

Ventilation in homes infested by house-dust mites

Sundell J, Wickman M, Pershagen G, Nordvall SL. Ventilation in homes infested by house-dust mites. Allergy 1995; 50: 106–112. © Munksgaard 1995.

**J. Sundell¹, M. Wickman^{1,2,4},
G. Pershagen^{1,4}, S. L. Nordvall^{2,3}**

¹ Institute of Environmental Medicine, Karolinska Institute, Stockholm; ² Department of Pediatrics, St Görans Hospital, Karolinska Institute, Stockholm; ³ Department of Clinical Immunology, Karolinska Hospital, Stockholm; ⁴ Department of Environmental Health and Infectious Diseases Control, Karolinska Hospital, Stockholm, Sweden

Thirty single-family homes with either high (≥ 2000 ng/g) or low (≤ 1000 ng/g) house-dust mite (HDM) allergen levels in mattress dust were examined for ventilation, thermal climate, and air quality (formaldehyde and total volatile organic compounds (TVOC)). Elevated concentrations of HDM allergen in mattress and floor dust were associated with the difference in absolute humidity between indoor and outdoor air, as well as with low air-change rates of the home, particularly the bedroom. No correlation was found between concentration of TVOC or formaldehyde in bedroom air and HDM allergen concentration. In regions with a cold winter climate, the air-change rate of the home and the infiltration of outdoor air into the bedroom appear to be important for the infestation of HDM.

Key words: air humidity; formaldehyde; house-dust mites (HDM); total volatile organic compounds (TVOC); ventilation.

J. Sundell
Erstagatan 16^{IV}
S-116 36 Stockholm
Sweden

Accepted for publication 28 March 1994

Infestation of homes by house-dust mites (HDM) has been considered to be rare in the Stockholm area for climatic reasons: long and cold winters resulting in a prolonged heating season and dry indoor conditions. In a study done in 1975, HDM were found in 1.5% of the homes of adult patients with respiratory allergies (17). A decade later, in the same geographic area, Nordvall et al. (13) found mite antigens in mattress dust in 67% of the homes of HDM-sensitized children, and a subsequent study in 1987 revealed that 40% of the homes of HDM-sensitized children were infested, as well as 23% of the homes of nonallergic neighborhood children (19).

Infestation by HDM is associated with indoor air humidity (3, 4, 6, 7, 10, 12, 19). The infestation rate is low in homes with indoor absolute humidity below 7 g/kg air during 1–2 months of the winter, corresponding to a relative humidity of 45% at 20–22°C (1). In regions such as the Fenno-Scandinavian countries, it should be possible to keep the indoor air humidity satisfactorily low by ventilation. It has been proposed that ventilation rates ≥ 1.0 air changes per hour (ach; m^3/m^3 per h = 1/h) in homes in Denmark would protect against mite infestation (1).

The major aim of this study was to investigate the relationship between HDM infestation and ventila-

tion rates. Occurrence of airway irritants such as volatile organic compounds (VOC) and formaldehyde was also studied in relation to mite infestation and ventilation. The hypothesis was that low ventilation rate and high indoor air humidity cause elevated concentrations of such air pollutants, which may act as adjuvants for the development of allergy.

Material and methods

The 13 homes with the highest HDM allergen concentration (≥ 2000 ng/g) of mattress dust and 17 homes without or with a low (≤ 1000 ng/g) HDM allergen concentration in mattress dust were selected from a case-referent study of HDM-sensitized children (19, 20). One home with high allergen concentration in mattress dust was not occupied during the week of measurements, and was excluded.

All homes were single-family homes situated in the same area of Stockholm. Measurements and inspections of the homes were done during 2 weeks in December 1989. The outdoor air temperature during the period was between +1°C and –11°C. The homes were inspected for type of building, type of ventilation, and occurrence of water/mold damage.

Dust samples from the mattresses of the children's beds and bedroom floors were collected by a technician, as specified by Mosbech & Lind (11). The families' own vacuum cleaners were used with a nozzle containing a filter with an average pore diameter of 5–6 μm (19). Vacuum cleaning of the bed mattress was done for 5 min after removal of the bed linen and for 2 min of 2–3 m^2 of the bedroom floor near the bed. The major allergens of *Der p* I, *Der f* I, and *Der m* I of the three *Dermatophagoides* species *pteronyssinus* (*Dpt*), *farinae* (*Df*), and *microceras* (*Dm*) were measured separately by enzyme-linked immunosorbent assay at Allergologisk Laboratorium A/S, Denmark (9, 19). In the analyses, the sum of the concentrations of *Der p* I, *Der f* I, and *Der m* I was used as the dependent variable, HDM allergen concentration.

Measurements of ventilation, integrated over 1 week, were made with a passive multiple tracer gas method developed by Brookhaven National Laboratory (14). Homes were divided into at least two zones with the child's bedroom as one. The zone-to-zone air flow, as well as the infiltration and exfiltration of air from and to the outside, was measured. Analyses were done at the Danish Building Research Institute. The method makes it possible to assess the air flows during normal use of the home and over a prolonged time span. This work focuses on the following variables:

- the total ventilation of the home expressed as air-change rate (ach) and outdoor air-flow rate per person (l/s.p.)
- the specific air-change rate of the bedroom (infiltration of outdoor air directly to bedroom), also expressed as ach and l/s.p. (number of persons sleeping in bedroom)
- the air-flow rate between the bedroom and the rest of the home, expressed as air-flow rate in l/s.p. in the home, and as air-change rate of the bedroom (ach).

Measurements of air temperature and humidity, outdoors and in the child's bedroom, were made twice with a 1-week interval with calibrated hot wire instruments (Rotronic Hygroskop DV-2). The bedroom measurements were made in the middle of the room and 1 m above floor level. The additional humidity (AH) was calculated as the difference between the absolute humidity in indoor and outdoor air. On both occasions of humidity measurement, approximately the same association was found (as tested by multiple regression analysis) between AH indoors, outdoor temperature, and time of day of measurements. The AH was reduced by 0.1 g/m^3 per h from 8 am until 7 pm, and by 0.2 g/m^3 per degree Celsius in the outdoor temperature interval of -11 to $+1^\circ\text{C}$. Adjustments were made accordingly, and the values used in the analyses, "adjusted ad-

ditional humidity" (AAH), refer to 8 am and to an outdoor temperature of 0°C .

The concentrations of formaldehyde and VOC were measured once in the child's bedroom. Formaldehyde concentration was determined by a chemisorption method employing 2,4-dinitrophenylhydrazine-impregnated fiberglass filters with a flow of 1 l/min (8). The total volume sampled was 24–30 l. The fiberglass filters were extracted in acetone and analyzed by liquid chromatography (HPLC system with UV detector). The VOC were trapped on Tenax tubes (40 mg Tenax GC) and analyzed by gas chromatography (GC) and mass spectrometry (MS). The sampling flow was 0.5 l/min, and the total sampled volume was approximately 20 l. Quantitative analysis was done with *n*-decane as standard. The analyses of formaldehyde and VOC were made at the Department of Occupational Medicine, Örebro, Sweden.

Statistics

Because the number of homes was low, and the distributions of HDM allergen concentrations were skewed, nonparametric statistical methods were used. For test of differences between groups, Wilcoxon's rank sum test was used; for test of associations between variables, Spearman's rank correlation coefficient (r_s) was used. Two-tailed *P* values were used in both tests.

Logarithmic values of HDM allergen concentration, and air-flow rates were close to normal distribution. Parametric methods such as linear regression have therefore also been used to interpret associations found in nonparametric analyses. (Results of the different methods were in close agreement.)

Data were analyzed with the SPSS/PC + (SPSS, Inc, Chicago, IL, USA) and Epi Info version 3 (Centers for Disease Control, Atlanta, GA, USA) statistical packages.

Results

Concentrations of HDM allergen in bed mattress dust and floor dust

Eight homes exhibited HDM allergen concentrations in mattress dust exceeding 20 000 ng/g dust, while the remaining 21 showed concentrations below 3000 ng/g dust. The mattress-dust HDM allergen concentration correlated with the allergen concentration in the same bed 1 year earlier ($r_s = 0.86$; $P < 0.001$) (19). However, in four cases, the change in allergen level was large (one order of magnitude) between the two measurements. In the final classification, 11 homes with mattress dust concentrations of ≥ 1000 ng/g were selected as a "high-infestation

group" and the remaining 18 homes with concentrations below 500 ng/g as a "low-infestation group" (Table 1).

The concentrations of HDM allergen were lower in floor than in mattress dust, but there was a significant association between the two ($r_s = 0.70$; $P < 0.001$). Five out of six floor dust samples from rooms with wall-to-wall carpets exhibited similar or higher concentrations of HDM allergen than the corresponding mattress dust. In comparison, only three of 23 dust samples from floors without wall-

to-wall carpets exhibited HDM allergen concentrations equal to or higher than those of the corresponding mattress dust samples.

Characteristics of homes and rooms

Nine of 11 homes in the high-infestation group had only a single floor, as opposed to 2/18 in the low-infestation group ($P = 0.001$) (Table 1). One-floor homes had significantly higher concentrations of HDM allergen in mattress dust ($P = 0.002$) and floor

Table 1. Number of floors (including basement) of investigated single-family homes and measured values of outdoor air supply (ventilation) of total home and bedroom, indoor thermal climate in bedroom, mite allergen levels in mattress and floor dust, and amount of formaldehyde and amount of total volatile organic compounds (TVOC) in bedroom air

Home no.	Number of floors	Ventilation of		Temp °C	AAH g/m ³	Mite allergen in		Formaldehyde µg/m ³	TVOC µg/m ³
		Home ach	Bedroom ach			Mattress dust 1000 µg/g	Floor dust 1000 ng/g		
Low-infestation group									
1	2	0.2	2.0	18	1.4	0.1	0	30	110
2	2	0.2	0.8	21	1.6	0.01	0.05	30	130
3	1	0.5	0.2	18	1.7	0.04	0.09	20	270
4	2	0.2	0.7	19	2.1	0.03	0.09	30	420
5	3	0.1	0.2	18	1.1	0.2	0.2	20	120
6	2	0.5	0	18	2.9	0.1	0	40	150
7	3	0.4	0	20	1.8	0.1	0	40	100
8	2	0.2	0.4	18	2.6	0.3	0.09	50	470
9	2	0.2	0.7	20	1.2	0	0.02	20	35
10	3	0.3	4.8	18	3.1	0.2	0.06	30	200
11	2	0.1	2.5	19	2.7	0.3	0	50	200
12	3	0.2	1.5	19	0.5	0.05	0	10	33
13	2	0.2	1.4	20	2.7	0.03	0	60	77
14	2	0.3	0.6	21	1.6	0.01	0.02	20	89
15	1	0.1	0.1	20	2.8	0.03	0.09	70	165
16	2	0.8	0	20	1.4	0.03	0	30	150
17	2	0.2	—	20	2.4	0.1	0	60	180
18	2	0.5	0.1	20	0.7	0	0	30	350
Mean	1.9	0.3	0.9	19	1.9	0.09	0.04	36	181
SD	0.3	0.2	1.2	1	0.8	0.09	0.05	17	124
Median	2.0	0.2	0.6	20	1.7	0.04	0.009	30	150
High-infestation group									
1	1	0.3	0	17	1.6	540	0.6	30	—
2	1	0.2	0	19	1.7	2.1	0.6	30	220
3	1	0.2	0.3	21	4.1	456	0.8	80	180
4	1	0.3	0.2	20	2.4	21	4.2	20	90
5	1	0.2	0.3	19	2.4	56	0.1	20	110
6	1	0.1	0.1	20	2.7	179	1.1	30	140
7	2	0.6	0	17	3.0	3.1	0.3	20	120
8	2	0.2	0.3	19	2.8	43	0.08	50	210
9	1	0.1	0.5	20	2.2	28	8.3	280 [#]	590 [#]
10	1	0.2	0.3	20	2.6	21	0.2	40	93
11	1	0.2	0	20	2.9	1.0	6.8	40	170
Mean	1.2*	0.2	0.2*	19	2.6*	123*	2.1*	36	148
SD	0.4	0.1	0.2	1	0.7	193	2.9	18	49
Median	1.0	0.2	0.2	20	2.6	28	0.6	30	140
Total									
Mean	1.6	0.3	0.6	19	2.2	47	0.8	36	170
SD	0.5	0.2	1.0	1	0.8	130	2.0	17	106
Median	2.0	0.2	0.3	20	2.4	0.2	0.09	30	160

AAH: adjusted additional humidity.

[#] Outliers (reconstruction) that were not included in analysis.

* Means that levels of high-infestation group were significantly different from those of low-infestation group.

dust ($P \leq 0.0001$), and a tendency to a lower air-change rate of the bedroom ($P = 0.08$) than homes with more than one floor.

Homes had a mean volume of 263 m³ (range 140–500 m³, median 280 m³), and the mean number of persons living in the homes was 4.1 (range 2–6, median 4). Bedrooms had a mean volume of 24.6 m³ (range 15–40 m³, median 25 m³). There were no significant differences in number of persons in the home, home volume, or bedroom volume between high- and low-infestation homes.

Water or mold damage (visual damp areas or growth of mold, or a moldy odor) was noted in 13/29 homes, but no associations between such observations and HDM allergen concentrations in dust were found.

Temperature and humidity of air in bedroom

The mean air temperature in the bedroom was 19.1°C, median 19.5°C (Table 1). A tendency to inverse relation was found between HDM allergen concentrations in bed mattresses and air temperature ($r_s = -0.33$; $P = 0.08$).

There was a significant association between AAH and the concentration of HDM allergen in mattress dust ($r_s = 0.49$; $P = 0.008$) (Fig. 1), and a nonsignificant association between AAH and HDM allergen concentration in floor dust ($r_s = 0.34$; $P = 0.07$). In total, there were only weak and nonsignificant associations between AAH and ventilation rates. In homes with a total ventilation rate below or equal to the median value, there were borderline significant associations between AAH and total home ventilation expressed in l/s.p. ($r_s = -0.52$; $P = 0.05$; $n = 15$), and bedroom ventilation (expressed in ach or l/s.p.) ($r_s = -0.50$; $P = 0.07$; $n = 15$).

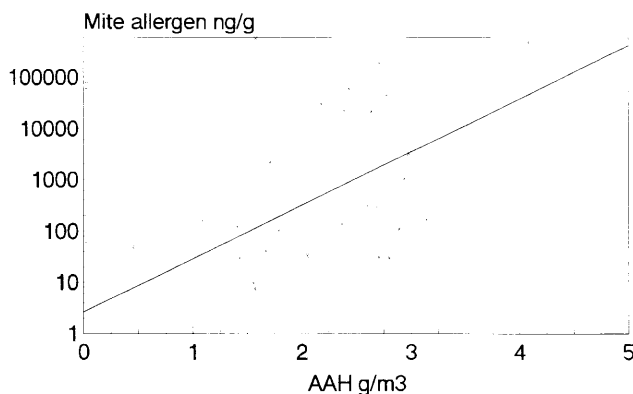


Fig. 1. HDM allergen in mattress dust as function of adjusted additional humidity (AAH) in home (difference between absolute humidity in air indoors and outdoors). Corr.: $r = 0.52$; $P = 0.004$.

Ventilation

The total air-change rate of the homes was low (Tables 1 and 2). In none of the homes was the ventilation in accordance with the Swedish building regulations (a total air-change rate of the home, as well as of each room, of ≥ 0.5 l/h). In most cases, the infiltration of outdoor air (ach) directly into the bedroom was different from the air-change rate of the entire home (Table 1), and there was a significant negative association between the two ($r_s = -0.40$; $P = 0.04$). Thus, low total air-change rate of the home was associated with high bedroom air-change rate.

The homes in the high-infestation group had lower ($P = 0.04$) bedroom outdoor air-flow rates and a tendency ($P = 0.07$) to lower home outdoor air-flow rates measured as air-flow rate per person (l/s.p.), but not as air-change rate per hour (ach; $P = 0.5$), than the low-infestation group (Tables 1 and 2). In general, the flow of air into the bedroom from the rest of the home was much higher than the infiltration of outdoor air directly into the bedroom (Table 2), but it was not significantly different between the high- and low-infestation groups of homes.

Associations between mite allergen concentrations or AAH and total home ventilation were generally stronger for air-flow rates expressed as air-flow rate per person (l/s.p.) than for air-flow rates expressed as air-change rate (ach). The correlation between HDM allergen in mattress dust and home outdoor air-flow rate in l/s.p. was $r_s = -0.50$ ($P = 0.007$), as compared with $r_s = -0.21$ ($P = 0.3$) with outdoor air-flow rate expressed in ach.

Parametric and nonparametric regression analy-

Table 2. Ventilation characteristics of high- and low-infestation homes

	High-infestation homes			Low-infestation homes		
	Mean	Median	Range	Mean	Median	Range
Outdoor air-flow rates						
Total home						
ach	0.2	0.2	0.1–0.6	0.3	0.2	0.1–0.8
Wrst.P. 0.5						
l/s.p.	3.9	3.2	2.1–7.3	5.5	4.6	2.0–15
Wrst.P. 0.07						
Bedroom						
ach	0.2	0.2	0.0–0.5	0.9	0.6	0.0–4.8
Wrst.P. 0.04						
l/s.p.	1.3	1.2	0.0–2.9	5.6	3.5	0.0–20
Wrst.P. 0.04						
Air flow to bedroom from home						
l/s.p.	3.8	1.8	0.7–14	4.6	2.7	0.8–25
Wrst.P. 0.5						
ach	2.3	1.0	0.4–6.7	3.1	1.9	0.4–18
Wrst.P. 0.9						

Wrst.P.: P value for difference between high- and low-infestation homes, as tested by Wilcoxon's rank sum test.

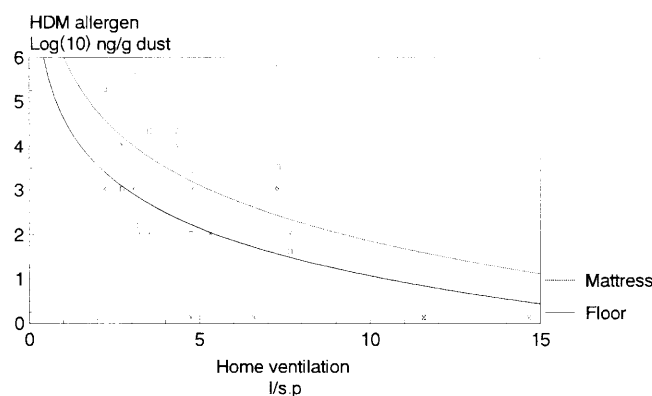


Fig. 2. HDM allergen in mattress ($\square$) and floor ($\times$) dust and outdoor air-flow rate, in homes with infiltration of outdoor air, into bedroom $\leq$ median. Corr.: mattress $r = -0.59$ ($r_s = -0.57$); floor $r = -0.57$ ($r_s = -0.62$).

ses yielded from close to similar results in associations between HDM allergen concentrations and air-flow rates. The associations were moderate in analyses of the total sample of homes (r_s range -0.23 to -0.50 ; r range -0.27 to -0.47), but more pronounced in analyses of homes stratified by the median value for home and bedroom ventilation, respectively (Figs. 2 and 3).

All HDM allergen values above 1000 ng/g of dust in mattresses were found in bedrooms with an air-change rate (infiltration of outdoor air directly into the bedroom) below 0.5 ach (Table 1).

Formaldehyde and TVOC in bedroom air

Table 1 shows the concentrations of formaldehyde and TVOC (total volatile organic compounds) in the bedroom air. In most of the investigated homes, the VOC were of three categories:

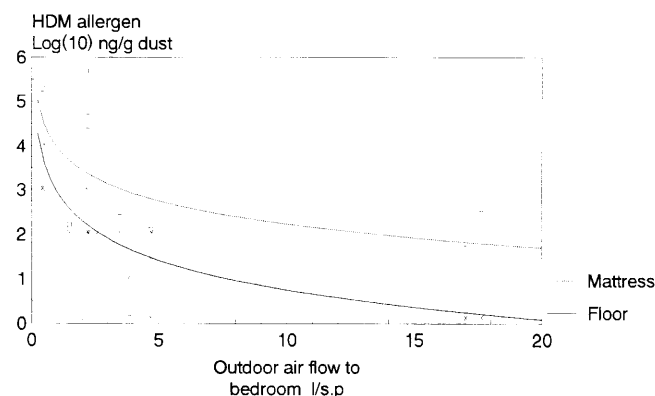


Fig. 3. Mite allergen in mattress ($\square$) and floor ($\times$) dust and bedroom outdoor air-flow rate in houses with total home ventilation rate below median. Corr.: mattress $r = -0.48$ ($r_s = -0.52$); floor $r = -0.78$ ($r_s = -0.79$).

- 1) ordinary aliphatic and aromatic compounds emitted from solvent-based paints and to a minor extent from traffic
- 2) esters, di-alcohols, and glycol ethers typically emitted from water-based paints
- 3) some alcohols and aldehydes probably emitted from floor coverings such as polyvinyl chloride and linoleum carpets.

In most bedrooms, the TVOC and formaldehyde concentrations were low. In only one home, during reconstruction, were the concentrations of TVOC and formaldehyde above $500 \mu\text{g}/\text{m}^3$ and $80 \mu\text{g}/\text{m}^3$, respectively. There were no associations between HDM allergen concentrations and levels of formaldehyde and TVOC or numbers of identified VOC.

Discussion

Importance of effect of ventilation on HDM infestation

This study indicates that the ventilation of homes is an important factor in the presence of mite allergen in mattress and floor dust. Furthermore, the ventilation of the bedroom seems to be as important as the total ventilation of the home. Thus, even in homes that are well ventilated, infestation of HDM may occur if the bedroom is not well ventilated also. In many homes, bedrooms are not well ventilated. On the contrary, most homes in Sweden are ventilated by natural or exhaust-only mechanical systems, which "guarantee" ventilation only of rooms with exhaust air terminal devices: i.e., kitchens and bathrooms.

Air-flow rates related to number of persons in the home appeared to be a stronger risk indicator of high AAH and HDM infestation than air-flow rates related to home volumes. This probably reflects the fact that the main source of humidity in homes is people. The lack of influence of air-flow rate from the home into the bedroom on HDM infestation may reflect the fact that indoor air is more humid than outdoor air, and that such air flows reduce bedroom humidity only to a minor degree.

The influence of ventilation on HDM infestation is also suggested by the association between type of home and degree of HDM infestation. A lack of thermal forces leading to reduced ventilation rates probably contributes to the higher infestation rate in one-floor homes. These interpretations agree with other recent reports that improved ventilation (18) and high air-change rate of bedrooms (4) are associated with low concentration of HDM allergen in dust. Our previous findings (13, 19) indicate that the infestation rate in apartments is very low, a finding which may be explained by a higher air-change rate than in single-family houses, because of more frequent use of mechanical ventilation, and more efficient natural ventilation in high-rise buildings. In a

recent nationwide survey of indoor climate in Swedish residential buildings, the mean air-change rate of homes in apartment buildings was found to be 0.50 ach, and in single-family houses 0.35 ach (2). The latter value is close to the mean value found in this study. Furthermore, in approximately 15% of the Swedish apartments and 40% of the single-family houses, air-change rates below 0.25 ach were detected (2).

TVOC and formaldehyde

No association was found between HDM allergen concentration and formaldehyde or TVOC. However, further studies are needed with a greater number of homes and measurements of irritants during longer time periods to reject the hypothesis that high mite-allergen concentrations are associated with high levels of airborne irritants. Doubts have been expressed regarding the validity of TVOC as a health-related air-quality indicator (16).

Measurements

Measurements of ventilation, temperature, humidity, HDM allergen, formaldehyde, and air-flow rates are well standardized and have good reliability. No standard for measurement of VOC exists, however, and no interlaboratory calibration procedure. Therefore, it is difficult to compare results from such measurements between studies. On the other hand, the measurements, per se, are reliable, and this makes comparisons within a study possible.

Adjusted additional humidity (AAH)

The indoor air humidity is a function of the absolute humidity of outdoor air, the outdoor air-flow rate (air-change rate), and the presence of sources of humidity within the home. The additional humidity (AH) – the difference between the absolute humidity in indoor and outdoor air – is a function of the production of humidity in the home (room), adsorption and desorption of humidity to and from surfaces, and the amount and humidity of supplied air. The lower the outdoor air humidity, the larger the “additional” humidity, because of a higher desorption of humidity from surfaces within the home.

AAH was calculated from daytime measurements, in most cases in homes without inhabitants and thus with reduced moisture source strength. Possibly this estimate of AAH underestimates nighttime humidity, especially in rooms with low outdoor air-infiltration rate, i.e., the rooms with the highest HDM allergen concentrations in dust.

In daytime, air humidity is relatively equal throughout the home because doors are kept open, and it

appears probable that AAH is associated with the total air-change rate of the home and not with the infiltration of outdoor air into a particular room. Furthermore, it seems likely that the bedroom HDM allergen levels are associated with the infiltration into the bedroom of outdoor air, a factor that strongly influences the humidity of the bedroom air at night.

Conclusions

Building characteristics that influence indoor air humidity are important for the degree of mite infestation in homes. The study indicates that the ventilation of the home, and of the bedroom, separately, are such factors. Measures to improve ventilation, particularly of bedrooms, may be important in both primary and secondary allergy prevention.

Acknowledgments

We thank all the families who participated in this study. The research was sponsored by the Swedish Council for Building Research and the FOLKSAM Insurance Group.

References

1. ANDERSEN I, KORSGAARD J. Asthma and the indoor environment. Assessment of the health implications of high indoor humidity. *Environ Int* 1986; 12: 121–7.
2. BOMAN CA, KRONVALL J. Ventilation rates in the Swedish housing stock. *Proc Indoor Air* 1993; 5: 3–8.
3. HALLAS TE, KORSGAARD J. Annual fluctuations of mites and fungi in Danish house-dust. An example. *Allergol Immunopathol (Madr)* 1983; 11: 195–200.
4. HARVING H, KORSGAARD J, DAHL R. House-dust mites and associated environmental conditions in Danish homes. *Allergy* 1993; 48: 106–9.
5. KORSGAARD J. Preventive measures in mite asthma. A controlled trial. *Allergy* 1983; 38: 93–102.
6. KORSGAARD J. Mite asthma and residency. A case-control study of exposure to house-dust mites in dwellings. *Am Rev Respir Dis* 1983; 128: 231–5.
7. KORSGAARD J. House-dust mites and absolute indoor humidity. *Allergy* 1983; 38: 85–92.
8. LEVIN JO, ANDERSSON K, LINDAHL R, NILSSON C-A. Determination of sub-part-per-million levels of formaldehyde in air using active or passive sampling on 2,4-dinitrophenylhydrazine-coated glass fiber and high-performance liquid chromatography. *Anal Chem* 1985; 57: 1032–5.
9. LIND P. Enzyme-linked immunosorbent assay for determination of major excrement allergens of house dust mite species *D. pteronyssinus*, *D. farinae* and *D. microceras*. *Allergy* 1986; 41: 442–51.
10. MOSBECH H. House-dust mite allergy. *Allergy* 1985; 40: 81–91.
11. MOSBECH H, LIND P. Collection of house dust for analysis of mite allergens. *Allergy* 1986; 41: 373–8.
12. MURRAY AB, FERGUSON MB, MORRISON BJ. Sensitization to house dust mites in different climatic areas. *J Allergy Clin Immunol* 1985; 76: 108–12.
13. NORDVALL SL, ERIKSSON M, RYLANDER E, SCHWARZ B. Sensitization of children in the Stockholm area to house dust mites. *Acta Paediatr Scand* 1988; 77: 716–20.
14. RUSSEL N, DIETZ RW, GOODRICH EA, COTE R, WIESER RF. Detailed description and performance of a passive per-

- fluorocarbon tracer system for building ventilation and air exchange measurements. BNL 36327, Brookhaven National Laboratory, February 1985.
15. SPORIK R, HOLGATE S, PLATTS-MILLS T, COGSWELL J. Exposure to house dust mites allergens (*Der p I*) and the development of asthma in childhood: a prospective study. *N Engl J Med* 1990; 323: 502–7.
 16. SUNDELL J, ANDERSSON B, ANDERSSON K, LINDVALL T. Volatile organic compounds in ventilating air in buildings at different sampling points and their relationship to the prevalence of occupant symptoms. *Indoor Air* 1993; 3: 82–93.
 17. TUROS M. Mites in house dust in the Stockholm area. *Allergy* 1979; 34: 11–18.
 18. WICKMAN M, EMENIUS G, EGMAR L, AXELSSON G, PERSHAGEN G. Reduced mite allergen levels in dwellings with balanced mechanical ventilation. *J Allergy Clin Immunol* 1994; 24: in press.
 19. WICKMAN M, NORDVALL SL, PERSHAGEN G, SUNDELL J, SCHWARTZ B. House dust mite sensitization in children and residential characteristics in a temperate region. *J Allergy Clin Immunol* 1991; 88: 89–95.
 20. WICKMAN M, GRAVESEN S, NORDVALL SL, PERSHAGEN G, SUNDELL J. Indoor viable dust-bound microfungi in relation to residential characteristics, living habits, and symptoms in atopic and control children. *J Allergy Clin Immunol* 1992; 89: 752–9.