

Original article

The influence of air conditioning, humidity, temperature and other household characteristics on mite allergen concentrations in the northeastern United States

Background: Information about the influence of housing and occupant characteristics on mite allergen concentrations is crucial to determine which methods could be used to decrease exposure of susceptible subjects.

Objectives: To identify housing and occupant characteristics that are associated with mite allergen concentrations in house dust collected from living rooms and mattresses.

Methods: We collected dust samples from 750 homes in the northeastern US. The influence of various characteristics on concentrations of mite allergens (Der p 1 and Der f 1) was studied using multiple linear regression analysis.

Results: Some characteristics, like absence of air conditioners, the presence of mold or mildew, and a lower temperature were consistently associated with higher concentrations of both mite allergens in dust from all sampling locations. However, none of these factors changed Der p 1 or Der f 1 concentrations by more than a factor of 2. People of white ethnic background had roughly two times higher mite allergen concentrations, while family income, family size, and education level only marginally influenced mite allergen concentrations.

Conclusions: Various housing characteristics have some influence on mite allergen concentrations, and could possibly be used to decrease exposure of susceptible subjects. However, only a limited percentage of the variation in mite allergen concentrations was explained by these characteristics.

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In temperate areas of the world, many people with asthma are allergic to house dust mites. This and evidence about the influence of home dampness (1) triggered research to determine how exposure to mite allergens influences the development of mite allergies and asthma. It has been shown that mite allergen exposure early in childhood is associated with the development of mite allergies, but that the development of asthmatic symptoms may be less clearly related to mite allergen exposure (2–6). However, studies among sensitized individuals showed that reducing mite allergen exposure, either by transferring patients to mite free environments (7, 8) or in trials of intervention using mite impermeable mattress covers (9–11), resulted in less severe asthma. Most randomized trials were successful in reducing mite allergen exposure, but one study failed to see changes in asthma severity among sensitized individuals (12). With the possibilities for reduction of mite allergen exposure for primary and secondary prevention in mind, several studies have described the influence of household characteristics on the mite allergen content of house dust worldwide (13–21). From these studies it became clear

that while some household characteristics were clearly associated with the presence of mite allergens, most of the variation in the mite allergen concentration could not be explained by household characteristics.

Some studies only measured Der p 1 (the major allergen of *Dermatophagoides pteronyssinus*), or summarized Der p 1 and Der f 1 (the major allergen of *Dermatophagoides farinae*) to create one mite allergen concentration. Several studies (22–24), however, showed that Der p 1 and Der f 1 are not very highly correlated, and that different housing characteristics, climates, or geographic areas influence the two different mite species differently (25). Cut-off concentrations for sensitization (2 µg per gram dust) and for the development of symptoms in allergic individuals (10 µg per gram dust), which were initially proposed for Der p 1 (26), were later also used for Der f 1. Furthermore, the use of cut-off concentrations as threshold limits seems too restrictive, since Wahn et al. showed that sensitization can occur at lower mite allergen concentrations (4). This suggests that Der p 1 and Der f 1 should be studied separately, and without the use of cut-off concentrations.

Our study was carried out among children from diverse ethnic backgrounds in Connecticut and Massachusetts, USA. Previously, we showed that in their homes, increased humidity and temperature were associated with increased indoor air mold concentrations (27). The analyses presented here are supplemental to those presented in an earlier paper by Leaderer et al. (28), which showed that higher socio-economic status was associated with higher mite allergen concentrations in house dust. In this paper, Der p 1 and Der f 1 concentrations in dust from the main living area, dust from infant's mattresses, and dust from their asthmatic sibling's mattresses are investigated. The influence of household characteristics on mite allergen concentrations, with a special emphasis on the measured relative humidity and temperature in the home, is described, and a possible explanation for the association of mite allergen concentrations with socio-economic status is sought.

Methods

Subjects

Between September 1996 and December 1998, 33 341 women delivering babies in five Connecticut hospitals and in one hospital in southcentral Massachusetts were screened for inclusion in the study. To obtain a cohort of high-risk infants, mothers who had already had a child at home younger than 11 years of age with a physician's diagnosis of asthma (asthmatic sibling) were invited to the study. Of the 1448 families identified as eligible for the study, 1002 enrolled, 334 declined to participate, and 112 could not participate due to technical reasons (moving out of area, no telephone, etc.). The Human Investigation Committee of Yale University approved this study, and all respondents gave their informed consent before participation.

Home visit

A trained research assistant visited the home when the children were between 2 and 4 months old, and administered a questionnaire to each mother to obtain information about home and family characteristics, as well as potential environmental exposures for the infant. This age range was chosen to obtain valid baseline exposure measurements for the infants. During these home visits, dust samples were collected from the infant's bed, from the asthmatic sibling's bed, and from the main living area using a standardized protocol. Dust samples were collected with a Eureka Mighty Mite II portable vacuum cleaner (The Eureka Company, Bloomington, IL, USA) fitted with Whatman cellulose extraction thimbles (single thickness, 19 × 90 mm). Extracts of sieved dust were analyzed for levels of house dust mite allergen (Der p 1 and Der f 1). Sampling, handling, and analysis of dust samples is described elsewhere (28). Results are shown in micrograms per gram of fine dust for Der p 1 and Der f 1. Detection limits were 0.1 µg/g for Der p 1 and Der f 1. All samples with concentrations below 0.1 µg/g were assigned a concentration of 0.07 µg/g dust (two-thirds of the detection limit). During the home visit, temperature and relative humidity were measured in the main living area and in the infant's bedroom, using Mannix LAM880D devices (Mannix testing and measurement, Lynbrook, NY, USA). In 750 homes (75%), dust samples were taken, and complete information on all questionnaire items was

available. Only data from these 750 homes were used in the analyses presented here.

Home and behavioral characteristics of the inhabitants, which may influence mite allergen concentrations in house dust, were identified from the questionnaire. The following characteristics were studied: type of floor cover, presence of drapes or curtains, presence of cloth upholstery in the living room, presence of air conditioning, age of the house, heating system in the house, number of rooms in the house, use of a dust mop for cleaning, use of a vacuum cleaner for cleaning, type of house, reported presence of mold or mildew in the house, use of a plastic mattress cover, use of extra layers of blankets or sheets on the children's beds, presence of stuffed animals on the children's beds, washing temperature for the bedding, age of the infant's bed, use of a humidifier, crowding, maternal education level, annual family income, number of people living in the house, and their ethnic background. All these characteristics are categorical by nature, and the exact categories are shown in Table 1.

Statistical analysis

Temperature and relative humidity were used as continuous variables, and the change in mite allergen concentration associated with an increase equal to the interquartile range of the temperature (living area: 4.4 °C, infant bedroom: 4.1 °C) and relative humidity (living area: 18.7%, infant bedroom: 17.8%) was calculated. Home visits were conducted throughout the year. To adjust for seasonal differences, the season of the home visit was added to the multivariate models. Der p 1 and Der f 1 concentrations in dust from the main living area, the infant's bed, and the asthmatic sibling's bed were best described by a lognormal distribution. Therefore, allergen concentrations were ln-transformed, and the influence of all previously mentioned characteristics was assessed using multivariate linear regression analysis based on the ln-transformed allergen concentrations. All characteristics were entered into a regression model, but only variables that showed some evidence for an association ($P < 0.10$) were kept in the final model. The association between the presence or absence of a characteristic and the concentration of mite allergen is represented by the means ratio (MR) and its 95% confidence interval. The adjusted MR shows the ratio of the geometric mean of the mite allergen concentration in the group under consideration, compared to the geometric mean in the reference group, with all other characteristics in the model being equal.

Statistical significance was assumed at $P < 0.05$. All analyses were carried out using SAS statistical software version 8.2 for Windows (SAS Institute, Cary, NC, USA).

Results

Table 1 shows the distribution of all characteristics that were used to predict Der p 1 and Der f 1 concentrations in dust samples from the main living area, the infant's bed, and the asthmatic sibling's bed. It includes characteristics of the house and the family, specific characteristics of the living area and the two bedrooms, and habits pertaining specifically to the use of both beds and the bedding.

Table 2 shows concentrations of Der p 1 and Der f 1 in dust from the main living area, the infant's bed, and the asthmatic sibling's bed. The concentration of Der p 1 was about two times lower than the concentration of Der f 1 in all three dust-sampling locations. This is also reflected

Table 1. Characteristics of 750 homes in Southern New England, USA

	House, n (%)	Living area, n (%)	Infant's bed, n (%)	Sibling's bed, n (%)
Season				
Fall (ref)	191 (25.5)			
Winter	137 (18.3)			
Spring	226 (30.1)			
Summer	196 (26.1)			
Temperature (°C)				
Median		21.6	21.8	N/A*
Interquartile range		19.5–23.9	19.8–23.9	
Minimum–maximum		10.9–32.2	10.1–30.8	
Relative humidity (%)				
Median		46.2	46.9	N/A
Interquartile range		36.7–55.3	37.8–55.3	
Minimum–maximum		4.0–88.7	12.6–89.3	
Floor cover				
Smooth (ref)		139 (18.5)	209 (27.9)	197 (26.3)
Smooth with rug		227 (30.3)	134 (17.9)	144 (19.2)
Carpeted		384 (51.2)	407 (54.3)	409 (54.5)
Drapes/curtains				
No (ref)		232 (30.9)	215 (28.7)	228 (30.4)
Yes		518 (69.1)	535 (71.3)	522 (69.6)
Cloth upholstery in living room				
No (ref)		90 (12.0)		
Yes		660 (88.0)		
Air conditioning				
No (ref)	240 (32.0)			
Yes	510 (68.0)			
Building year of the house				
Before 1949 (ref)	155 (20.7)			
1949–1979	261 (34.8)			
After 1979	161 (21.5)			
Unknown	173 (23.1)			
Heating system				
Electric (ref)	133 (17.7)			
Hot water/steam	257 (34.3)			
Forced air	360 (48.0)			
Number of rooms in the house				
<5 (ref)	167 (22.3)			
5	139 (18.5)			
6–7	252 (33.6)			
>7	192 (25.6)			
Use of dust mop for cleaning				
No (ref)	490 (65.3)			
Yes	260 (34.7)			
Use of a vacuum cleaner				
No (ref)	117 (15.6)			
Yes	633 (84.4)			
Type of housing				
Apartment (ref)	138 (18.4)			
House	612 (81.6)			
Mold or mildew anywhere in the home				
No (ref)	440 (58.7)			
Yes	310 (41.3)			
Mattress cover				
Plastic (ref)			645 (86.0)	215 (28.7)
Cloth			105 (14.0)	535 (71.3)
Extra layers over child				
0 (ref)			51 (6.8)	29 (3.9)
1			391 (52.1)	250 (33.3)
2			235 (31.3)	309 (41.2)
>2			73 (9.7)	162 (21.6)

Table 1. Continued

	House, n (%)	Living area, n (%)	Infant's bed, n (%)	Sibling's bed, n (%)
Stuffed animals on bed				
0 (ref)			376 (50.1)	416 (55.5)
1			294 (39.2)	260 (34.7)
>1			80 (10.7)	74 (9.9)
Washing temp. of bedding				
Cold (ref)			209 (27.9)	206 (27.5)
Warm			309 (41.2)	286 (37.1)
Hot			112 (14.9)	113 (15.1)
Varying			120 (16.0)	145 (19.3)
Infant mattress				
New mattress (ref)			236 (31.5)	N/A
Used mattress			449 (59.9)	
Now own bed			65 (8.7)	
Humidifier use				
No (ref)	308 (41.1)			
Yes	442 (58.9)			
Crowding				
≤ 1 person/room (ref)	617 (82.3)			
>1 person/room	133 (17.7)			
Maternal education level				
Some high school (ref)	95 (12.7)			
High school	187 (24.9)			
Some college	208 (27.7)			
College	260 (34.7)			
Annual household income (1000\$)				
<20 (ref)	190 (25.3)			
20–50	170 (22.7)			
>50	390 (52.0)			
Number of people in the household				
4 or less (ref)	304 (40.5)			
5	271 (36.1)			
More than 5	175 (23.3)			
White ethnic background				
No (ref)	308 (41.1)			
Yes	442 (58.9)			

* N/A: not applicable, cq. not available.

in the number of samples with undetectable allergen concentrations. Der p 1 was undetectable more often than Der f 1.

Figure 1 shows the individual data points of the Der p 1 and Der f 1 concentration in dust samples from the living area, the infant's bed, and the asthmatic sibling's bed. In 14% of the dust samples taken from the main living area, concentrations of both mite allergens (Der p 1 and Der f 1) were below the limit of detection. For infant's bed and asthmatic sibling's bed, this was the case for 16 and 17% of samples. Pearson correlation coefficients of ln-transformed Der p 1 and Der f 1 concentrations in the same sample were 0.46, 0.48, and 0.47, respectively, for the living area, the infant's bed, and the asthmatic sibling's bed. Pearson correlation coefficients for ln-transformed Der p 1 concentrations in samples taken from different locations in the same house ranged from 0.56 to 0.65. For Der f 1, these correlation coefficients ranged from 0.42 to 0.54.

Table 2. Mite allergen concentrations (µg/gram dust) in dust from the main living area, the infant's bed, and the sibling's bed in 750 homes in Southern New England, USA

	Not detectable	GM	GSD	Median	Interquartile range	Range
Main living area						
Der p 1	269	0.51	8.54	0.26	0.07–2.32	0.07–901.32
Der f 1	143	0.84	6.90	0.75	0.16–3.64	0.07–172.30
Infant's bed						
Der p 1	298	0.32	5.70	0.21	0.07–0.99	0.07–260.23
Der f 1	154	0.55	5.07	0.49	0.13–1.75	0.07–607.39
Sibling's bed						
Der p 1	333	0.32	6.41	0.17	0.07–1.18	0.07–214.08
Der f 1	160	0.81	7.13	0.69	0.14–3.27	0.07–258.89

All home and occupant characteristics listed in Table 1 were studied for their association with Der p 1 and Der f 1 concentrations in dust from the living area, the infant's bed, and the asthmatic sibling's bed (shown in Fig. 2), but only those characteristics that seemed to have some influence ($P < 0.1$) were kept in the models. Figure 2 shows that the Der p 1 concentration in dust from the living area (open diamonds) was significantly increased in samples taken in the fall (compared to spring), with lower living area temperatures, higher relative humidity, in the presence of cloth upholstered furniture, in houses without air conditioning, in older houses, in houses with electric heating, in houses with reported mold or mildew, and in houses of people with a white ethnic background. The Der f 1 concentration in dust from the main living area was significantly increased in houses with a lower living area temperature, in the presence of cloth upholstered furniture, in houses without air conditioning, in older houses, in houses with electric heating, in houses with more than seven rooms, in houses *vs* apartments, in

houses with reported mold or mildew, and in houses of people with a lower educational level. The Der p 1 concentration in dust from the infant's bed (filled squares) was significantly increased in samples taken during the fall, at lower bedroom temperatures, in houses without air conditioning, in older houses, in houses with electric heating, in houses *vs* apartments, in houses with reported mold or mildew, in homes of larger families, and in houses of people of white ethnic background. The infant bed Der f 1 concentration was increased at lower bedroom temperatures, in houses without air conditioning, in older houses, in houses *vs* apartments, in houses with reported mold or mildew, when the infant shares a bed, and in houses of people of white ethnic background. The asthmatic sibling's bed (filled circles), Der p 1 concentration was significantly increased in samples taken during fall, in bedrooms with rugs, in houses without air conditioning, in houses with electric heating, in houses with fewer than five rooms, in houses *vs* apartments, in houses with reported mold or mildew, in homes of families, and in houses of people of white ethnic background. The asthmatic sibling's bed Der f 1 concentration was significantly increased in samples taken during summer and fall, in bedrooms with carpets, in houses without air conditioning, in houses built between 1950 and 1979, in houses with electric heating, in houses *vs* apartments, in houses with reported mold or mildew, and when the mattress was not fitted with a plastic mattress cover.

Discussion

This large study shows that the absence of air conditioning, lower indoor temperatures, and reported mold or

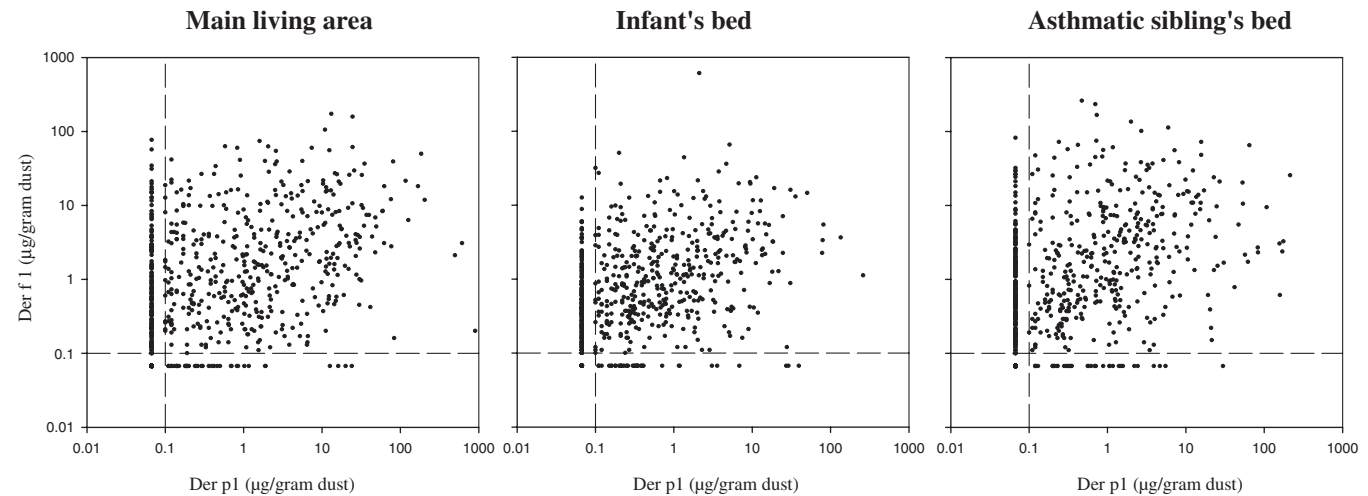


Figure 1. Der p 1 *vs* Der f 1 in dust from the main living area, the infant's bed, and the asthmatic sibling's bed for 750 homes in Southern New England, USA. Dashed lines show limit of detection for both allergens (0.1 µg/g dust). Der p 1 and Der f 1 were both undetectable in 106 samples from the main living area, 116 samples from the infant's bed, and 126 samples from the asthmatic sibling's bed.

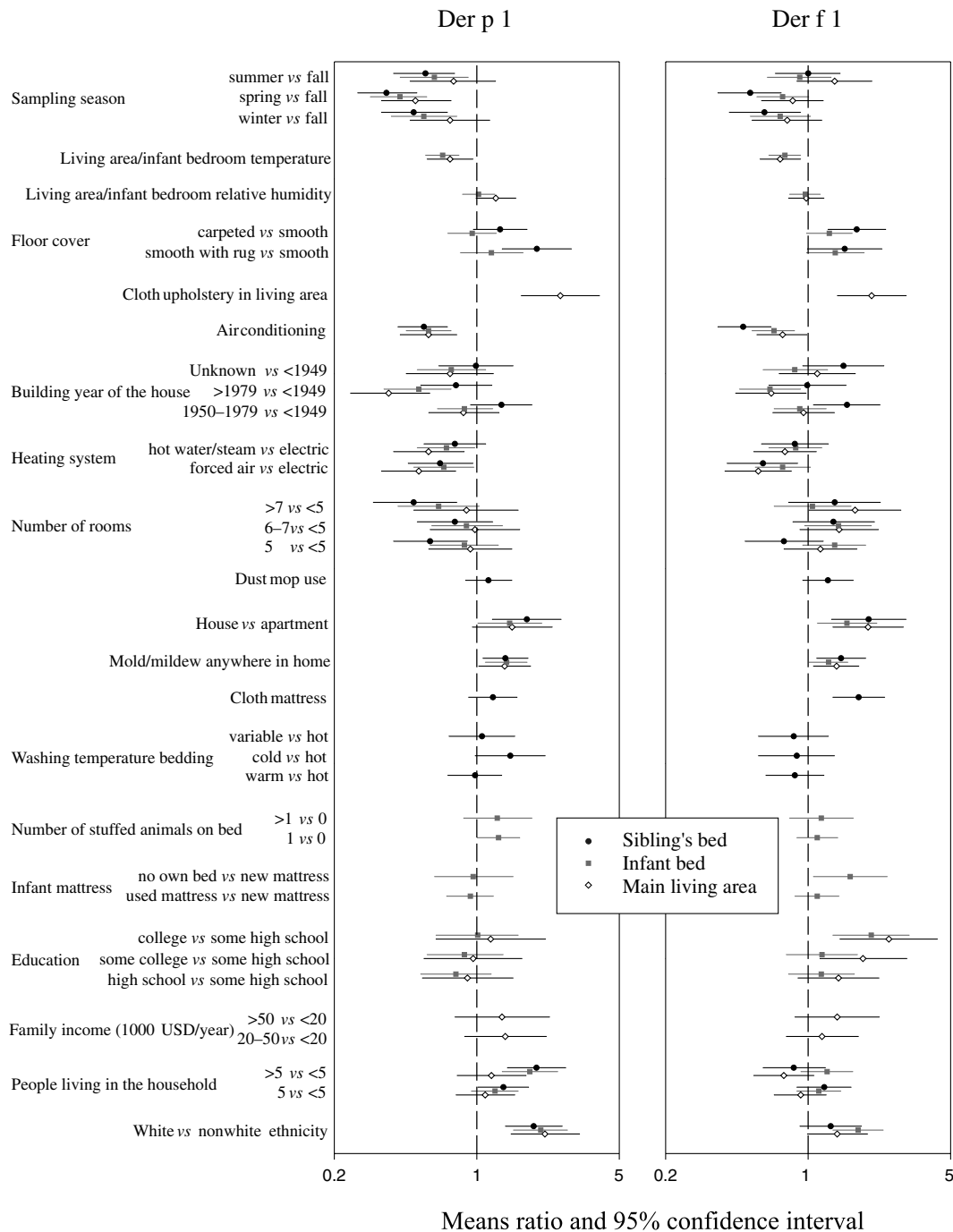


Figure 2. Multiple linear regression analysis ($n = 750$) for Der p 1 and Der f 1 concentrations in dust from the main living area (open diamonds), infant's bed (filled squares), and sibling's bed (filled circles) in relation to various home characteristics. Geometric means ratio (and 95% confidence interval) for the listed characteristic is shown.

mildew were independently and consistently associated with increased concentrations of Der p 1 and Der f 1 in house dust samples taken from the mattresses and from the living area of houses in southwestern New England, USA. Furthermore, our study also shows that measures frequently recommended to decrease mite allergen expo-

sure, such as covering the mattress, removing stuffed animals, and removing drapes or curtains, have only a limited influence on actual mite allergen concentrations.

Living area and asthmatic sibling's bed mite allergen concentrations were low compared to other studies (14, 20, 29, 30), this could be due to climatic differences

between study areas, but it could also be due to avoidance measures taken to reduce allergen exposure of the asthmatic sibling. Infant bed mite allergen concentrations were comparable to concentrations found in other studies (4, 24). Unfortunately, the amount of dust was not recorded, so the mite allergen concentration could not be adjusted for the amount of dust. The increase in mite allergen concentrations associated with the absence of air conditioning was not higher than a factor of 2, but statistically significant for both mite allergens in dust from all three sampling locations. Only one other North American study showed the same result for the presence of air conditioning in a house (29), while other studies claim to see no effects (16, 31). A decrease of living area or bedroom temperature of about 4 °C (the interquartile range) was associated with higher Der p 1 and Der f 1 concentrations by a factor of 1.4 in all dust from the living area and dust from the infant's bed. Temperature and relative humidity measurements in the living area and the infant's bedroom were taken during the home visit in a 'snapshot' manner. Even though this type of measurement represents only a moment in time, increasing temperature was associated with decreasing mite allergen concentrations, independently from season, while Ren et al. showed that increasing temperature was associated with increasing mold exposure (27). No multiple measurements per house in different seasons were available, so we were not able to estimate the reproducibility, while seasonal differences are obviously important (32). In contrast with other studies (14, 22, 33, 34), relative humidity measurements were not associated with mite allergen concentrations. Evidence from previous studies, showing an association between reported evidence of mold or dampness in the house and mite allergen concentrations (14, 21, 22, 34, 35), were confirmed. Moldy homes were associated with about 1.4 times higher Der p 1 and Der f 1 concentrations in all three sampling locations. Furthermore, concentrations of both mite allergens in dust from the living area were increased in the presence of cloth upholstery, but surprisingly not in the presence of carpets or rugs. Houses (opposed to apartments), houses with electric heating, and houses with more rooms had consistently higher mite allergen concentrations in dust from the living area and both mattresses. Apart from the association for cloth upholstery in the living area, mite allergen levels never increased by more than a factor of 2 in the presence of these characteristics. Frequently recommended measures to reduce mite allergen concentrations in house dust, like removal of drapes or curtains, removal of stuffed animals, and increasing washing temperature of the bedding, did not seem to influence mite allergen concentrations when all other factors were taken into account. The use of mattresses with a plastic mattress cover for the asthmatic sibling's bed was associated with lower mite allergen concentrations, but this difference was not seen for the infant's bed.

Socio-economic indicators, such as higher income, higher education level, and white ethnic background, were previously reported to be associated with higher mite allergen exposure (28, 30). Leaderer et al. (28) found increased mite allergen concentrations in dust from the living area of people with higher education levels, higher income, white ethnic background, and less crowded households in the same sample of houses studied here. It was our intention in this analysis to see whether the housing characteristics studied here would help explain the socio-economic determinants of mite allergen exposure. When looking closely at the analyses done for the Der p 1 and Der f 1 concentrations in dust from the living area, higher Der p 1 concentrations were associated with white ethnicity, but not with higher income or higher education levels. On the other hand, higher Der f 1 concentrations were associated with a higher education level of the mother, but not significantly with white ethnicity. About two times higher Der p 1 concentrations were found for mattress dust of the infant's bed and the asthmatic sibling's bed in families with a white ethnic background, compared to families with black or Hispanic ethnic background. This difference was independent from other characteristics, such as family income, education level, use of a new mattress, type of floor covering in the bedroom, size of the household, and a variety of building characteristics. Apart from white ethnicity, high maternal education was associated with a high Der f 1 concentration in dust from the infant's bed. This was not found for Der f 1 in dust from the asthmatic sibling's bed. No conclusion can be drawn from our study concerning the influence of socio-economic indicators on mite allergen concentrations in house dust, but it does show that future studies should focus on the influence of ethnic background, independent from income, education level, and housing characteristics.

To put all our findings in some perspective, it is necessary to point out that the adjusted R^2 for the multiple regression analyses never exceeded 0.21. This means that in the best case (Der f 1 in dust from the living area), only 21% of the variation was explained by factors taken into account in the current analyses. Omitting houses with undetectable mite allergen concentrations decreased the percentage of explained variation. The explained variation of mite allergen concentrations may not be very high and the practical use of studies like this was questioned (16), but we think that some useful information for lowering mite allergen exposure of susceptible individuals can be obtained this way.

Der p 1 and Der f 1 concentrations were only weakly correlated, as reported also by Gross et al. (23). They also concluded that Der p 1 and Der f 1 concentrations in house dust have different determinants. We could not find a clear difference between determinants for Der p 1 and Der f 1 concentrations, but measurement of both mite allergens and separate analysis of their health effects is still required, since there is some evidence that

sensitization rates for the two house dust mites are different (36).

In research on the influence of housing characteristics on mite allergen concentrations in house dust, generally two different methods are used. Some studies (16, 28, 30) use cut-off levels for the mite allergen concentration (i.e. 2 and 10 µg/g dust) and calculate odds ratios for the chance of exceeding these threshold levels. Other studies (14, 20, 23, 31, 37) use means ratios to estimate the factor change in geometric mean mite allergen concentration associated with the presence of a certain characteristic. The cut-off method claims a high degree of standardization by using constant cut-off concentrations, but methodological differences in allergen sampling (different protocols and equipment) and analysis (different handling of samples, different assays) persist between studies, and relatively small variations of laboratory conditions can already cause factor differences in the final allergen concentration (38). Comparison of geometric mean mite allergen concentrations does not assume comparability between studies; however, it does assume a normal distribution of mite allergen concentrations or transformed concentrations. Comparing geometric means utilizes all the available data, instead of grouping data in categories. In this study, the Der p 1 concentration was undetectable in many samples (up to 44% in dust from the asthmatic sibling's bed), while the Der f 1 concentrations was undetectable in fewer samples (up to 21% in the asthmatic sibling's bed). Potentially, this could cause a problem; therefore, all analyses were repeated, while omitting undetectable samples (data not shown), and

residuals were checked for normality (data not shown). The main difference between the analyses with and without undetectable samples was a reduction in power, with fewer associations being statistically significant. The direction of all statistically significant associations, however, remained the same when omitting undetectable samples. Residuals of the reported multiple linear regression analyses had a mean of 0 and were distributed close to normality, although not statistically significant (Shapiro-Wilk test). When omitting undetectable samples, the distribution of the residuals did not approach normality any better than in the original analyses. Taking all these considerations into account, we concluded that comparing geometric means to study associations between mite allergen concentrations and housing characteristics was the preferred method.

In summary, this study shows that mite allergen concentrations are significantly higher in colder houses, in houses without air conditioning, in moldy houses, and in houses of families of white ethnicity. Many of these factors can be addressed when trying to lower exposure to mite allergens to prevent the onset, or the exacerbation of allergic disease.

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