

Indoor environmental factors associated with house-dust-mite allergen (Der p 1) levels in south-eastern Australian houses

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Background Eighty households in the Latrobe Valley, Victoria, Australia, were sampled for house-dust-mite allergen (Der p 1). Allergen levels vary greatly between houses within climate regions. The reasons for this are not well understood.

Methods House-dust-mite allergen samples were collected on six occasions between March 1994 and February 1995. All participating households contained at least one child between 7 and 14 years with a total of 148 subjects, 53 of whom were asthmatic. A detailed house survey was performed during every sampling visit, and a dwelling questionnaire was completed. Relative humidity was measured at the time of sample collection.

Results The median bed allergen level was 30 µg/g during the first sampling period. Significantly higher allergen levels were associated with wool bedding and inner-spring mattresses ($P < 0.001$). As estimated from a multiple linear regression model, up to 70% reduction in bed allergen levels may be achieved by avoiding wool bedding and inner-spring mattresses. Other risk factors for high allergen levels included high indoor relative humidity, presence of substantial visible mould growth, brick cladding, and concrete slab foundation of the house.

Conclusions Avoiding wool bedding and replacing inner-spring mattresses with foam could substantially reduce bed allergen levels.

Key words: allergen avoidance; Australia; bedding; environment; house dust mite; humidity; mattress; wool.

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The house-dust mite (*Dermatophagoides* spp.) produces very potent allergens, which are an important contributing factor in asthma and other allergic diseases (1). The proportion of children who develop house-dust-mite allergy is greater in areas with high house-dust-mite allergen (Der p 1) exposure than in low exposure areas (2). Furthermore, high allergen exposure leads to a greater risk of developing asthma in those already allergic to house-dust mites (2). Thus, if a reduction in allergen exposure could be achieved in the general community, the prevalence of allergic disease and asthma should be reduced.

Regional variation in house-dust-mite allergen levels depends largely on climate differences. Since mites rely on high humidity for their survival, dry or very cold climates are generally low in allergen, while areas with high humidity and mild winters,

such as south-eastern Australia, have the highest allergen levels. In addition to such general distribution patterns, there is also great variation in allergen levels between houses within the same climate region, and the reason for this variation is not well understood (3). One possible explanation is that housing characteristics are responsible for these differences by affecting indoor humidity, thereby having an influence on the mites. This hypothesis has been tested and several scientific papers report an association between environmental factors and allergen levels, but the results are not conclusive. Some of the variability in results is probably caused by differences in climate between studies. For example, sufficient ventilation during winter has been found to be a critical factor for controlling house-dust mites in Scandinavia (4). However, in warmer climates which do not require

extended heating in winter and where the ambient humidity remains high, control measures become more complex (3). To further complicate matters, housing design and living habits vary quite considerably between continents, and such variation is likely to influence the effect of other environmental factors on allergen levels. Consequently, the most useful methods of lowering allergen levels are likely to vary between climate regions and probably also between cultural regions.

This paper presents house-dust-mite allergen (Der p 1) data from a mild temperate climate region of Australia where winter temperatures drop below 0°C on only a few occasions per year. The humidity exceeds the requirement for house-dust-mite proliferation for most of the year with only short periods below the suggested threshold of 7 g/kg (5).

Material and methods

Eighty houses in the Latrobe Valley, Victoria, Australia, were recruited for an indoor environmental study. In addition to the house-dust-mite allergen (Der p 1) data presented in this paper, levels of nitrogen dioxide, formaldehyde, and airborne fungal spores were measured. An outline of the methodology for the study has been published (6). Eighty families, with children aged 7 to 14 years, were recruited as volunteers from local doctors and primary schools. A total of 148 children in the age-group resided in the 80 households, 53 of whom were asthmatic. Forty-three households had at least one asthmatic child in this age-group, while the remaining households had only nonasthmatic children. Sampling visits were made to the households on six occasions over 1 year. The first visit was made in March–April 1994 with the following on a 2-monthly cycle finishing in January–February 1995.

Dust samples for assessment of house-dust-mite allergen (Der p 1) levels were collected from the beds of all study children, from bedroom floors and from living rooms. Bed samples included dust from the pillow, doona (continental quilt), mattress, and blankets. Bedroom floor samples were a mixture of dust from various parts of the floor, while living-room samples included dust from the floor and any soft furniture. All samples were collected during 2-min vacuuming of 1.0 m², using a frame (1/8 m²) to measure the sampled area. A domestic vacuum cleaner (Hoover, SCO28) was used with a nylon bag (open area 20%) inserted into the hose to trap each sample. Dust samples were sieved (0.3 mm), and 0.10 g of each sample was extracted in 1.0 ml phosphate-buffered saline, pH 7.4, with 0.2% bovine serum albumin (Sigma A-7030). The

samples were shaken on a shaker table for 40 min and then centrifuged (3000 rpm, 2 min), and the allergen content of the supernatant was analysed (7). The WHO standard for Der p 1 was obtained from the National Institute for Biological Standards and Control, Hertfordshire, UK. In addition, a 50% *D. pteronyssinus* extract in glycerine was used as a working standard (Hollister Stier, Spokane, WA, USA), and its concentration was determined from the WHO standard. Standard concentrations ranging from 3.0 to 200 ng Der p 1/ml were used to calculate a standard curve for each analysis. For this purpose, the concentration was log₁₀-transformed and plotted against the absorption values, resulting in an S-shaped curve fitted by nonlinear regression (8). Only the linear part of the curve was used for calculations of sample concentrations, they being diluted to a concentration within that range. Duplicate wells of sample extracts were analysed, and only results with a coefficient of variation of less than 5% were used. Results are expressed as µg Der p 1/g fine dust.

A detailed survey of the house was performed for each sampling visit. Evidence of condensation, visible mould growth, musty odour, and water intrusion were noted in every sampled room. In addition, mattress type (inner-spring or foam) and presence of bedding materials such as wool and feather-down were recorded. During the first visit to the households, a dwelling questionnaire was completed, recording information about ventilation habits, vacuum cleaner type, and any measures taken to reduce allergen levels in the house by parents of asthmatic children. Building features such as type of foundation, cladding, and floor covering were also recorded. A point measure of the temperature and relative humidity was taken in the middle of every sampled room at the time of sample collection with a digital sensor.

Statistical analysis of data was performed with SPSS for Windows, version 6.0 (SPSS, Inc., Chicago, IL, USA, 1993) (8). Mite-allergen data were positively skewed, and the nonparametric Mann-Whitney U test was therefore used for comparisons. A log₁₀-transformation was performed in order to gain a close-to-normal distribution for further analysis. Pearson's correlation coefficient was calculated to test the correlation between allergen levels and other continuous variables. Multiple linear regression was subsequently applied to identify environmental risk factors for elevated bed-allergen levels, using a forward selection method of variables with an entry criterion of $P < 0.05$. If not otherwise stated, comparisons and correlations were considered significant when $P < 0.05$.

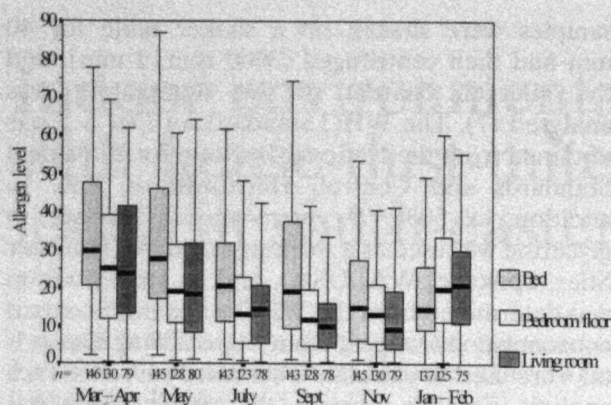


Fig. 1. House-dust-mite allergen (Der p 1) levels ($\mu\text{g/g}$) in bed, bedroom-floor, and living-room samples by sampling period. Box-plot shows median as heavy line, while box extends to 25th and 75th percentiles. Whiskers extend to furthest point which is not outlier (>1.5 interquartile ranges from box). Outliers are not shown.

Results

House characteristics

All study households resided in single family dwellings, which are the dominant form of housing, constituting 86% of dwellings in the Latrobe Valley, Victoria, Australia. Fitted carpets were present in 97% of bedrooms and in 98% of living rooms, but only in 6% of kitchens. The indoor relative humidity in the study houses varied from a mean (for all indoor measurements) of 53% in winter (July) to 62% in early autumn (March–April). Specific humidities were also calculated, with sampling period means varying from 6.3 g/kg in winter (July) to 9.8 g/kg in summer (January–February). The mean indoor temperature was 17°C in winter and 23°C in summer. During winter, higher relative humidities were recorded in bedrooms (55% RH) than kitchens (53%) and living

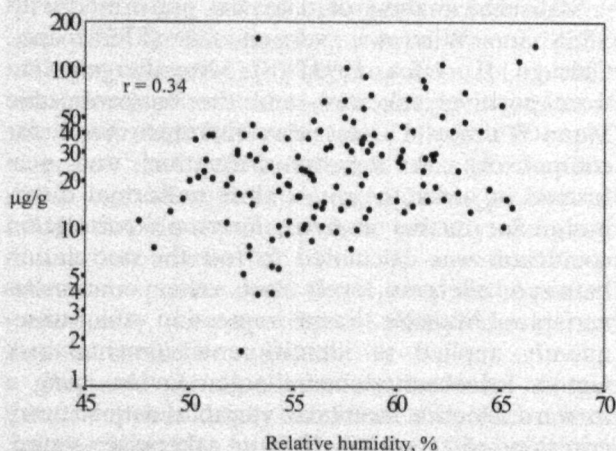


Fig. 3. Scatter plot of mean bed allergen levels (note log-scale) by mean bedroom relative humidity ($n=133$ rooms).

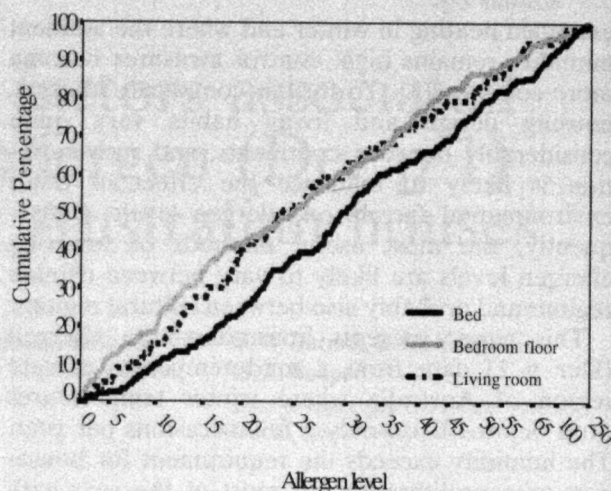


Fig. 2. Cumulative percentage of plot of allergen levels in beds, bedroom floors, and living rooms during first sampling period (Mar–Apr).

rooms (51%), and mean bedroom temperatures (17°C) were lower than in the living areas (18°C).

Allergen levels

The median house-dust-mite allergen level, including bed, bedroom floor, and living-room samples, was 17.6 $\mu\text{g Der p 1/g}$ fine dust, ranging from 0.2 to 594 $\mu\text{g/g}$. Highest levels were recorded in beds (median 21.1 $\mu\text{g/g}$), with significantly lower levels for both bedroom floors (15.9 $\mu\text{g/g}$) and living rooms (15.2 $\mu\text{g/g}$). Bed allergen levels varied by sampling period (Fig. 1), with the highest levels recorded during the first sampling period in early autumn (March–April). There was a trend for lower levels with each consecutive sampling period. Such a trend was not present for either living-room or bedroom-floor samples, where a minimum was noted in spring followed by higher levels in summer (Fig. 1). This seasonal variation for floor samples was significant, with levels around twice as high in early autumn as in spring. The median bed allergen level for the first sampling period in early autumn (March–April) was 30 $\mu\text{g/g}$, (mean 41 $\mu\text{g/g}$). All bed samples in this season exceeded 2 $\mu\text{g/g}$, while 91% of samples exceeded 10 $\mu\text{g/g}$. A cumulative distribution of allergen concentrations in bed, bedroom-floor, and living-room samples is shown in Fig. 2.

Associations with environmental factors

Environmental factors were tested for an association with allergen levels in the three sampled locations: bed, bedroom floor, and living room. A significant correlation between relative humidity in the sampled room (mean humidity of six measurements in six seasons) and bed allergen levels (mean

Table 1. Allergen levels ($\mu\text{g Der p 1/g}$ fine dust) in three sampled locations by environmental factors; geometric means are given

Variable		Bedrooms			Living rooms	
		<i>n</i>	Bed	Floor	<i>n</i>	
Brick cladding†	Yes	43	28.6	21.7	43	18.2
	No	37	19.4**	10.5**	37	11.7*
Substructure†	Slab	30	24.5	23.3	30	15.2
	Stumps	50	23.6	12.2**	50	14.6
Carpet‡	Wool	64	—	20.7	39	14.8
	Synthetic	35	—	9.9**	21	14.6
Visible mould‡	Substantial	39	29.5	15.7	17	17.7
	None/slight	94	20.5*	15.4	63	14.1

*Significantly lower, $P < 0.05$; **Significantly lower, $P < 0.01$.

†Comparison of house means, $n = 80$.

‡Comparison of room mean levels, $n = 133$ bedrooms and 80 living rooms. Carpet material was not known by 20 householders, or no carpet was present (six rooms only).

of six measurements, $\log_{10}$ -transformed) was evident ($n = 130$) ($r = 0.34$, $P < 0.001$) (Fig. 3). No significant correlation between living-room or bedroom-floor levels and relative humidity was apparent ($r < 0.10$), and there was no significant correlation between allergen levels and specific humidity ($\text{g H}_2\text{O/kg air}$). House age showed a significant but weak negative correlation with bedroom-floor allergen levels ($r = -0.38$) and with living-room levels ($r = -0.25$), but the correlation with bed allergen levels was not significant ($r = -0.09$). This implies higher floor allergen levels in new houses. Features of new houses which were associated with higher allergen levels included brick cladding and slab-type foundation (Table 1). The correlation with house age did not remain significant after adjusting for cladding and foundation type. Brick cladding was significantly associated with higher allergen levels in all three sampled locations, while slab-type foundation was significantly associated with higher allergen levels in bedroom-floor samples only. Wool carpets (65% of carpets) were associated with higher allergen levels in bedroom-floor samples ($P < 0.001$), but such an association was not seen in living rooms ($P = 0.89$) (Table 1). Carpeted floors ($n = 204$) had a geometric mean allergen level of $17.8 \mu\text{g/g}$ (16.0–19.8, 95% confidence interval), while samples from rugs ($n = 6$) had higher levels with a geometric mean of $40.6 \mu\text{g/g}$ (25.6–64.6, 95% CI). Only three samples from smooth floors were analysed, and these ranged from 1.8 to $7.3 \mu\text{g/g}$.

Measures of dampness, noted in each sampled room, were tested for an association with allergen levels. Presence of visible mould growth (substantial) was associated with higher bed allergen levels, but not with bedroom-floor or living-room levels (Table 1). Musty odour showed a marginal

Table 2. Bed allergen levels ($\mu\text{g/g}$) associated with presence of bedding materials; geometric means (GM) and 95% confidence intervals (CI) are given ($n = 130$ beds)

Variable		<i>n</i>	GM	95% CI
Wool bedding	Always	51	30.6	24.8–37.8
	Sometimes	53	23.6	20.0–27.7
	Never	26	11.2**	8.6–14.6
Mattress type	Inner-spring	109	25.0	21.9–28.6
	Foam	21	13.0**	8.9–19.1

** $P < 0.01$; lower allergen level.

association with bed allergen levels ($P = 0.10$). No significant association between allergen levels and condensation evidence or water intrusion was seen. Furthermore, no significant association between allergen levels and carpet age, carpet condition, vacuum cleaner type (upright or barrel), air conditioning (36% of houses), or presence of electric blankets (27% of beds) was seen.

Bed allergen levels were tested for associations with bedding materials. Wool bedding and inner-spring mattresses were associated with significantly higher allergen levels ($P < 0.001$) (Table 2). On the other hand, feather-down bedding, presence of soft toys, presence of spare beds or sofas, and number of occupants of the bedroom were not significantly associated with allergen levels. Inner-spring mattresses were somewhat less common among asthmatic children ($P = 0.07$), as was feather bedding ($P = 0.05$), while there was no significant difference in the distribution of wool bedding. Since asthmatics are more likely to attempt allergen avoidance, it is possible that the difference in allergen levels by mattress type was caused by such attempts. Therefore, allergen levels in foam and inner-spring mattresses were compared separately for asthmatics and nonasthmatics. Inner-spring mattresses recorded significantly higher levels in both groups ($P = 0.003$ and $P = 0.03$), and so the difference is not likely to have been caused by foam mattresses being more common among asthmatics. Data on allergen-avoidance measures practised for asthmatic children were collected, but no significant differences were seen in the small sample ($n = 53$), and the results are therefore not presented.

Mean bed allergen levels over the six sampling periods ($\log_{10}$ -transformed $\mu\text{g/g}$) were used as the dependent variable in a multiple linear regression model in order to identify major risk factors. All variables which showed some association with bed allergen levels in bivariate analyses were tested in the model. The results of the analysis are presented in Table 3. A major influence of wool bedding and mattress type was noted, and high indoor relative humidity, brick cladding, and presence of visible mould growth were also significant risk factors.

Table 3. Multiple linear regression results using bed allergen levels ($\log_{10}$ -transformed $\mu\text{g/g}$) as dependent variable

Variable	Estimate, B	SE (B)	Beta*	T statistic	P value
Relative humidity, %	0.020	0.006	0.26	3.62	<0.001
Brick cladding†	0.155	0.051	0.21	3.02	0.003
Inner-spring mattress†	0.250	0.065	0.28	3.84	<0.001
Visible mould growth‡	0.148	0.052	0.21	2.87	0.005
Wool bedding§	0.145	0.033	0.33	4.36	<0.001
Intercept	-0.508	0.342			
			R = 0.63		
			R ² = 0.40		

*Standardized regression coefficient.

†Dichotomous variables, 0=not present, or 1=present.

‡Dichotomous variable, 0=none/slight, 1=more than slight.

§Wool bedding coded as 0=never, 1=sometimes, and 2=always.

Factors which were tested but found to have no significant association with bed allergen levels included house age, resident's opinion of home dampness, insulation, extractor fans, and dwelling shade. The model explains 40% of the variation in bed allergen levels. Similar models predicting living-room levels or bedroom-floor levels were not developed due to the limited number of variables significantly associated with these measures in bivariate analyses.

Discussion

Wool bedding and inner-spring mattresses were important risk factors for allergen levels in beds, as suggested by the presented data. This appears to be the first report of wool bedding associated with allergen levels in the scientific literature. Inner-spring mattresses have been associated with mite numbers (9) and increased airway responsiveness and mite sensitivity (10). While no association between mattress material and allergen levels has been reported (11, 12), it is possible that an effect of bedding is easier to detect in areas with high allergen levels, such as in this study, and this possibility should be further explored in future studies. A reduction of bed allergen levels to around one-third of original values simply by removing wool bedding and inner-spring mattresses is implied by the current results (Table 3). While it is recognized that the allergen level is reduced only from very high to high concentrations, such a reduction may still significantly improve the health of a dust-mite-allergic child sleeping in the bed, or reduce the likelihood of developing an allergy for children who are not already sensitized. In addition, traditional methods of allergen avoidance (3) are likely to be more successful if initial allergen levels are lower, and such measures may therefore lead to a further substantial reduction in allergen levels.

Wool bedding and inner-spring mattresses may

affect allergen levels through a greater capacity to hold larger amounts of dust than other materials. Both woollen blankets and inner-spring mattresses are bulky, and neither is generally washed on a regular basis, allowing reinfestation of other washed bedding from these materials. Another possibility is that wool and inner-spring mattresses can hold moisture for longer than other bedding materials and therefore maintain a more suitable microenvironment for the mites.

The levels of house-dust-mite allergen (Der p 1) recorded in the present study are similar to those previously reported from south-eastern Australia, and among the highest recorded in the world (13). Similarly high levels have been reported from New Zealand (14), Taiwan (15), and Brazil (16). In the present data, a gradual decrease in bed allergen levels was seen with each sampling period. Such a trend was not present for floor samples. The explanation of this effect on bed samples may be that a depletion of the dust reservoir in the bed occurred by the sample collection itself. A greater sample collection effect on bed samples than floor samples may be explained by the more usual practice of vacuuming floors and by the greater area available for sample collection on floors.

Humidity is regarded as the key factor determining the extent of house-dust-mite allergen production in houses (4). From the present study, it can be seen that with indoor relative humidities above 50%, bed allergen levels are likely to exceed 10 $\mu\text{g/g}$ (Fig. 3). A correlation between humidity and bed allergen levels is present, but, while significant, the correlation is weak and not present for floor samples. Thus, the current data suggest that other environmental factors play an important role in determining allergen levels at humidities above 50%. This is consistent with the findings from other studies (17–19). Furthermore, air humidity measured at the time of sample collection (as in the present study) may be a poor reflection of the humidity in the mite microenvironment. A stronger correlation between humidity and allergen levels has been reported when a hygrometer has been used to measure humidity over a longer period (20).

Older houses had higher allergen levels in two previous studies (19, 20), but no such association was seen in another study (18). In the present study, new houses had the highest allergen levels. It is possible that these variations can be explained by the diverse building styles in the different studies. Brick cladding and slab foundation were more common in newer houses in the present study, and these two features appeared to account for the higher allergen levels, as no significant correlation between allergen levels and house age remained after adjustments.

Carpeted floors are known to contain more allergen than smooth floors (3). Recommendations for removal of fitted carpets have therefore been made to households attempting allergen avoidance, but even rugs can harbour very high allergen levels, according to the present study. Thus, it is important to wash, air, and sun rugs in order to eliminate mites. Carpet material has also been suggested as a factor affecting allergen levels. In the present study, significantly higher allergen levels were associated with wool carpets in bedrooms, but such an association was not seen in living rooms. Previously, Price et al. (21) found no association between carpet material and allergen levels in settled dust, while airborne allergen levels were higher in rooms with wool carpets. The association is therefore uncertain, but wool carpets may be a risk factor for higher allergen levels.

Evidence of dampness was recorded in sampled rooms during each visit. A significant association between presence of substantial visible mould growth and allergen levels was seen, while there was a weak trend for higher allergen levels in rooms with musty odour. These associations confirm previous reports of higher allergen levels in houses with mould problems from Sweden and The Netherlands (20, 22). A likely explanation for this association is that the conditions of dampness favour the proliferation of both mites and fungi.

In conclusion, the present data suggest that the common use of wool bedding and inner-spring mattresses contribute significantly to the high allergen levels recorded in south-eastern Australia. Avoiding these materials could lead to as much as a 70% reduction in bed allergen levels, and possibly a significant reduction in the prevalence and severity of allergic diseases such as asthma.

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