (10.7)
Gender: female; no.	41	32
Ethnicity; no.		
Caucasian	58	58
Asian	2	1
Smoking; no.		
Smoker	12	17
Ex-smoker	7	13
Never smoker	41	29
Plasma cotinine, ng/ml	3.4 (2.0–63.0)	3.2 (2.0–68.0)
Duration of asthma; years	21.0 (9.2–30.7)	16.0 (9.0–25.0)
BMI (kg/m ²)	28.4 (5.5)	29.6 (6.3)
Morning PEF (l/min)	414.5 (116.9)	409.1 (91.6)
Evening PEF (l/min)	428.2 (112.4)	426.9 (94.9)
Spirometry (% predicted)		
FEV ₁ prebronchodilator	83.7 (18.0)	82.7 (17.7)
Postbronchodilator	86.6 (18.1)	89.5 (15.6)
FVC prebronchodilator	93.5 (13.6)	95.0 (15.4)
Short-acting β -agonist (daily no. puffs)	2.0 (1.0–2.7)	2.0 (1.0–3.0)
Asthma control score (0–6)	1.57 (1.18–2.54)	1.86 (1.14–2.71)
St George's score (0–100%)	35.3 (23.9)	34.6 (20.4)
Co-morbidity; no.		
Hay fever or nasal allergy	44	47
Eczema	15	14
Hypertension	5	8
Angina	2	3
Diabetes	3	2
Previous stroke	1	2
Other respiratory	0	1
Previous M.I.	0	1
Inhaled corticosteroid; beclomethasone equiv. μ g	1000 (800–2000)	800 (400–1200)
Other asthma medication; no.		
β_2 -agonist (short-acting inhaled)	60	58
β_2 -agonist (short-acting oral)	1	1
β_2 -agonist (long-acting)	41	34
Theophylline	4	4
Anti-cholinergic	5	6
Leukotriene receptor antagonist	15	9
Oral steroid	4	3
Rhinitis VAS (1–10)		
Sneeze	4.50 (1.20–6.30)	5.00 (1.82–5.47)
Nasal discharge	3.60 (0.80–6.00)	5.00 (1.35–7.22)
Nasal blockage	4.7 (3.00–6.76)	5.00 (1.90–7.37)
Serum HDM IgE antibody	5.7 (1.6–13.1)	6.1 (2.3–15.2)
Der p 1 (μ g/g of dust)		
Bed	27.6 (7.0–60.8)	29.6 (3.6–44.0)
Bedroom carpet	12.7 (8.6–42.6)	17.7 (10.0–47.4)
Living room carpet	8.5 (4.8–25.5)	16.8 (7.2–37.2)

The values within parenthesis are given as mean and standard deviation, or median and inter-quartile range.

MHRV, mechanical heat recovery ventilation system; no., number; HDM, house dust mite.

MHRV group and the control group, nor were there differences in total or house dust mite specific IgE levels. There were no significant differences in secondary analyses of cat dander allergen (Fel d1), dog dander allergen (Can f1), β (1–3) glucan or endotoxin (Table 2).

Table 2. Comparison of clinical outcomes at baseline and 12 months

Outcome	MHRV mean (SD)	Placebo mean (SD)	Adjusted difference ANCOVA (95% CI)	P-value
Subject numbers	53	47		
PEF a.m. (l/min)				
Baseline	414.5 (116.9)	409.1 (91.6)	13.59 (−2.66 to 29.85)	0.1
12 months	419.2 (127.9)	395.8 (96.0)		
Change	6.4 (38.8)	−7.1 (38.5)		
PEF p.m. (l/min)				
Baseline	428.2 (112.4)	426.9 (94.9)	24.56 (8.97 to 40.15)	0.002
12 months	436.1 (124.7)	405.9 (93.4)		
Change	12.0 (36.4)	−12.4 (37.9)		
ACQ (0–6)				
Baseline	2.0 (1.1)	2.0 (1.0)	−0.25 (−0.57 to 0.08)	0.14
12 months	1.5 (1.1)	1.8 (1.1)		
Change	−0.4 (0.7)	−0.1 (1.0)		
Rescue medicine (no. puffs)				
Baseline	3.5 (2.5)	4.0 (3.7)	−0.04 (−1.00 to 0.92)	0.93
12 month	3.5 (2.8)	3.5 (3.4)		
Change	0.0 (1.9)	0.1 (2.3)		
St George's Q (0–100)				
Baseline	35.3 (23.0)	34.6 (20.4)	−2.83 (−7.82 to 2.16)	0.26
12 months	29.7 (24.4)	31.2 (19.9)		
Change	−5.2 (13.7)	−2.1 (12.4)		
FEV ₁ (% pred)				
Baseline	83.7 (18.0)	82.7 (17.7)	1.32 (−2.56 to 5.19)	0.50
12 months	86.6 (18.1)	82.5 (16.9)		
Change	1.8 (8.3)	1.0 (11.3)		
Exacerbation; no				
Oral steroids	12	17	0.51 (0.21–1.22)	0.12
ED visits	4	2	1.78 (0.31–10.16)	0.51
GP visits	0	1	0.90 (0.42–1.93)	0.28
GP out of hours	24	22		0.79
Hospitalizations	0	4		0.12
Sneezing VAS				
Baseline	4.3 (3.1)	4.2 (2.7)	−0.76 (−1.70 to 0.18)	0.11
12 months	2.6 (2.6)	3.1 (2.3)		
Change	−1.7 (3.0)	−0.8 (2.3)		
Nasal discharge VAS				
Baseline	3.7 (3.1)	4.3 (3.1)	−0.46 (−0.47 to 0.55)	0.37
12 months	2.7 (2.9)	3.4 (2.4)		
Change	−0.9 (3.1)	−0.5 (2.7)		
Nasal blockage VAS				
Baseline	4.7 (3.0)	4.8 (3.1)	−0.51 (−1.68 to 0.66)	0.39
12 months	3.7 (3.0)	4.0 (3.0)		
Change	−0.9 (3.1)	−0.5 (3.2)		
Der p 1				
Bed				
Baseline	4.9 (14.4)	2.2 (5.1)	−0.32 (−0.84 to 0.21)	0.23
12 months	0.7 (1.5)	2.6 (9.6)		
Change	−3.2 (−6.7 to 0.4)	−1.3 (−2.3 to −0.2)		
Living room				
Baseline	2.7 (7.4)	3.1 (6.2)	0.1 (−0.8 to 0.9)	0.85
12 months	0.9 (2.0)	1.0 (2.1)		
Change	−1.9 (−4.0 to 0.2)	−2.8 (−4.7 to −0.9)		
Bedroom				
Baseline	3.0 (7.5)	1.7 (3.6)	1.46 (−2.65 to 5.57)	0.48
12 months	2.3 (11.1)	1.5 (1.8)		
Change	−0.4 (−4.7 to 3.8)	−0.5 (−1.6 to 0.6)		

Table 2. (Continued)

Outcome	MHRV mean (SD)	Placebo mean (SD)	Adjusted difference ANCOVA (95% CI)	P-value
Der p 2				
Bed				
Baseline	1.1 (2.2)	0.9 (2.1)	−0.04 (−0.16 to 0.08)	0.49
12 months	0.3 (0.7)	1.0 (4.0)		
Change	−0.6 (−1.0 to −0.3)	−0.6 (−1.0 to −0.1)		
Living room				
Baseline	1.2 (3.1)	1.4 (3.1)	0.56 (−0.65 to 1.77)	0.35
12 months	0.9 (3.3)	0.5 (1.3)		
Change	−0.2 (−1.5 to 1.1)	−1.3 (−2.4 to −0.2)		
Bedroom				
Baseline	1.7 (3.6)	1.0 (2.0)	1.07 (−1.63 to 3.76)	0.43
12 months	1.6 (7.3)	0.9 (1.3)		
Change	0.1 (−2.4 to 2.7)	−0.3 (−0.7 to 0.2)		
Cat allergen				
Bed				
Baseline	2.9 (5.5)	3.3 (0.6)	−0.29 (−2.63 to 2.06)	0.80
12 months	3.3 (5.6)	3.4 (0.2)		
Difference	0.0 (−1.3 to 1.4)	0.4 (−1.7 to 2.5)		
Living room				
Baseline	2.1 (3.8)	2.7 (5.0)	−1.81 (−4.35 to 0.73)	0.16
12 months	3.5 (5.9)	4.6 (7.9)		
Difference	1.1 (−0.5 to 2.7)	2.9 (0.8 to 5.0)		
Bedroom				
Baseline	3.1 (5.4)	4.0 (7.8)	0.61 (−1.59 to 2.81)	0.58
12 months	3.6 (5.1)	3.3 (5.6)		
Difference	0.3 (−1.1 to 1.8)	−1.1 (−3.9 to 1.7)		
Dog allergen				
Bed				
Baseline	22.2 (41.8)	21.5 (3.8)	7.22 (−8.64 to 23.07)	0.36
12 months	25.4 (56.1)	11.0 (31.7)		
Difference	−1.7 (−12.1 to 8.7)	−8.4 (−23.5 to 6.7)		
Living room				
Baseline	97.7 (461.4)	29.8 (50.8)	−3.17 (−29.3 to 23.0)	0.81
12 months	41.9 (71.9)	34.8 (53.1)		
Difference	−67.1 (−207.1 to 73.0)	5.8 (−11.9 to 23.4)		
Bedroom				
Baseline	29.8 (57.9)	26.2 (54.1)	−5.20 (−22.4 to 12.0)	0.55
12 months	34.4 (59.1)	26.2 (4.1)		
Difference	−1.4 (−13.9 to 11.2)	7.2 (−6.6 to 21.1)		
Mould (µg/g dust)				
β(1–3) glucan				
Living room				
Baseline	322 (453)	390 (582)	−7.8 (−26.0 to 10.2)	0.38
12 months	108 (111)	113 (37.2)		
Change	−241 (486)	−360 (657)		
Bed				
Baseline	347 (483)	255 (304)	22.7 (−0.4 to 45.9)	0.05
12 months	99 (50.8)	77.8 (35.4)		
Change	−273 (544)	−214 (366)		
Bedroom				
Baseline	351 (966)	226 (216)	−15.4 (−40.4 to 9.5)	0.22
12 months	107 (39.4)	114 (64.9)		
Change	−270 (1063)	−142 (233)		
Endotoxin (EU)				
Bed				
Baseline	3539 (3213)	4479 (3475)	−1187 (−2935 to 560)	0.18
12 months	4583 (3450)	5952 (3617)		
Change	1109 (3934)	1253 (4969)		

Table 2. (Continued)

Outcome	MHRV mean (SD)	Placebo mean (SD)	Adjusted difference ANCOVA (95% CI)	P-value
Living room				
Baseline	5136 (2990)	6318 (2891)	497 (−679 to 1674)	0.40
12 months	7776 (2548)	6986 (2589)		
Change	2666 (4488)	555 (4418)		
Bedroom				
Baseline	5725 (3202)	5005 (3438)	−64.6 (−1465 to 1336)	0.92
12 months	6996 (3047)	6916 (2754)		
Change	1148 (4541)	1902 (3823)		
IgE to HDM				
Baseline	15.8 (25.8)	20.4 (31.6)	2.09 (−5.67 to 9.85)	0.59
12 months	15.5 (24.2)	16.5 (26.1)		
Change	−0.3 (21.7)	−3.8 (13.9)		

Data represented as mean (SD). Values represent mean difference (CI) compared with baseline. Allergen concentration in µg/g dust.

CI, confidence interval; PEF, peak expiratory flow; FEV₁, forced expiratory volume in 1 s; ACQ, Asthma Control Questionnaire score (range: 0–6, with higher scores indicating worse asthma control); St George's Respiratory Questionnaire (range: 0–100, with higher scores indicating worse quality of life); ED, Emergency Department, GP, General Practitioner; VAS, visual analogue scale (range: 1–10, with higher scores indicating worse symptoms); IgE, immunoglobulin E; Der p 1 and Der p 2, *Dermatophagoides pteronyssinus* allergen 1 and 2; EU, endotoxin units.

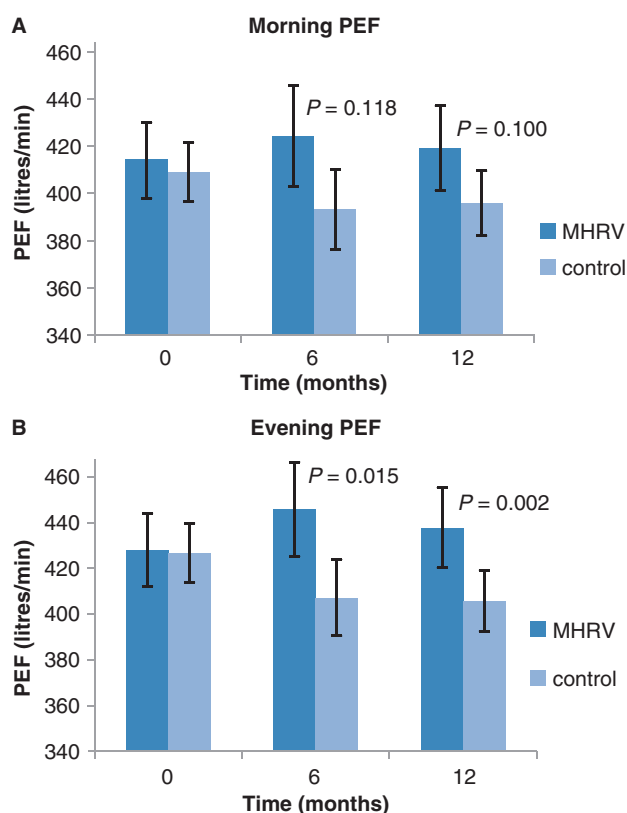


Figure 3. Morning and evening peak expiratory flow (PEF) measurements at baseline and during follow-up. (A) At 6 and 12 months, the change in mean morning PEF, as compared with baseline, did not differ between the MHRV group and the control group. (B) At 6 and 12 months, the change in mean evening PEF, as compared with baseline, was significantly greater in the MHRV (mechanical heat recovery ventilation) group compared with the control group (6 months, $P = 0.015$ and at 12 months, $P = 0.002$).

Discussion

This randomized, double-blind, placebo-controlled study examined the effect of the installation of domestic MHRV on asthma control in adults sensitive to house dust mite allergen. It was based on the hypothesis that a warm, humid environment favours the growth of the house dust mite population and that decreasing indoor air humidity with mechanical ventilation would reduce the dust mite allergen burden and improve asthma control.

We found that the MHRV intervention reduced indoor relative humidity in the autumn and winter months, but with no associated effects on Der p 1 burden. We found at 12 months that there was no change in morning PEF; which was our primary end-point, but there was an improvement in evening PEF. The evening PEF is a secondary outcome measure and although the observed improvement was statistically significant, this might have been by statistical chance. Interpretation of this result, therefore, will need to be speculative; however, because the mean improvement of 24.5 l/min was also of clinical significance, this should not be discounted. The morning PEF changes were internally consistent with these evening PEF changes, but they did not quite achieve statistical significance. One reason for this is probably because the study was insufficiently powered to demonstrate a clinical response; only 100 of a projected optimum number of 128 participants completed follow-up. This level of subject attrition reflected the complexity and difficulties in project managing this level of domestic intervention and should be factored in any future study.

It was clear that the reduced relative humidity was insufficient to impact on Der p1 burden, and there was also no difference between the groups in change in serum house dust mite specific IgE antibody. Domestic dehumidification has reduced mite allergen burden in some

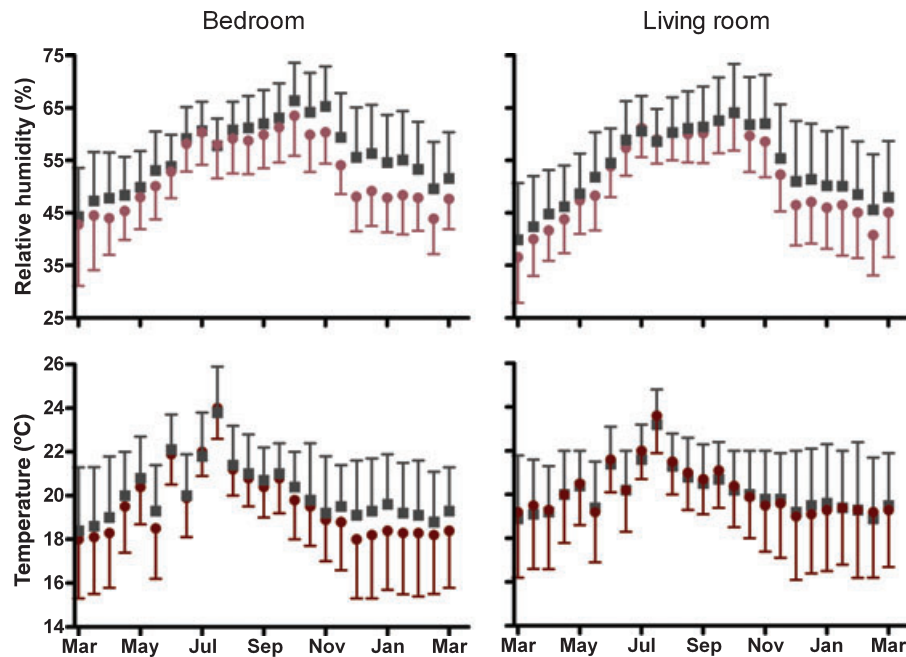


Figure 4. Relative humidity values and temperature over 12 months. The twice monthly mean (standard deviation on one-side) relative humidity and temperature in the bedroom and living room show an annual periodicity with the lowest levels in March. MHRV reduced humidity in the bedrooms during April ($P < 0.05$) and then for a sustained period from October to February ($P < 0.001$). The humidity in the living room was significantly reduced ($P < 0.05$) from December to February. There was no effect of MHRV on temperature. ■ Placebo group; ● MHRV group.

(13) but not in this, or other (26, 27) trials. Even within overall humidity control, minor fluctuations of humidity levels may permit mite survival. For example, a New Zealand study (26) showed that, although active ventilation did reduce relative humidity to less than 50% for 7 months of the year, there was no effect on mite levels because values were below the critical equilibrium humidity for mite survival for only 39% of the total of 24-h periods for which measurements were made. In another UK study, Fletcher (27) also found no impact of MHRV on Der p 1. It is also possible that 12 months was too short a period to measure a difference in seasonally affected mite re-colonization rates. One underlying reason for this variable lack of efficacy in mite control may be related to climate (28). For ventilation to reduce indoor humidity, the outdoor air humidity must be sufficiently lower; and this may be relevant for our study located in the particularly humid West of Scotland and in others, for example, New Zealand (26). Based on these observations, a future development in the intervention would be a humidistat controller, set at the optimum proportion of relative humidity for temperature, linked to a variable flow fan unit to ensure more refined humidity suppression.

Although we found no effect of MHRV on mite burden, we did not measure airborne allergen concentrations, and it is possible that the increased ventilation rather than the, albeit inadequate, dehumidification could

be helpful. We would suggest that ventilation and air sampling for allergen removal be considered in any future intervention trial. There is some evidence for this concept. Burr et al. (29) recently conducted an unblinded mould eradication trial that included improved home ventilation and found symptomatic improvement in wheeze, medication use and rhinitis. However, in our study no difference between fungal glucan exposures was observed between the groups. Other possible factors affected by improved ventilation would include a reduction in respiratory viruses (30), but in our study there was no associated change in GP visits, and other components of indoor air quality, such as particulate matter or volatile organic compounds, seem unlikely. In this case, we can speculate on some of the secondary outcome results of our study. We found that with the MHRV intervention, there was a more prolonged and more significant reduction in relative humidity in the bedrooms, and that the Der p1 levels were lower in bedding, which is arguably the most important exposure. There may be some merit in considering simple improved ventilation in bedrooms of asthmatic children.

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