

House-dust mite exposure reduction in specially designed, mechanically ventilated “healthy” homes

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Exposure to house-dust mites (*Dermatophagoides* spp.) was investigated in 30 asthmatic patients before and after moving to homes with mechanical ventilation systems. Median house-dust mite concentration was 110 mites per gram of mattress dust at the initial investigation and 20 mites per gram at the first follow-up after a mean of 4.7 months in the new homes. This was lower ($P < 0.05$) than counts in a control group of 23 asthmatic patients that had unchanged counts. At a second follow-up, after 15.0 months, mite counts in the study group were further reduced ($P < 0.01$) from initial values. Among 16 patients, with initial mite counts above the recommended threshold limit value (TLV) of 100 mites per gram of dust, the mite counts fell, in most cases, below this TLV. Air-exchange rates increased ($P < 0.001$) from a median value of 0.40 air changes per hour (ach) to 1.52 ach at the second follow-up investigation. Furthermore, a reduction ($P < 0.01$) was found in indoor absolute air humidity, with a median value of 5.6 g of water/kg. No such changes were found in the control group. The present study indicates that reduction of air humidity through an increased supply of fresh air may significantly diminish and, in some cases, even eliminate house-dust mites in homes.

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Residential air quality with regard to allergen exposure and sensitization is the subject of increasing concern and attention. In the last two decades, the energy-conserving measures introduced have tended to reduce air exchange and, consequently, raise indoor humidity and concentration of indoor pollutants, leading to the specific problem of house-dust mites, which are the source of one of the major indoor allergens. High air humidity facilitates mite growth, and determines the reproductive rate of such mites in homes (5). Abnormally high mite counts in temperate climates are mainly found in homes with an absolute air humidity of more than 7 g/kg during the dry winter season (12).

In homes where the high humidity is not due to water damage or other construction deficiencies, it seems to be possible to prevent or reduce mite growth by lowering indoor humidity. Lower air humidity is most effectively achieved by increasing air exchange through installation of mechanical ventilation systems (15).

Deterioration of indoor air quality can adversely affect health (19); this reinforces the need of experi-

mentation to design or modify homes in order to maintain healthy indoor environments.

Special attention has been paid to persons suffering from bronchial asthma, who are considered to be particularly susceptible to airborne irritants (14).

In Denmark, a “healthy” housing project was developed with the aim of providing homes having improved indoor air quality and low allergen exposure, especially suited for asthma sufferers.

This paper reports house-dust mite exposure in asthmatic patients before and after moving into these “healthy” homes.

Material and methods

Housing

The housing project consisted of 111 row houses in Aarhus, a coastal city in Denmark. Each house was equipped with a mechanical ventilation system combined with a heat exchanger, and without air recirculation. All living rooms and bedrooms were constructed with fresh air inlets, while exhaust air was expelled from the dampest rooms, i.e., kitchens and

bathrooms. The system was designed to maintain an air-exchange rate of at least 1 air change per hour (ach). Building materials were selected on the basis of nontoxicity, i.e., minimum emission of particulate and gaseous pollutants. Rooms and fixtures were specially designed to be easy to clean. The technical details of this housing project are described elsewhere (16).

Patients

To attract medically relevant tenants, the project was specially advertised in local news media and promoted by Aarhus County general practitioners. Twenty-five families each having one or more asthma sufferers initially joined the study group, and agreed to move into the "healthy" homes. In addition, seven such families moved in later (see below). All but two of the families were Aarhus residents before moving. These 32 families are hereafter referred to as the study group.

For parallel investigation, a group of 29 control patients were randomly selected from among asthmatic patients who had been referred to Aarhus University Hospital Chest Clinic within the preceding 5 years; they are hereafter referred to as the control group. Before they moved out, air-quality measurements (AQM) were done in the patients' old homes. Similar AQM were done again after they moved into the "healthy" homes, approximately 1 year later, to neutralize seasonal variations.

The initial AQM of the patients' former homes were done from February to April 1984 because the new homes were scheduled for occupation in April 1984. Investigation of the study group, after the move into the "healthy" homes, was done in January–April 1985; and the control group's homes were contemporaneously reinvestigated.

Because of construction delays, moving into the "healthy" homes could not begin before October 1984; this meant that the scheduled 1-year follow-up investigation of both groups was done soon after the study group had moved. Consequently, a second follow-up investigation of the study group was done (1 year later) in the winter of 1985/86. Because of budget restrictions, this second follow-up could not, unfortunately, be done on the control group. The decision to conduct a second follow-up investigation had been taken before the first follow-up was initiated.

However, this delay made it possible to include another seven families in the study group investigations in late autumn 1984. These families were investigated before moving in and only once later (1 year later), i.e., at the same time that the second follow-up of the initial study group took place, winter 1985/86. The average durations of residence in the

"healthy" homes at the time of the two on-location investigations were, respectively, 4.7 (SD $\pm$ 0.94) and 15.0 months (SD $\pm$ 2.32).

Of the 32 study group families that underwent the initial AQM before moving, two dropped out before the first follow-up: one of them had moved again, and the other no longer wished to participate. By the second follow-up investigation, another two families had moved out.

In the control group, six families dropped out. Four families had moved to other parts of the country before the first follow-up investigation, and two declined to participate further.

Indoor environment investigations

In both groups, house-dust mite concentration was measured, along with air-exchange rates, humidity, and temperature.

Dust mite concentration was measured in dust samples collected from patients' mattresses and the floor surface beside their beds in the following manner: 1 m² surface area of each sampling site was vacuumed (maximum suction -0.1 bar) for 2 min with a portable vacuum cleaner with disposable paper bags, which were immediately placed in plastic Ziplock storage bags and kept at -18°C until counting. Processing of the dust samples was done blinded. Counting and mite identification were done as described previously (13).

Bedroom air exchange was measured with windows and doors closed and without human activity by the tracer-gas-decay method. Continuous measurements, lasting 16–24 h, of bedroom temperature and air humidity were done with thermohygrographs. Absolute air humidity was calculated on the basis of simultaneous measurements of relative humidity and temperature (6).

In addition to AQM, we administered a standard lifestyle questionnaire on furniture and equipment, as well as cleaning, bathing, laundering, and cooking habits.

Clinical investigation of study and control groups

Results, to be published separately ("Clinical efficacy of mite exposure reduction", submitted to *Allergy*), will report each group's clinical histories, symptoms registration, medication, inhalation challenge tests, blood tests, and lung function tests.

Results

The mite counts in the participants' former homes showed that house-dust mites (*Dermatophagoides* spp.) constituted 79% of the mites found, in accordance with previous Danish findings (10).

Table 1. Concentration of house-dust mites (*Dermatophagoides* spp.) before (1984) and after moving to "healthy" homes (1985, 1986)

	House-dust mites/g dust Mattress						House-dust mites/g dust Bedroom floor					
	Study group			Control group			Study group			Control group		
	Median	IQR	n	Median	IQR	n	Median	IQR	n	Median	IQR	n
1984	110	20-340	30	105	40-550	23	95	25-450	30	140	20-350	23
1985	20 [†]	10-170	23	210	40-560	23	10 [‡]	5-30	23	140	10-260	23
1986	35 [‡]	10-100	28				40 [‡]	0-55	28			

IQR=Interquartile range.

[†] $P < 0.05$, as compared with control group (Mann-Whitney U-test).[‡] $P < 0.01$, as compared with initial values (Wilcoxon matched-pairs test).

Median house-dust mite counts and interquartile ranges (IQR) are shown in Table 1. The concentration of house-dust mites was higher in mattresses than on floors.

The study and control groups showed similar mite concentrations in the initial samples. Dust mite counts in control group samples remained unaltered from 1984 to 1985. In the study group, dust mite concentration fell from a median value of 110 mites per gram of mattress dust in 1984 to 20 mites per gram in 1985 ($P < 0.05$), and 35 mites per gram in 1986 ($P < 0.01$) (Table 1 and Fig. 1). A significant difference between the two groups' mattress dust mite concentrations was observed in 1985 ($P < 0.05$) (Fig. 1).

A marked reduction in dust mite concentration was found in 16 homes that had initial mite counts above the recommended TLV of 100 mites per gram of dust (Fig. 2) (18). In most of these homes, the mite counts fell below TLV; in three of them, the dust mite concentrations were unchanged; and in one, the mite count increased.

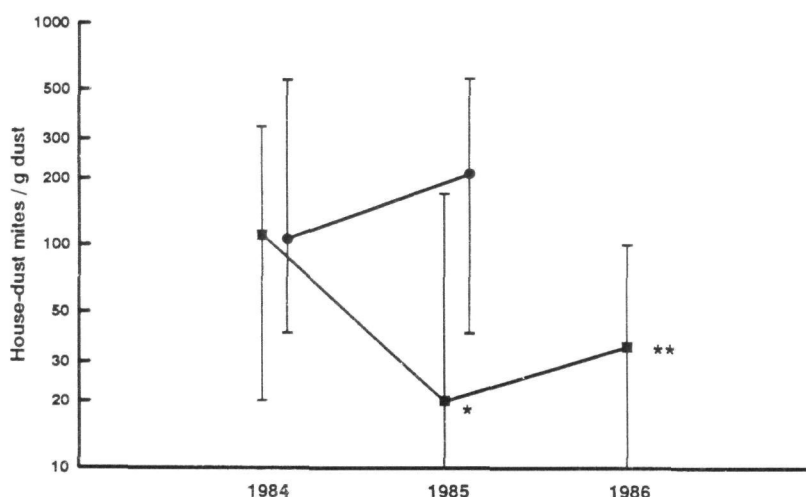


Fig. 1. House-dust mite (*Dermatophagoides* spp.) median concentration and interquartile range in dust of study group mattresses (■ - - - - ■) before (1984) and after moving into "healthy" homes (1985, 1986), and corresponding control group measurements (● - - - - ●). * $P < 0.05$, as compared with control group. ** $P < 0.01$, as compared with initial values.

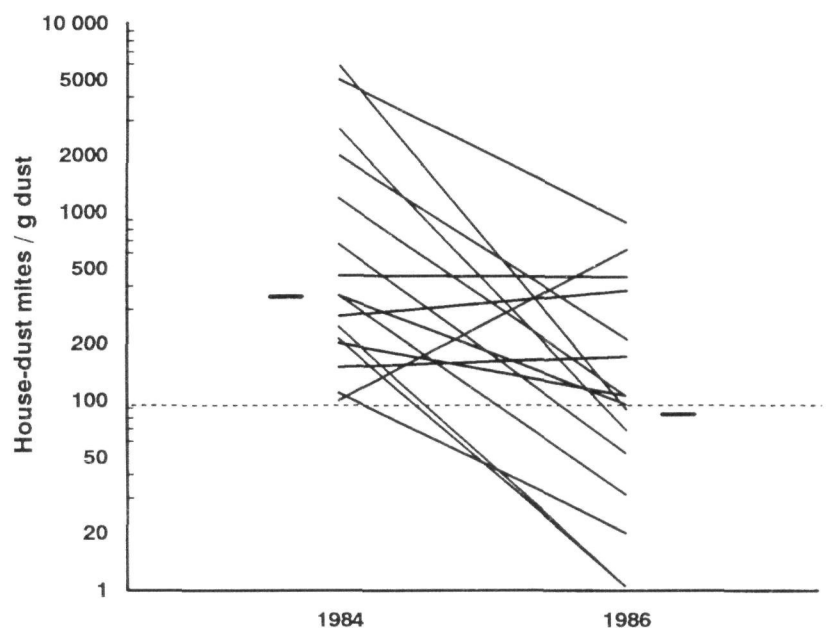


Fig. 2. Mite (*Dermatophagoides* spp.) concentration changes in mattress dust of study group participants that had high mite counts before moving. (—) denotes median values.

All the study group families who had former home mite counts below TLV maintained sub-TLV dust mite counts throughout the study.

Floor dust mite concentration changes showed the same pattern as that in mattress dust (Table 1).

Air-exchange rates in the former homes (Table 2) were relatively low, as compared with recommended values (20), with median air-exchange rates of 0.40 in the study group and 0.29 in the control group (not significantly different). The "healthy" home air-exchange rates were over two times higher than those of the study group's former homes, while such measurements remained unchanged in the control group homes (Fig. 3).

Initial bedroom air humidity measurements (Table 2) showed about equal median values in both the study and control groups, being 6.6 g/kg and 6.9 g/kg, respectively; but after the move, study group air humidity fell ($P < 0.01$) to a median value of 5.6 g/kg in 1986, while control group air humidity showed no change (Fig. 4).

Table 2. Air-exchange rate (tracer-gas-decay method) and absolute air humidity in bedroom before (1984) and after moving into "healthy" homes (1985, 1986)

	Air-exchange rate (ach)						Absolute humidity (g/kg air)					
	Study group			Control group			Study group			Control group		
	Median	IQR	n	Median	IQR	n	Median	IQR	n	Median	IQR	n
1984	0.40	0.13–0.72	30	0.29	0.20–0.58	23	6.6	5.7–7.8	30	6.9	6.0–7.7	23
1985	1.04 [†]	0.78–1.66	23	0.29	0.19–0.80	23	6.3	5.8–6.9	23	6.9	6.2–7.3	23
1986	1.52 [‡]	1.09–1.71	28				5.6 [§]	4.9–6.2	28			

IQR: Interquartile range.

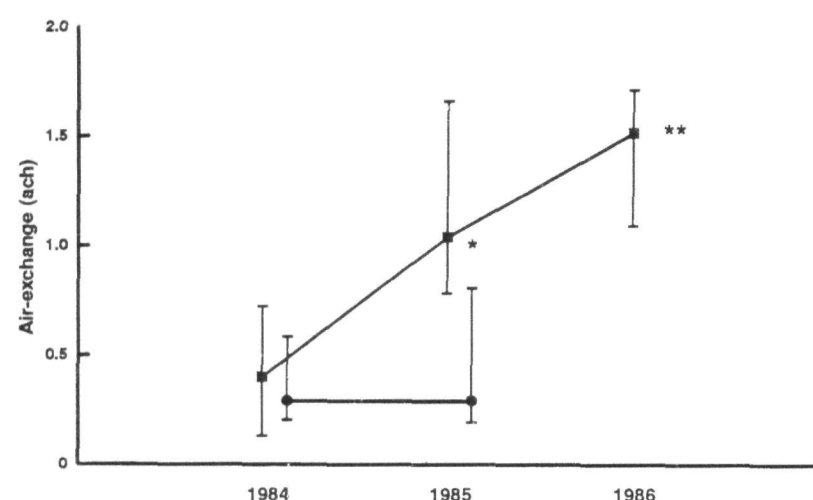
[†] $P < 0.01$, as compared with control group (Mann-Whitney U-test).[‡] $P < 0.001$, as compared with initial values (Wilcoxon matched-pairs test).[§] $P < 0.01$, as compared with initial values (Wilcoxon matched-pairs test).

Fig. 3. Median values and interquartile range of bedroom air-exchange rates of study group (■ - - - - ■) before (1984) and after (1985, 1986) moving to new homes, and corresponding control group measurements (● - - - - ●). * $P < 0.01$, as compared with control group. ** $P < 0.001$, as compared with initial values.

Analysis of the lifestyle questionnaires consistently showed that the indoor behavior of both groups remained largely unchanged in frequency of

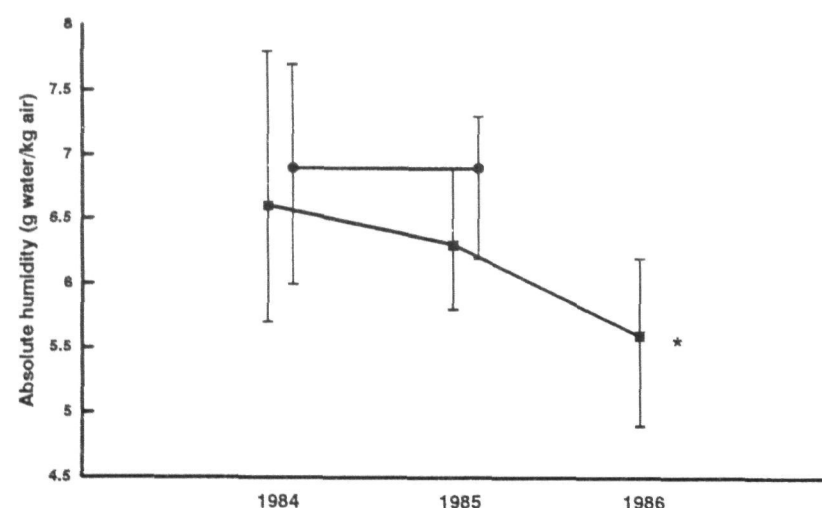


Fig. 4. Median values and interquartile range of bedroom absolute air humidity of study group (■ - - - - ■) before (1984) and after (1985, 1986) moving to new homes, and corresponding control group measurements (● - - - - ●). * $P < 0.01$, as compared with initial values.

housecleaning, change of bedding, and bathroom use, although the study group registered a reduction in washing/drying of clothes as a result of laundry facilities being situated in a separate location of the "healthy" housing site.

The frequency of study and control group open-window bedroom airing was the same before the former moved house, about 50% of all of them opening their windows for approximately 1 h per day; however, afterwards, because their "healthy" homes were equipped with mechanical ventilation systems, 80% in 1985 and 60% in 1986 of the study group no longer opened any window.

As for bedroom furniture, five study group families had replaced their mattresses before the first follow-up investigation in 1985, and another three before the second follow-up in 1986. In the control group, three families changed their mattresses during 1984/85. The distribution of house-dust mite counts in all these cases was not different from the study group and the control group in general. Furthermore, the mattress dust mite counts of the five study group families who had replaced their mattresses before the first follow-up investigation showed no increase at the second follow-up; in one of these cases, a further mite count reduction below TLV was seen, while in the other four cases, counts remained below TLV.

Discussion

In homes, house-dust mite concentration is usually highest in the bedroom (2, 21). In mite allergy, the most widespread recommendation for mite avoidance has been mite eradication procedures in selected areas, which often include intensified domestic cleaning, mainly in the bedroom; wrapping mattresses in plastic; and changing indoor materials and furniture.

Yet, in controlled trials, these mite eradication procedures have yielded ambiguous results: some studies report no effect on mite counts (3, 11), while

others report dust mite reduction after wrapping of mattresses (17, 22).

In recent years, a number of acaricides for mite control have been tested, especially benzyl benzoic acid, which has caused significant house-dust mite reduction, but mite growth recovers within a few months (1, 8, 9).

Overall, however, both hygienic and chemical mite eradication approaches lower mite concentration below TLV in very few locations, if any.

In our study, mite avoidance strategy has been fundamentally different: we focused on prevention instead of eradication by changing indoor environmental factors that influence air humidity. High air humidity, conducive to mite growth, most often results from an insufficient fresh air supply in modern homes; therefore, one of the "healthy" housing project's main aims was to reduce air humidity by installing mechanical ventilation systems. Our data show that this objective was achieved. "Healthy" home air-exchange rates were well above the recommended 0.5 ach limit (20); and their air humidity, although only marginally reduced at the first follow-up investigation, which was done shortly after the building construction, a poor result which was undoubtedly due to the new building materials, was at the second follow-up investigation substantially lower than in the study group's former homes.

Most importantly, it was shown that study group median mite concentrations were significantly reduced after the move to the "healthy", well-ventilated homes. Furthermore, this reduction was significant in spite of the rather low initial median mite count of 110 per gram of dust (7).

We believe that mite concentration reduction was due solely to reduced air humidity, because resident indoor behavior, according to the questionnaires, was unchanged, and only minor changes were made in furniture and building fixtures; and although the mattresses were replaced in a few cases, previous investigations have shown that this has no long-term effect on house-dust mite concentration (4), because reinfestation takes place within months. Such a reinfestation did not occur in any of the five study group homes whose mite concentration was measured twice after replacement of mattresses. Furthermore, unchanged mite counts in the control group indicate that the reduction of dust mites in the "healthy" homes was not a periodic variation or placebo effect.

Regarding individual mite concentrations, we have found complete removal of mite populations, i.e., reduction of mite concentrations to a level below the proposed TLV of 100 mites per gram of dust, in most families that had shown elevated mite concentrations before the move. The present investigation is the first to show that it is possible to eliminate

house-dust mites from mattresses where they formerly were found in high numbers.

In the present study, we have compared findings in an unrandomized study group with a group of controls that did not move. Ideally, a randomized study group's results should have been compared with a control group that moved to other, ordinary homes. Taking into account that moving is a very crucial decision involving many family issues, we found it impossible to gather, still less to randomize, a group of asthmatic patients planning to move to new homes within a short period of time.

We did notice that a few study group families showed unchanged or increased dust mite concentrations. Particular analysis of these families did not reveal any environmental or behavioral differences from the rest of the study group. This would indicate that other factors may be determinants in low-humidity indoor environments.

We have recently found indications in Danish homes that increased house-dust mite exposure is related to low ventilation rates (7); this reinforces the present study's finding that reduction of air humidity through an increased supply of fresh air can significantly diminish and, in some cases, even eliminate house-dust mites in homes.

These findings imply that increased indoor fresh air supply can be beneficial in the treatment of house-dust mite allergy, and that a more vigorous effort to ensure adequate ventilation in modern homes is needed to diminish the health hazard of house-dust mite exposure.

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