

Environmental factors influencing the levels of indoor allergens

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The relationship between exposure to environmental allergens and the development of sensitization and asthma has been widely documented (1–4). Sensitization and allergic respiratory symptoms are enhanced by exposure to various environmental adjuvant factors (5–8). Exposure to inhalant allergens and environmental adjuvant factors seems to have a great impact on the development of allergic disease in allergy-risk newborns (9–11).

In industrialized countries people spend about 90% of their time indoors (12). Therefore, allergens especially of indoor sources are probably more important than outdoor allergen sources. Important indoor allergen sources are mites, cats, dogs, cockroaches, moulds and rat urine (Table 1) (2, 13, 14). Of these allergen sources, mites, cats and dogs have received much attention. Monoclonal antibody-based enzyme immunoassays are available for determination of major allergens from mites (15), cats (16) and dogs (17). The risk level for sensitization or asthma due to some major allergens (mite and cat) have been suggested (18, 19).

Removal of patients from high allergen exposure at home to an environment with significantly lower levels of allergens significantly reduced the symptoms of asthma and bronchial hyperreactivity (20). Therefore, identification of major indoor allergens and factors influencing their levels are important in order to prevent allergic sensitization and to reduce symptoms of allergic asthma. In this paper the possible interaction between various environmental factors and major mite (Der p I, Der f I), cat (Fel d I) and dog (Can f I) allergens in dust will be discussed.

Type of environment

To date, the majority of published papers focus on determination of various indoor allergens in house dust, i.e. home environment (2–4, 13, 17, 18). The relationship between early exposure to allergens and later development of hypersensitivity and asthma has been reported by many authors (1–4, 21–23). For children, exposure especially in day-care centers and schools are important and dust allergen levels in these locations have been reported (24–27). Exposure to indoor allergens in other public places, e.g. cinema halls, trains and shopping centers, are also of importance (28–30).

We investigated major allergens from mites (Der p I, Der f I), cats (Fel d I) and dogs (Can f I) in dust from three environments of children (31). Homes of asthmatic children (32, 33), allergic children (34, 35) and newborn babies with biparental history of allergy (36) were selected. Many small children stay in day-care centers and many older children and adolescents attend schools daily. Therefore, in addition to the homes, we also investigated the levels of these allergens in dust from day-care centers and schools in the same area (24–26). Various environmental factors that could influence allergen levels were studied (24–26, 31–36).

The median Der p I and Der f I allergen level from 131 homes in Linköping was 131 ng and from 29 classrooms it was 349 ng/g dust. In 22 sections from 7 day-care centers, no or <50 ng mite allergen/g of dust was found (median value, <16 ng/g). In Norway, low levels of mite allergens were found in schools (27). Levels of mite allergens in day-nurseries has recently been reported from, Marseille, France (37). In that study mite allergen levels in dust from day-nurseries varied from < detectable amounts to ≥1 µg/g dust. These data indicate that

Table 1. Allergens commonly found indoors

Mites:	Cockroaches:
D. pteronyssinus	Periplaneta americana
Der p I	Per a I
Der p II	Blattella germanica
D. farinae	Bla g I
Der f I	Moulds:
Der f II	Alternaria
D. microceras	Cladosporium
Der m I	Penicillium
Der m II	Aspergillus
Cats:	Rodents:
Felis domesticus	rat urine
Fel d I	
Dogs:	
Canis familiaris	
Can f I	

mite allergen levels found in day-care centers and schools are similar or higher than the levels found in homes.

Thus, these locations should be considered a cause of mite allergen exposure. Importance of mite allergen levels < 2 or < 10 $\mu\text{g/g}$ dust to induce sensitization or symptoms of asthma has been discussed recently (31, 38).

Compared with mite allergen levels cat and dog allergen levels were high. Both cat and dog allergen levels were higher in day-care centers and in schools than in homes (cat median, 877 ng/g; dog median, 1192 ng/g). The median concentration of cat allergen was 972 ng/g, dog allergen 3940 ng/g in 29 classrooms from 4 schools. In day-care centers both cat (median, 1633 ng/g, $n = 22$ sections) and dog (median, 4265 ng/g, $n = 22$ sections) allergen levels were higher than the levels found in schools. In Norway, cat allergen levels were higher than mite allergen levels and the levels of cat allergen were similar to the levels found in schools in Linköping (27). We found mite allergens in all classrooms ($n = 29$), whereas mite allergen was found in 52 of 60 classrooms in Norwegian schools. We found higher values of mite allergens on table surfaces, whereas in the Norwegian study, table surfaces were not investigated.

Similar to mite allergen levels, pet allergen levels were higher in day-care centers and in schools than the levels in homes of asthmatic and allergic children. Cat allergen levels in day-nurseries have been reported from France (37). Similar to our study pet allergen levels were higher than mite allergen levels in that study. Since, children spend a lot of time in day-care centers and schools these locations may be equally important for sensitization of children as their home environment.

Thus, our data suggest that schools and day-care centers are potential sources of indoor allergen exposure and indicate that these environments are a public health problem.

Climate

Both in- and out-door climates play a major role on the accumulation of allergen indoors (31). In addition to indoor environmental factors, e.g. living habits, water consumption, etc, outdoor temperature and humidity also influence the temperature and humidity indoors.

To study the influence of climate on mite and pet allergen levels, we considered three climatic zones in Sweden. The northern region Umeå, located 600 km north of Stockholm has a sub-arctic climate, Linköping in the central part of the country is situated 200 km south of Stockholm and Helsingborg in the southern region 400 km further to the south, has a maritime climate, located along the south-west coast of Sweden.

In northern Sweden mite allergen was found in 22% of the homes, in central Sweden in 63% and in the south in all but one home. Homes in Helsingborg contained significantly higher (median, 5212 ng/g, $n = 45$), levels of mite allergens than those in the central part (median, 25 ng/g, $n = 40$), which in turn contained higher concentrations of mite allergens than those in northern Sweden (median, < 16 ng/g, $n = 41$).

The climate in these three regions is different, which might explain regional differences in mite allergen levels. The levels of mite allergens in the central part (Linköping) were low compared with the levels found in the USA (39–42) and other parts of Europe (3, 43–45) (Table 2, 46–58). The geometric mean of mite allergen concentrations in homes of asthmatic children in Atlanta, USA, was reported to be 11.3 $\mu\text{g/g}$ dust ($n = 20$) (42) and in Poole, UK, 29.5 $\mu\text{g/g}$ dust (51), whereas in central Sweden this value was 77 ng/g dust ($n = 40$) (33). In the Stockholm area mite allergens were found in about 19% of the homes of atopic children (56, 59). Low levels of mite allergen indoors have also been reported from Norway (27) which has a climate similar to central Sweden.

It seems that as compared to other parts of the world mite allergen levels were generally low in a temperate region. However, in the southern coastal region where the climate is similar to other parts of Europe, the levels were rather high. Mite allergen levels in our studies and in other studies from Scandinavia (27, 56, 59) indicate that in cold regions mite allergen levels are low compared with areas located in warm and humid regions in England (3, 43, 51), USA (39–42) and other parts of the world (Table 2)

Table 2. Mite allergen levels in various parts of the world

Geographical locations	Homes selected	Sampling sites	Mite allergen levels ($\mu\text{g/g}$) §	n =	Ref.
Atlanta [USA]	Mite allergic asthmatic children	Bedding	11.3	20	(42)
Bangalore [India]	§§	Mattress or Bedding or floor	15.3 ¥	350	(46)
Bangkok [Thailand]	Mite-sensitive patients	Mattress	>10 ††	25	(47)
Bergen [Norway]	School	Carpeted or smooth floors	<0.02	60	(27)
Berlin [Germany]	Mite-sensitized children	Mattress	12.6 †, ††	35	(44)
Copenhagen [Denmark]	§§	Mattress	1.6 ‡†	12	(48)
Cordoba [Argentina]	Mite allergic asthmatics	Mattress or pillow	>2 ††	26	(49)
Lismore [Australia]	School children	Bed and floors	83	57	(50)
Poole [UK]	Asthmatic children	Mattress or floor	29.5	50	(51)
São Paulo [Brazil]	Mite allergic asthmatics	Bedding	38.4	20	(52)
Seoul [Korea]	§§	Bedding	1000 ¥¥	20	(53)
Shanghai [China]	Allergic patients	Mattress	9.79	25	(54)
South Fore [Papua N Guinea]	Farmers	Blanket	27.4 ¥	31	(55)
Stockholm [Sweden]	Mite-sensitized children	Mattress	<0.02 ¥†	53	(56)
Strasbourg [France]	Dpt-sensitized asthmatics or rhinitics	Mattress	28.2	70	(57)
Tokyo [Japan]	§§	Bedding and Floor	6.5	13	(58)

§ = Mean or geometric mean of Der p I, unless otherwise specified, §§ = Not mentioned, † = Median, †† = Der p I + Der f I, ¥† = Der p I + Der f I + Der m I, ¥ = Calculated from number of mites/g dust (100 mites = 2 $\mu\text{g/g}$), ¥¥ = Der f I.

(44–58, 60, 61). Thus, in a temperate region the climate generally does not support mite growth.

In contrast to mite allergens, pet allergen levels were equally distributed among the three climatic zones (31). Cat allergen (Fel d I) was found in all homes in all three regions. The median values in Umeå, 796 ng/g (n = 40), in Linköping, 685 ng/g (n = 38) and in Helsingborg, 498 ng/g dust (n = 44). Dog allergen (Can f I) was found in 92%, 90% and 80% of the homes and the median level was 1000 ng/g, 693 ng/g and 600 ng/g dust in Umeå, Linköping and Helsingborg, respectively.

In Sweden, the levels of pet allergens were higher than the levels of mite allergens in homes of atopic/asthmatic children (32–35). Studies from other climatic regions in USA (39, 62) and UK (4), show lower levels of pet allergens than mite allergens in homes of atopic/asthmatic patients.

Thus, pet allergens are the dominant indoor allergens in temperate climates. Whereas, the opposite is true in warmer and humid areas, where mite and cockroach allergens predominate (39, 63). Furthermore, our data suggest that unlike mite allergens, pet allergens seem not to be influenced by climate.

Season

As climate, season is also a determinant influencing allergen levels indoors. We have investigated the levels of mite and cat allergens four times a year in homes of newborn babies in Linköping (36). Both mite and cat allergen levels were higher in October and December than in March and June. The high levels of mite allergens during late autumn and winter in our study are in accordance with the result of Platts-Mills et al. (41) in the USA. In that study significantly higher levels of mite allergens was observed during early autumn and winter than during the summer months. Hong et al. in Seoul (53), have also reported similar results.

We have also found that the levels of cat allergen were higher during autumn and winter than during the summer months. This is probably due to the fact that, during the winter season, windows and doors are kept closed and many houses are poorly ventilated (33), which helps pet allergens to accumulate indoors.

Thus, it seems reasonable to assume that the second half of the year is more important than the first

half of the year when mite and pet allergen exposure is concerned.

Reservoir of allergen

During the last decade the levels of indoor allergens have been analysed in settled dust from many sites within homes (2, 18). These locations are collectively known as reservoirs of indoor allergens.

Fifteen sampling sites in various environments of children, i.e. homes, day-care centers and schools, were investigated to observe which of the reservoirs are most important for indoors. Among these sampling sites, reservoirs of allergens varied. Carpets and upholstery in homes, tables and/or chair surfaces in day-care centers and schools were found to be the most common reservoirs of mite allergens. Both cat and dog allergens were more commonly found in mattresses, carpets and other upholstery surfaces, e.g. furniture, curtains and soft toys, in homes and day-care centers. In schools highest levels of pet allergens were observed on chair surfaces, but curtains and upholstered chairs were not investigated.

Similar to our studies, high levels of mite allergens have been reported in dust from mattresses or beddings (3, 50, 64). Other authors (40, 65, 66) have reported higher concentrations of mite allergens in dust from upholstered surfaces than in dust from other surfaces.

The distribution of pet allergens indoors has been found similar to that of mite allergens. Thus, mattresses and carpets are considered to be the major reservoirs of cat allergen in homes (4, 27, 66, 67). Other reservoirs have also been found to contain cat allergen, including bedroom and living room floors (4, 68, 69), kitchen cabinets (69), wall surfaces (70), clothes (30) and various public places (30, 71). The distribution of dog allergen has not received much attention. However, our studies show that this allergen is more commonly found on various upholstered surfaces, and the levels most often higher than those of cat allergen.

All reservoirs taken together, it can be stated that upholsteries are common reservoirs of indoor allergens. Thus, to reveal allergen exposure, collection of dust from the upholstery must be done. Further, to clean or remove upholstery must be the most relevant elimination procedure.

Home characteristics

Dampness problems

As an indication of damp homes, criteria that have been considered are the presence of persistent visible damp spots in the house (either on walls, floors or in the ceilings), visible mould growth in the dwelling, water condensation on double-glazed win-

dows and unpleasant odour in the house noticed by dwellers or visitors. Homes with presence of at least one of the first three parameters with or without odour were considered as damp (33, 36).

We found that damp homes contained higher levels of mite allergens than those with no dampness problems. Water condensation on double windows was the strongest sign of dampness and high mite allergen levels. Earlier, it was reported from the Stockholm area, that house dust mite sensitized children were exposed to damp homes more often than a control group (72). Recently, from the same area, it has been demonstrated that water condensation was more common in homes of house dust mite sensitized and other atopic children than in the control group (8). Thus, all these studies from Sweden indicate that in a cold climate high levels of mite allergens are found in homes with dampness problems.

We have also observed higher levels of cat allergens in damp homes than in homes that had no dampness problems. This is probably due to the fact that the strongest sign of dampness (water condensation on windows) was related to high indoor humidity (see below).

Thus, the presence of dampness problems indoors may be an important risk factor for high mite and cat allergen exposure.

Basement in homes

We considered whether presence or absence of a basement in homes has any influence on the levels of mite allergens in dust. Significantly higher levels of mite allergens were found in homes without than homes with a basement (33). Similarly, in schools we observed that classrooms located on ground floors, contained higher levels of mite allergens than in classrooms located on the first or second floors (25). In the Stockholm area, it has been reported that mattress dust from ground floors or basements contained higher levels of mite allergens than mattress dust from upper floors (73). Similar findings have also been reported from Berlin (74).

Ground floors and basements are more prone to develop floor moisture than upper floors. Thus, it seems that homes with no basement are probably at risk for high mite allergen exposure.

Indoor humidity

Both absolute and relative humidity indoors are major determinants for increased allergen exposure. We have measured both absolute (AIH) and relative indoor humidity (RH) from 60 homes. A house was considered humid when the absolute indoor humidity was ≥ 7 g/kg air or the relative humidity $\geq 45\%$

(33). Conditions below these critical levels are unfavourable for mites and they can not survive (75). In practice, temperature and relative humidity are rarely constant. In a cold climate, during winter season when the AIH is below 7 g of water/kg air, the RH corresponds to about 45% at an indoor temperature of 20–22°C. Under these conditions no or few house dust mites are found (56).

In our study significantly higher mite allergen levels were found in homes with high indoor humidity, i.e. $\text{AIH} \geq 7$ g/kg or $\text{RH} \geq 45\%$. All homes that contained ≥ 2 µg of mite allergen/g of dust had an $\text{AIH} \geq 7$ g/kg or $\text{RH} \geq 45\%$. In 1983, Korsgaard in Denmark (76), reported higher mite levels in homes with high humidity ($\text{AIH} > 7$ g/kg) than in homes with lower humidity ($\text{AIH} < 7$ g/kg). In a recent study from the Stockholm area (56), it has been reported that higher levels of mite allergens were found in homes with $\text{AIH} \geq 7$ g/kg than in homes with lower humidity ($\text{AIH} < 7$ g/kg). In these two studies from Scandinavia indoor RH was not measured, however. Smith et al. (42) in Atlanta, demonstrated high levels of mite allergens in homes with high RH ($\text{RH} > 45\%$). In that study, AIH was not measured. In our study we measured both AIH and RH and higher levels of mite allergens were associated with increased humidity, i.e. $\text{AIH} \geq 7$ g/kg or $\text{RH} \geq 45\%$. All these studies indicate that increased humidity indoors is a risk factor for high mite allergen exposure.

Water condensation on double windows was associated with increased indoor humidity (33). We have also found high levels of cat allergen in homes with signs of increased humidity. Homes with high humidity more commonly had a low rate of ventilation (33). It has been reported that at high humidity the size of the atmospheric particles may increase rapidly due to water absorption, leading to higher settling rates (77).

Thus, it is probable that cat allergen, Fel d I, which remains airborne for prolonged periods of time (67, 78), settles rapidly in homes with high humidity. Increased humidity indoors, therefore, not only increases the risk for high mite infestation but also facilitates the accumulation of cat allergen on various surfaces.

Ventilation

It has been reported that by increasing ventilation by mechanical ventilation systems low indoor humidity could be achieved (79). Good ventilation, defined as at least 0.5 air changes per hour (ach), has been suggested for homes in Sweden (80, 81).

We measured the rate of ventilation, i.e. ach in 56 homes. Eighty-eight percent of the homes were poorly ventilated, i.e. $\text{ach} < 0.5$. In these homes, high

levels of mite allergens were more commonly found than in homes with an $\text{ach} \geq 0.5$ ach. Two of 7 homes with an $\text{ach} \geq 0.5$ contained > 10 µg of mite allergen in dust. These two homes were located in Helsingborg, a southern coastal town and had high humidity, AIH about 8 g/kg and RH about 55%.

Korsgaard (82), has recently showed that mite allergen levels were significantly lower in homes with a ventilation rate of 0.5 ach for 6 months. It has also been suggested that the rate of ventilation should be adjusted to the actual size of the dwelling, number of inhabitants and their living habits (80, 81, 83), e.g. use of water. Thus, 0.5 ach is probably sufficient in areas with a cold climate, whereas in a humid coastal areas a still higher rate of ventilation may be required. However, in areas with high outdoor humidity, i.e. where outside humidity is > 7 g/kg and the climate makes the indoor environment an optimal breeding condition for house dust mites, ventilation will probably not solve the problem.

In parallel, we have also investigated whether this suggested rate of ventilation has any influence on the levels of cat allergen in dust. Mean cat allergen levels in dust from poorly ventilated homes ($\text{ach} < 0.5$) were, however, higher than in dust from homes with better ventilation ($\text{ach} > 0.5$). This was not true for dog allergen, Can f I. It has been reported that the airborne Fel d I, were attached to small particles (78) and influenced by the rate of ventilation (66). The aerodynamic characteristics of dog allergen, Can f I is however, unknown. It seems that increased indoor humidity is related to poor ventilation and this in turn increases the risk for accumulation of allergens indoors.

Thus, in a temperate climate both high indoor humidity and poor ventilation are risk factors for increased allergen exposure. These factors partly covariate (31).

Living habits

Carpets

We studied mite and pet allergen levels in homes with wall-to-wall carpets compared with those of homes with no such carpets. Homes with carpets contained higher mite allergen levels than in homes without carpets. Dust from living rooms where there was at least one carpet also contained higher levels of mite allergens than dust from mattresses. Our finding thus confirms the results of other studies, i.e. higher numbers of mites/mite allergen concentration in carpets than in beds or floors (40, 65, 66).

Similar results were obtained for pet allergens (31). Previous studies have demonstrated that carpets are the most important reservoirs of cat allergen indoors (27, 66) and may contain as much as 100 times more cat allergen than is present in floor dust

(67). Thus, carpets should be considered a major risk for increased indoor allergen exposure.

Contact with pets

We found high levels of both cat and dog allergens in all homes keeping these animals. This finding confirms several previous studies (17, 63, 68, 84). We have also observed that dust from homes in which a cat or dog had lived previously but not at present, contained higher levels of these allergens, than dust from homes where such animals never had been (32). In another study we observed that cats in neighbouring homes were also associated with higher levels of cat allergen (36). Thus, it seems that presence of these animals not only in homes but also living with neighbours could influence allergen levels indoors. How, this could happen we have tried and are continuing to investigate (see below).

Several studies have found high levels of animal allergens in homes where these animals had never been kept (17, 62, 68). In some homes we have also observed a similar trend (35). In day-care centers and in schools pets are usually not allowed and we found much higher levels of pet allergens in these localities than the concentration found in homes of asthmatic/allergic children (24, 26). Pet allergens have been found in public places and it has been suggested that this allergen is probably dispersed from the population's clothing (71). Later on, we launched the hypothesis that pet allergens were probably brought to schools by people who had direct contact with pets (24). This was supported by the fact that high levels of cat allergen were found after temporary visits by pet owners to homes of allergic children who had never had a pet (35). Furthermore, we found more than 500 ng of Fel d 1 in dust from a jacket of a child after one day at school and who had no known contacts with cats (31).

Thus, in addition to the presence of a pet at home, indirect contacts with pets, may increase pet allergen exposure.

Cleaning habits

To reduce indoor mite or pet allergen levels many authors have performed studies in various ways using either a chemical substance or other liquids or use of mechanical device or by intervention with or without significant success (85–91). We have studied how common vacuum cleaners influenced allergen levels in dust (34, 35). Vacuuming is the method most often used by allergic patients at home.

To study the effect of vacuuming, five groups were randomly allocated with 10 or 11 patients in each. One group used 3% solution of tannic acid.

One group, designated as placebo group, used water and their own vacuum cleaners. Three other groups used either central vacuum cleaners or vacuum cleaners with HEPA (high efficiency particulate air) filter or microfilter device (34, 35).

All groups but the tannic acid group reduced the concentration of mite allergens significantly from their baseline level over a five-week period. In the placebo group, three of 10 patients already had a vacuum cleaner with a filter device. The reduction in the placebo group is probably due to the effect of this and more intensive cleaning during the trial. Tannic acid reduced mite allergen levels for a week and the levels increased again and reached baseline levels within a week or two (34). Thus, our study shows that tannic acid has a short-lasting effect on mite allergens, whereas regular use of a modern vacuum cleaner equipped with a filter device could significantly reduce mite allergens. In a cold climate, levels of mite allergens are generally low and modern vacuum cleaners with filter devices reduced the levels further. Whether similar results could be achieved in high mite infested areas remains to be investigated.

In contrast to mite allergen levels, using these vacuum cleaners, both cat and dog allergen levels were unchanged over a five-week period and in some cases the levels were even increased by 10–45 times. Only tannic acid reduced both cat and dog allergens for one week. The levels increased again and reached initial levels within next 2–3 weeks time (35). Failure to achieve pet allergen reduction by any of the vacuum cleaners was checked. It was revealed that the sudden increase, of cat allergen level was probably due to cat and cat owners visiting the home between the samplings. Our study indicates that family members and friends transport animal allergens home in their clothes and that homes with no pets may be continuously contaminated by external contacts.

Thus, to reduce pet allergen exposure along with other measures, direct and indirect contacts with pets must be avoided.

Concluding remarks

The relationship between exposure to indoor allergens and sensitization or allergic disease has been reported by many authors and the majority of these studies have considered allergen exposure in homes, as a model. However, in addition to home environment especially, for children, e.g. day-care centers and schools should also be considered.

High levels of mite allergens are found in tropical and subtropical regions, whereas in temperate regions mite allergens are generally low. Mite allergen levels vary between climates, whereas pet allergens

are ubiquitous in the environment and independent of climatic influence. Thus, it seems that mites are major problems in warm and humid regions and pets in cold regions.

Mite allergen levels are generally higher during the second half of the year than the first half of the year. This is also true for pet allergens in cold climates.

High levels of indoor allergens are found in dust from carpets, mattresses, sofas and curtains. Therefore, it seems that upholsteries are major reservoirs for indoor allergens. This should be considered when investigation, prevention or elimination procedures are taken.

In cold climates, mite allergens are rarely found. However, high levels of mite allergens may be found in homes with dampness problems, increased indoor humidity, poor ventilation and in homes with no basement, suggesting that correction of these factors must be done to avoid indoor allergen exposure.

Presence of carpets, pets at home or at neighbours, previous keeping of pets at home, occasional visits and other contacts with pet owners may all increase allergen exposure indoors.

Regular use of vacuum cleaner 'equipped with filter device' may reduce the levels of mite allergens in dust, whereas indirect contact with pets can confound the effect of cleaning procedures to reduce pet allergen exposure. Thus, to reduce pet allergen levels a multi-system approach is needed, i.e. cleaning must be combined with avoidance of pets and indirect pet contacts.

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