

Concentrations of cat and dust-mite allergens in dust samples from 92 large US office buildings from the BASE Study

Abstract The concentrations of cat (*Fel d1*) and dust-mite (*Der f1* and *Der p1*) allergens were measured in 92 large office buildings in the US Environmental Protection Agency's Building Assessment Survey and Evaluation (BASE) Study (251 dust samples; one to four samples per building). *Fel d1* was detected in almost all buildings and samples (91 buildings, 99%; 235 samples, 94%; range: <0.01–19 µg/g; median: 0.3 µg/g). Cat allergen exceeded 1 µg/g (a lower symptom threshold) in 56 samples (22%) from 45 buildings, but exceeded 8 µg/g (a sensitization threshold) in only two samples (1%) from two buildings. *Der f1* or *Der p1* was found in approximately half of all buildings and samples (63 and 70% of buildings; 45 and 51% of samples; range: <0.01–53 µg/g and <0.01–25 µg/g; median: <0.02 and 0.03 µg/g, respectively). Mite allergen exceeded 2 µg/g (a sensitization threshold) in seven samples (3%) from five buildings and exceeded 10 µg/g (a symptom threshold) in three samples (1%) from three buildings. *Fel d1* concentration was significantly higher in samples collected in summer (June to September, 48 buildings), but cat allergen was not correlated with either mite allergen. *Der f1*, but not *Der p1*, concentration tended to be higher in samples collected in winter (December to April, 44 buildings), and the two mite allergens were significantly correlated only in winter. Cat and mite allergens were detected in 78% of representative US office buildings, but the concentrations seldom exceeded levels associated with sensitization or symptom provocation.

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Key words: Cat allergen; Dust-mite allergen; Bioaerosols; Office buildings; Building Assessment Survey and Evaluation Study.

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Practical Implications

The information on the concentrations of cat and dust-mite allergens in representative large US offices has expanded the baseline data available for interpretation of measurements from other building investigations. With suggested refinements, the BASE protocol for measurement of allergen concentrations in dust samples may serve as a guide to future studies of building characteristics, bioaerosol concentrations, and occupant perceptions of the indoor environment.

Introduction

In 1994, the US Environmental Protection Agency (USEPA) initiated a major study of indoor environmental quality in public and commercial office buildings, the Building Assessment Survey and Evaluation (BASE) study. The project protocol and a companion paper in this issue provide information on the study design and collection of environmental samples (Tsai and Macher, 2005; USEPA, 2003). The authors of this paper did not participate in the design or implementation of the BASE study, but have summarized and interpreted portions of the data (<http://www.epa.gov/iaq/largebdgs/base/index.html>).

Dust samples were collected for measurement of three major indoor allergens to expand the existing

database on potential exposures to these known agents of allergic rhinitis and asthma. Cats and house dust-mites are among the few biological agents for which an expert panel determined that there is sufficient evidence of a causal relationship with asthma exacerbation [Institute of Medicine (IOM), 2000]. The other agents in this category are cockroaches, for which allergen concentration is unlikely to be elevated in US office buildings (Custovic et al., 1996; Zhang et al., 1997), and environmental tobacco smoke, for which a causal association with asthma has been demonstrated only for preschool-aged children (IOM, 2000). Dust-mites are the only agents for which the panel found sufficient evidence of a causal relationship between exposure and asthma development.

Skin test reactivity to mammalian allergens (primarily cat antigens) and house dust-mites has been found in over 25% of the population (IOM, 1993). A literature review (Ahlbom et al., 1998) concluded that concentrations of pet allergens typically are highest in residences, in particular those of animal owners, but may be found virtually everywhere, even in remote and pet-free environments (e.g. residences, hotels, ski lodges, hospitals, rest homes, churches, primary schools, childcare centers, cinemas, banks, offices, commercial aircraft, buses, trains, and pubs) (Almqvist et al., 1999; Berge et al., 1998; Custovic et al., 1996; Janko et al., 1995; Martin et al., 1998; Menzies et al., 1998; Siebers et al., 1999; Smedje and Norbäck, 2001; Wickens et al., 1997; Zhang et al., 1997). Allergen concentrations have been found to vary with visits by persons with pets, presence of textile surfaces, cleaning standards, ventilation, human activity patterns, and season (frequently higher in the fall or heating season, depending on the region) (Ahlbom et al., 1998; Chew et al., 1999; Smedje and Norbäck, 2001; Zhang et al., 1997).

Worldwide, the dust-mites most commonly found in homes are *Dermatophagoides farinae*, *Dermatophagoides pteronyssinus*, *Euroglyphus maynei*, and *Blomia tropicalis* (Arlian, 1989). In the US, *D. farinae* and *D. pteronyssinus* are found most frequently and are the most widely distributed geographically (Arlian, 1999), and *Der f1* and *Der p1* are the dust-mite allergens most commonly assessed for their associations with building characteristics and health outcomes (Gold, 2000). The major allergen from the common pet cat (*Felis domesticus*) is *Fel d1*. While the concentrations of cat and mite allergens in public and commercial buildings typically are lower than in residences, *Fel d1*, *Der f1*, and *Der p1* concentrations in office buildings may reach levels associated with provocation of allergic symptoms. Therefore, exposures to these and other common allergens could explain building-related symptoms outside the home in some hypersensitive persons (Bollinger et al., 1996; Custovic et al., 1996; Janko et al., 1995; Lundblad, 1991; Martin et al., 1998; Menzies et al., 1998; Wickens et al., 1997).

Methods

Sample collection

Dust samples were collected either in summer (June to September; 48 buildings) or winter (December to April; 44 buildings) on the fourth day (Thursday) of a 1-week visit. Dust was collected for 2 min with a small vacuum cleaner (e.g. Eureka Mighty Mite, Eureka Company, Bloomington, IL, USA) using an aspirator tube that held a 19- × 90-mm, cellulose, extraction thimble. The aspirator tube was cleaned with isopropyl alcohol between uses (EH&E, 2000). In each building, settled

floor dust was vacuumed from the immediate vicinity of one or more of three sites (no or insufficient samples from eight of 100 buildings; one and two samples only in five and 12 buildings, respectively; two samples from one site in one building). The randomly selected sampling locations represented areas occupied by at least 50 persons who worked at least 20 h per week and were located on no more than three floors in areas served by no more than two air handling units (USEPA, 2003). A total of 27 operators collected from one sample in one building to 42 samples in 14 buildings. Typically, one operator collected all dust samples in a building, but in three buildings two operators collected samples.

Dust samples were sieved at 425 μm , and an average of 0.19 g of dust (range: 0.005–0.65 g) was analyzed by allergen-specific immunoassays for cat allergen (*Fel d1*; detection limit: 0.01 $\mu\text{g/g}$) and house dust-mite allergens (*Der f1*, detection limits: 0.01 $\mu\text{g/g}$ for 219 samples in years other than 1995 and 0.04 $\mu\text{g/g}$ for 39 samples in 1995; and *Der p1*, detection limits: 0.01 and 0.10 $\mu\text{g/g}$, as above) (EH&E, 2000). Half of the respective analytical detection limit was used to calculate allergen concentration for samples reported as below the lower detection limit.

The primary floor finish in the buildings was reported as carpet or rug, wood, tile, or other (90, 13, 2, and 2%, respectively; more than one type of primary flooring was reported in seven buildings) based on observation and communication with the building owner, manager, or operator. Field technicians collected dust samples primarily from carpets or rugs (90%), smooth floors (wood, tile, vinyl, or hard surface; 4%), and other floor types (not reported, 7%). On average, larger areas of carpets or rugs were sampled than smooth floors (mean area: 3.2 and 1.6 m^2 for 221 carpet or rug and nine smooth floor samples, respectively; sample area was missing for four carpet or rug samples). However, average sample mass was similar for all floor types (mean mass: 0.17, 0.21, and 0.31 g for carpets or rugs, smooth floors, and other surfaces, respectively). The two largest dust samples were from a carpeted and an other type of floor (maximum mass: 0.60 and 0.65 g, respectively) and the smallest sample was from a smooth floor (minimum mass: 0.005 g). Although total sample area was reported, dust loading and allergen concentration per area sampled cannot be reported because the dust samples were divided for multiple analyses and the total amount of dust that was collected was not reported.

Data analysis was conducted using SAS version 8.2 (SAS Institute, Cary, NC, USA). All available allergen results were included in the data analysis (despite the inconsistencies in the number of technicians who collected samples, the number of samples collected per building, the area sampled, the mass of sample analyzed, and the detection limit of the assay) to

preserve the representativeness of the findings in this cross-sectional study. We examined the distributions of the original allergen data and the natural logarithm-transformed values. Separate distributions also were fit for the three site-specific data series. Both raw and log-transformed data were tested for a normal distribution using zero or half the respective analytical detection limit for samples reported as not detected. None of the allergen concentration distributions were normal, and *Fel d1* and *Der p1* showed marginally significant ($P < 0.10$) log-normal distributions only if zero was used for samples below the detection limit.

Results

Approximately one-third of the dust samples contained all three allergens and 10 samples contained no detectable cat or mite allergen, but in only one building were all samples below the respective detection limits (Table 1). No significant correlations were observed between *Fel d1* and *Der f1* or *Der p1* overall ($r = -0.023$ and 0.036 ; $P = 0.72$ and 0.58 , respectively) or in either season (data not shown). Little correlation was found between the concentrations of the two mite allergens overall ($r = 0.018$, $P = 0.77$) or in summer ($r = 0.037$, $P = 0.67$), but the mite concentrations were significantly correlated in winter samples ($r = 0.237$, $P = 0.01$).

Table 2 shows summary statistics for 251 individual measurements and 92 building-wide average concentrations. Significantly higher average concentrations of cat allergen were seen in summer versus winter samples ($P = 0.0057$) (Table 2A1). *Der p1* was detected in more buildings and samples than *Der f1*, and the median *Der p1* concentration was slightly higher. Average concentrations of *Der f1* were somewhat higher in winter and *Der p1* concentrations were somewhat higher in summer, but the seasonal differences were not statistically significant ($P = 0.12$ and $P = 0.33$, respectively) (Table 2B1 and C1). No consistent patterns in allergen concentrations were observed when the samples that were collected in each season were sorted by summer or winter temperature or by summer humidity (data not

Table 1 Number and percentage of samples and buildings in which allergens were detected

	<i>Fel d1</i>	<i>Der f1</i>	<i>Der p1</i>	Samples ($n = 251$)		Buildings ($n = 92$)	
				Number	Percentage	Number	Percentage
–	–	–	–	10	4.0%	1	1.1%
+	–	–	–	85	33.9%	19	20.7%
–	+	–	–	1	0.4%	0	–
–	–	+	–	1	0.4%	0	–
+	–	+	–	42	16.7%	14	15.2%
+	+	–	–	27	10.8%	8	8.7%
–	+	+	–	4	1.6%	0	–
+	+	+	–	81	32.3%	50	54.3%

Table 2 Distributions of allergen concentrations ($\mu\text{g/g}$) by season and type of floor surface for 251 individual and 92 building-wide average samples; 131 and 120 summer and winter samples; 225, 9, and 17 carpet or rug, smooth floor, and other surface samples, respectively

Variable (above detection limit)	Mean	s.d.	Minimum	Median	Maximum
(A) <i>Fel d1</i>					
Individual samples (94%)	0.84	1.71	<0.01	0.30	19.20
Building-wide averages (99%)	0.83	1.23	<0.01	0.43	8.36
1. Summer (92%)	1.12*	2.21	<0.01	0.42	19.20
Winter (95%)	0.54*	0.79	<0.01	0.22	4.70
2. Carpet or rug (94%)	0.80	1.28	<0.01	0.31	11.80
Smooth floor (78%)	2.34	6.33	<0.01	0.10	19.20
Other surface (94%)	0.66	1.16	<0.01	0.20	4.70
(B) <i>Der f1</i>					
Individual samples (45%)	0.41	3.44	<0.01	0.02	52.82
Building-wide averages (72%)	0.38	2.12	<0.01	0.04	19.58
1. Summer (39%)	0.08	0.19	<0.01	0.005	1.60
Winter (52%)	0.78	4.95	<0.01	0.03	52.82
2. Carpet or rug (48%)	0.46	3.63	<0.01	0.02	52.82
Smooth floor (22%)	0.02	0.02	<0.01	0.005	0.05
Other surface (18%)	0.05	0.10	<0.01	0.02	0.40
(C) <i>Der p1</i>					
Individual samples (51%)	0.22	1.57	<0.01	0.03	24.60
Building-wide averages (77%)	0.22	0.92	<0.01	0.05	8.74
1. Summer (44%)	0.31	2.16	<0.01	0.01	24.60
Winter (59%)	0.13	0.22	<0.01	0.05	1.30
2. Carpet or rug (52%)	0.24	1.66	<0.01	0.03	24.60
Smooth floor (33%)	0.03	0.02	<0.01	0.03	0.07
Other surface (47%)	0.08	0.06	<0.01	0.05	0.20
(D) <i>Der f1 + Der p1</i>					
Individual samples (62%)	0.64	3.81	<0.01	0.08	53.09
Building-wide averages (86%)	0.60	2.39	<0.01	0.11	20.20
1. Summer (56%)	0.39	2.18	<0.01	0.07	24.61
Winter (68%)	0.91	5.01	<0.01	0.09	53.09
2. Carpet or rug (64%)	0.70	4.02	<0.01	0.09	53.09
Smooth floor (44%)	0.05	0.03	<0.01	0.06	0.08
Other surface (47%)	0.14	0.14	<0.01	0.07	0.60

* $P = 0.0057$ (*Fel d1* concentration higher in summer than winter).

shown). The numbers of samples from smooth and other floors were too small to determine if allergen concentrations differed by floor type, but all allergens were detected in more samples from carpets or rugs than from smooth floors (*Fel d1*: 94% vs. 78%; *Der f1*: 48% vs. 22%; and *Der p1*: 52% vs. 33%, respectively) (Table 2A2, B2, and C2).

Figure 1 shows the number and percentage of samples in different concentration ranges and the fractions that exceeded proposed guidelines for the risk of sensitization (cat allergen: $8 \mu\text{g/g}$; mite allergen: $2 \mu\text{g/g}$) and for symptom provocation in sensitized persons (cat allergen: not established but observed to be as low as $1 \mu\text{g/g}$; mite allergen: $10 \mu\text{g/g}$) (Chapman, 1995; Chapman et al., 1988; Chew et al., 1998; Dreborg, 1998; Hung et al., 1993; IOM, 1993; Leaderer et al., 2002; Platts-Mills, 1989; Platts-Mills et al., 1990). The maximum concentration as well as the fraction of samples above proposed threshold levels were higher for *Der f1* than *Der p1* (Table 2B and C, Figure 1b1 and b2). Fewer samples were below the detection limit but only one additional sample excee-

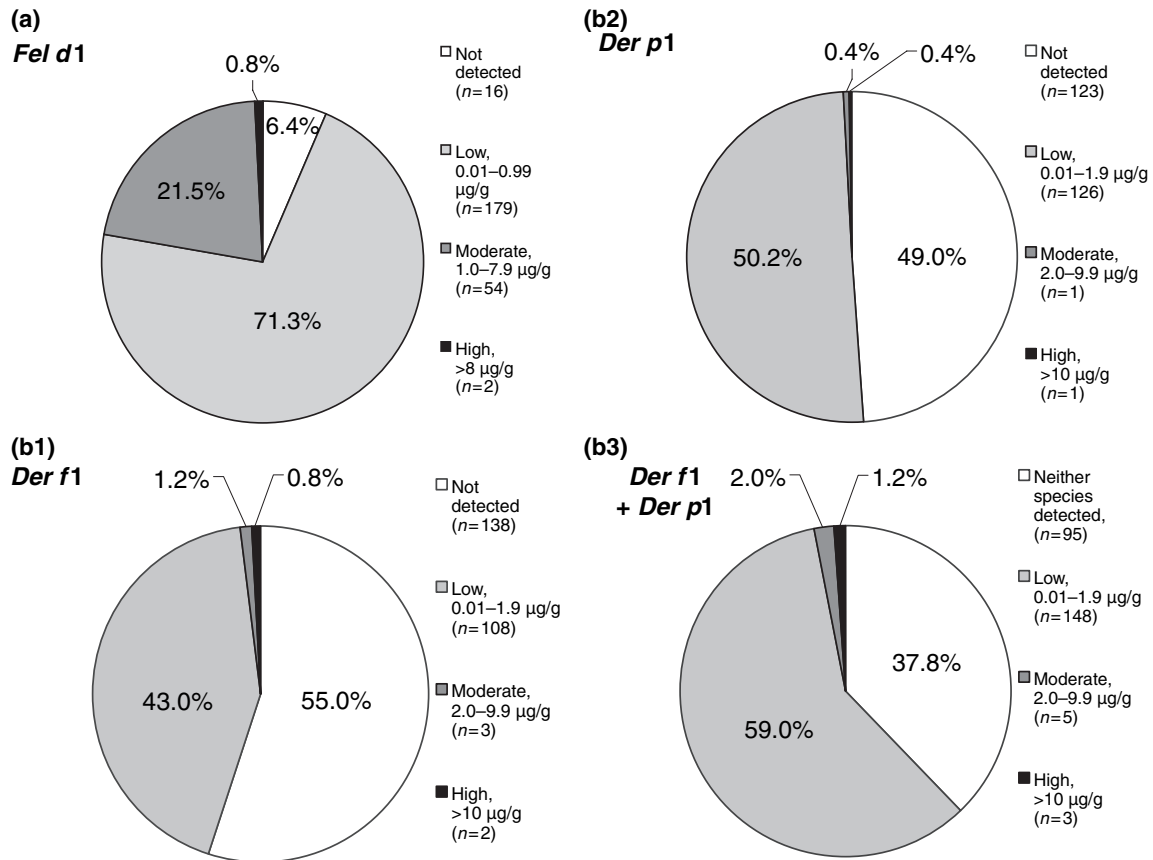


Fig. 1 Fractions of 251 dust samples in different concentration ranges: (a) cat allergen (observed threshold for symptom provocation and proposed threshold for sensitization = 1 and 8 µg/g, respectively); *Fel d1* was detected at 11.8 and 19.2 µg/g in summer samples from two buildings. (b) House dust-mite allergens (proposed thresholds for sensitization to dust-mites and symptom provocation: 2 and 10 µg/g, respectively)

1. *Der f1* was detected at 2.5 µg/g; 5.3 and 52.8 µg/g; and 6.1 and 10.9 µg/g in winter samples from three buildings, respectively
 2. *Der p1* was detected at 2.6 and 24.6 µg/g in summer samples from two buildings
 3. Fewer samples were below detection and one additional sample exceeded 2 µg/g if the concentrations of the two dust-mites were summed (eight combined samples > 2 µg/g: 3.1, 3.1, 3.2, 6.1, 7.4, 12.0, 24.6, and 53.1 µg/g).

ded the sensitization threshold if the concentrations of the two dust-mites were summed (Figure 1b3).

Discussion

Other studies also have found cat and dust-mite allergens in non-residential buildings. For example, Martin et al. (1998) found *Fel d1* in 95% of 203 floor samples from public places in New Zealand but at approximately half the concentration measured in homes without cats (geometric mean: 0.9 vs. 1.7 µg/g; 95% confidence intervals: 0.6–1.4 vs. 1.2–2.4 µg/g, respectively). Hung et al. (1993) detected *Fel d1* in 94% of 50 carpet dust samples from five office buildings in Philadelphia, PA and Washington, DC, USA (median: 0.50 µg/g; range: <0.04–46 µg/g) and found *Der f1* and *Der p1* in 64 and 44% of their samples (median: 0.10 and <0.10 µg/g, respectively; range: <0.10–16.1 and <0.10–2.0 µg/g). Lundblad (1991) detected guanine (a nitrogenous waste product of house dust-mites) in dust samples from an office in which two

mite-allergic occupants experienced rhinitis, eye irritation, and upper respiratory tract irritation. Janko et al. (1995) also found *Der p1* or guanine in approximately half of dust samples from 14 complaint offices. Concentrations exceeded 1 µg/g in four offices and were the probable cause of the occupants' health complaints in two of these workplaces.

Carpeting is common in modern office buildings, and dust and allergens can accumulate in fabric floor and furniture coverings (Bellanti et al., 2000; IOM, 1993). Higher concentrations of cat and mite allergens have been measured from carpeted as compared with smooth floors and in upholstered furniture as compared with floors (Chew et al., 1998; Custovic et al., 1996; Hung et al., 1993; Janko et al., 1995; Martin et al., 1998; Smedje and Norbäck, 2001; Wickens et al., 1997; Zock and Brunekreef, 1995). Vacuuming has been shown to reduce allergen concentrations in residential carpet dust with a greater effect for recent or more frequent cleaning (e.g. weekly vs. monthly) (Bellanti et al., 2000; Martin et al., 1998).

However, a study of public places did not see an association between *Der p1* concentrations and cleaning frequency (Wickens et al., 1997). No strong association was found in an examination of the cleaning practices in the BASE buildings (data not shown), perhaps because of adjustment of the interval between cleanings to maintain similar levels of cleanliness in office buildings.

On average, approximately twice as large an area was sampled for carpets or rugs than smooth floors; however, the number of samples from smooth floors was small ($n = 9$) and there was no significant difference between the amounts of dust analyzed from the two floor types. Laboratories typically extract approximately 0.10 g of dust to measure allergen content. The median dust sample mass in this study was 0.17 g; 53% of the samples equaled or exceeded 0.10 g and 70% contained at least 0.05 g. Less than the standard amount of dust was analyzed in some cases because the composition of the dust differed or only a limited amount was available.

Collection of insufficient dust to perform all desired analyses results in incomplete data (i.e. missing values for some sites or buildings) and the use of less than the recommended amount of sample and less reliable allergen measurements. However, collection of dust from areas that may not truly reflect potential occupant exposure to previously suspended or readily re-aerosolized particles to obtain sufficient dust in cleaner buildings (e.g. vacuuming around the perimeter of a room, in corners, under desks, or behind shelves) also is a questionable practice. The distribution of dust-mite allergen has been found to be unequal on smooth-surface floors, i.e. higher around the border of a room than in the center, most likely because occupant activities displace particles from the middle of the floor to the perimeter (Maas et al., 2003) or because difficult-to-reach areas are cleaned less often or less efficiently, which also may occur on carpeted surfaces.

It is unclear whether allergen mass concentration expressed per unit of area sampled ($\mu\text{g}/\text{m}^2$) or mass of dust analyzed ($\mu\text{g}/\text{g}$) better predicts exposure and risk of sensitization or symptom provocation (Dreborg, 1998) nor how total dust load ($\mu\text{g dust}/\text{m}^2$) should be considered. Therefore, investigators should report the total floor surface, the area vacuumed, the total amount of dust that was collected, and the amount of sample that was used for analysis so that findings can be expressed in units comparable with other studies and to identify the best measurement unit for prediction of health response (Custovic and Chapman, 1998; Custovic et al., 1999).

Pet ownership has been shown to be a strong predictor of cat allergen concentration in residences (Chew et al., 1999), and in office buildings elevated *Fel d1* concentrations have been measured in the vicinity of occupants with cats at home (Hung et al.,

1993). However, information on exposure to pets was not obtained in the BASE study. It has not been shown that the threshold levels derived from epidemiological studies of homes can be applied to public and commercial buildings to predict occupant risk of hypersensitivity development or symptoms. The relative importance of home versus community-wide exposure to cat allergen and the risk of specific sensitization to cats is unknown (Gold, 2000; IOM, 2000).

In non-residential settings, occupant activities and exposure times may differ substantially, resulting in higher or lower exposure to allergenic particles than in homes. Exposure to cat allergen may be higher outside the home for persons without pets because cat allergen has been found in almost all buildings and the small allergen-containing particles (many below $5 \mu\text{m}$) of cat dander, saliva, and urine remain suspended in air after being shed by pet owners and following resuspension from contaminated floors and furnishings (IOM, 2000). However, exposure to dust-mite allergens may be lower in non-residential buildings than in homes because dust-mites typically are found in greatest abundance in mattresses and bedding and exposure is presumed to occur while people are in bed. Antigen-containing particles of mite feces are large ($10\text{--}25 \mu\text{m}$) and do not remain suspended very long if they become airborne (IOM, 2000), thus decreasing the opportunities for exposures to mite allergens outside the home.

Dust samples were assayed for only three allergens (*Fel d1*, *Der f1*, and *Der p1*). Different sources of cat and mite allergens are a possible explanation for their low correlation. Both mite allergens were detected in more samples than either species alone (Table 2, Figure 1), but their concentrations were significantly correlated only in winter samples. Other studies have failed to observe correlations between mite species, but the investigators did not differentiate between seasons (Gross et al., 2000; Hung et al., 1993). The life cycles of various species of dust-mites differ as do their temperature preferences and water requirements, all of which affect fecundity and longevity as well as feeding and waste production (Arlian, 1999). Therefore, the factors contributing to the presence of *D. farinae* and *D. pteronyssinus* may differ, and both *Der f1* and *Der p1* should be measured in initial building investigations to determine which dust-mites are present in the region under study.

It would be useful in future investigations to collect baseline information on cockroach, dog, rodent, and bird antigens in office buildings. Personal sampling and measurement of allergen concentrations in air as well as dust also are recommended as is collection of dust from upholstered furniture, in which allergen concentrations consistently have been observed to be higher than in floor dust and to which people have closer contact (Custovic and Chapman, 1998; Custovic et al., 1996; Custovic et al.,

1999; Martin et al., 1998; Renström, 2002; Solomon, 2003; Virtanen and Mäntyjärvi, 1994). Likewise, repeated measurements of allergens in settled dust in the same buildings (e.g. in both the heating and cooling season) would improve the estimation of occupant exposures and the understanding of the environmental factors related to allergen accumulation (Heinrich et al., 2003).

Conclusions and implications

Cat allergen was found in 91 of 92 US office buildings even though cats seldom enter offices. The source of cat allergen was assumed to be flakes of cat skin, dried saliva, and urine shed not from the animals themselves but from persons in contact with cats at home or whose clothing was contaminated elsewhere (Ahlbom et al., 1998; Enberg et al., 1993; Tovey et al., 1995). A possible source of dust-mite allergens in office buildings likewise is passive transfer from elsewhere but also colonization of suitable habitats (IOM, 1993, 2000). Mites can multiply in any carpets or upholstered furniture if provided with sufficient food (primarily human skin flakes), warmth, protection, and moisture. It may not be possible to prevent the introduction of cat or mite allergens into non-residential indoor environments, but mite growth can be limited through moisture control and both allergens can be reduced through prevention of dust accumulation.

Seasonal comparisons of the data can be made only in a general sense because no buildings were studied in both seasons, but approximately equal numbers of buildings were studied in each season. Higher *Fel d1* concentrations were found in samples collected in summer (June to September) versus winter (December to April) in contrast to residential studies for which seasonal shedding and the keeping of cats indoors in

winter have been proposed as explanations, which may not apply in office settings (Ahlbom et al., 1998; Chew et al., 1999; Heinrich et al., 2003). Either or both *Der f1* and *Der p1* were detected in more than three-quarters of the buildings (78%). *Der f1* concentration was somewhat higher in winter, for which elevated indoor moisture has been proposed as an explanation (Arlian, 1999; Chew et al., 1999), and the concentrations of the two mite allergens were significantly correlated only in winter samples.

The BASE study has expanded the data available on allergen exposures in non-residential settings and has provided background concentrations for comparison with measurements in problem buildings. Exposure to cat and dust-mite allergens in workplaces may be fairly common in the USA, but the concentrations in office buildings without widely publicized complaints were relatively low. Overall, the concentrations of cat or mite allergens in 251 samples from 92 representative office buildings exceeded the higher threshold levels for cat or dust-mite allergens in only five samples (2%) from five buildings (5%). Future analyses of the bioaerosol data from the BASE study will explore the associations between biological agents and climate zone, cleaning practices, and indicators of elevated indoor moisture.

Acknowledgements

The authors appreciate the assistance of Derek G. Shendell (Lawrence National Berkeley Laboratory). This work was supported in part through Service Agreement 1W-2348-NANX between the USEPA, Washington, DC and the Public Health Foundation Enterprises, Inc. (PHFE), City of Industry, California. The views expressed in this paper are those of the authors and do not necessarily reflect those of the USEPA or CDHS.

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