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Determinants of Allergen Concentrations in Apartments of Asthmatic Children Living in Public Housing

Junenette L. Peters, Jonathan I. Levy, Christine A. Rogers, Harriet A. Burge, and John D. Spengler

ABSTRACT *There is growing evidence linking poor housing conditions and respiratory diseases, including asthma. The association between housing conditions and asthma in the inner city has been attributed in part to cockroach and mouse infestation and the resulting allergen exposures. Multiple social and behavioral factors can influence environmental exposures and health conditions, necessitating a thorough examination of such factors. As part of the Healthy Public Housing Initiative, we evaluated the association between physical and household characteristics and pest-related allergen levels in three public housing developments in Boston, MA. We detected cockroach allergens (Bla g 1 and Bla g 2) in bedroom air, bed, and especially high concentrations in kitchen samples. In multivariate Tobit regressions controlling for development and season, clutter and lack of cleanliness in the apartment were associated with a tenfold increase in Bla g 1 concentration in the air, a sevenfold increase in Bla g 1 and an eightfold increase in Bla g 2 concentrations in the bed, and an 11-fold increase in Bla g 2 in the kitchen ($p<0.05$ for all). Holes in the wall/ceiling were associated with a six- to 11-fold increase in kitchen cockroach allergen concentrations ($p<0.05$). Occupancy in an apartment unit of 2 years or more was also associated with increased cockroach allergen concentrations. In contrast, there were low concentrations of mouse urinary protein in this population. In conclusion, these results suggest that interventions in these homes should focus on reducing cockroach allergen concentrations and that building-wide interventions should be supplemented with targeted efforts focused on high-risk units.*

KEYWORDS *Asthma, Allergen, Cockroach, Mouse, Home characteristics, Low-income, Community-based participatory research*

Abbreviations: HPHI – Healthy Public Housing Initiative; ELISA – Enzyme-linked immunosorbent assay; MUP – Mouse urinary protein; LLOD – Lower limit of detection; NCICAS – National Cooperative Inner-City Asthma Study; CCCEHS – Columbia Center for Children's Environmental Health Study; NSLAH – National Survey of Lead and Allergen in Housing

Peters, Levy, Rogers, Burge, and Spengler are with the Department of Environmental Health, Harvard School of Public Health, Boston, MA, USA; Burge is also with the Environmental Microbiology Laboratory, San Bruno, CA, USA; Rogers is also with the University of Massachusetts Amherst, Morrill 1 N 239A Amherst, MA 01003, USA.

Correspondence: Junenette L. Peters, Department of Environmental Health, Harvard School of Public Health, P. O. Box 15697, Landmark Center East/Room 3-111-23, 401 Park Drive, Boston, MA 02215, USA. (E-mail: jpeters@hsph.harvard.edu)

INTRODUCTION

Among children living in impoverished urban neighborhoods, asthma is now the leading cause of school absence.[1] Indoor allergen exposure is considered an important risk factor in both developing and exacerbating asthma.[2] Sensitivity to cockroach combined with exposure to high bedroom concentrations of cockroach allergen has been associated with higher asthma morbidity in inner-city populations,[3–5] and mouse allergen is a possible risk factor as well.[6–9]

Homes in high-poverty areas in the Northeastern US are more likely to have higher cockroach allergen concentrations than homes in low-poverty areas,[5,10,11] associated with having lower household income and level of maternal education, living in multifamily homes with higher occupancy rates, and being Black or Hispanic.[10,11] Studies have also linked allergen concentrations to housing conditions and specifically to the degree of disrepair.[11–13]

Public housing is a unique housing setting of usually low- to very-low-income residents living in multiunit dwellings operated by a government landlord. By design or evolution, public housing developments are primarily located in urban, poor minority neighborhoods, especially in the Northeastern US. It would therefore be hypothesized that these developments would have elevated rates of both asthma and allergen exposures.

Surveys of two of the developments that were included in our study found asthma rates among children of 22%,[14] considerably higher than the state average of 6.5%,[15] with significant differences between developments even after adjustment for sex, age, years in public housing, and Hispanic status. These surveys found higher odds of reporting the presence of cockroach and mouse in the development with the higher asthma rate. While a majority of residents reported seeing cockroaches or mice, no environmental measures were available, impairing interpretation of the findings. Notably, reporting mouse or cockroach infestation was not uniform within developments or buildings, indicating that detailed sampling might provide insight about risk factors and intervention strategies.

In this study, we investigate the determinants of pest-related allergen concentrations and high allergen burden in three public housing developments before the implementation of pest-management intervention measures. This study is part of the Healthy Public Housing Initiative (HPHI), which seeks to understand and improve housing conditions, particularly those that affect children with asthma. HPHI is a community-based participatory research project involving three universities, Boston City housing and health agencies, and public housing community groups and consultants.[16] Given the U.S. Department of Housing and Urban Development's healthy housing directive (Public Law 105-276), identifying the determinants of high allergen levels can contribute to understanding where housing interventions and policy changes might be most influential.

METHODS

Population

Families from three public housing developments in Boston, MA, were recruited between April 2002 and January 2003 to be part of an intervention study aimed at primarily reducing pest-related allergen levels in the apartment units. Community Health Advocates trained from the developments or surrounding neighborhoods

were part of the study recruitment and data collection team. To be part of the study, a family had to include an asthmatic child between the ages of 4 and 17. Forty-nine households received environmental sampling between July 2002 and May 2003. Eleven families dropped out of the study before the environmental sampling; reasons for dropping out included time and inconvenience. This study was approved by the institutional review boards of the three collaborating universities. Informed written consent was obtained from all study participants.

The three public housing developments, Franklin Hill, Washington Beech, and West Broadway, are mid-rise walk-up family developments containing 364, 268, and 727 apartment units, respectively. West Broadway was built in 1949 and has undergone two major renovations: exterior roof and façade reconstruction and interior refurbishing and reconfiguration in 1984–1990, and a new heating system in 2000.[14] The Franklin Hill and Washington Beech developments were built in 1952 and have not undergone any major renovations to date.[14]

Collection and Analysis of Dust Samples

Two separate vacuum dust samples were collected from each apartment—one from the child's bed and the other from the kitchen floor—in cellulose extraction thimbles placed in a retrofitted wand extension and capped with a crevice tool. The protocol for dust sample collection was based on the method outlined by Chew et al.[17] In brief, for bed samples, all layers of the bedding, including the mattress and pillows, were vacuumed for a total of 5 min. For kitchen samples, the cupboard under the kitchen sink and the kitchen floor, focusing on the baseboards and around the refrigerator and stove, were vacuumed for a total of 5 min.

We collected air samples using a commercially available electrostatic precipitator (Ionic Breeze Quadra, The Sharper Image, San Francisco, CA, USA). This device has been used to measure airborne allergen and endotoxin concentrations and is described in Custis et al.[18–20] Briefly, the precipitator uses a corona discharge to charge particles, which are then attracted to an oppositely charged stainless-steel array (three $4.5\times0.4\times42.5$ cm blades). The device creates a drag on the air, which induces an average flow rate through the device of 1.48 ± 0.09 m^3 min^{-1}.[20] For each sample collection, an Ionic Breeze was placed in the bedroom and operated on medium speed for 2 weeks. Particles were removed from the array by scraping and wiping dust from blades with metal spatulas and weighing paper.

For immunoassay analysis, all samples were sieved through a 425-μm mesh to remove large particles and divided into 100 mg aliquots and stored at −20°C until extraction. Samples were extracted using borate-buffered saline at 2 ml per 100 mg of sample. Kitchen samples were analyzed for cockroach allergens (Bla g 1 and Bla g 2) and mouse urinary protein (MUP). Air and bed samples were analyzed for Bla g 1 and Bla g 2, dust mite (Der p 1 and Der f 1), cat (Fel d 1), and dog (Can f 1) allergens and MUP. For the detection and quantification of Der p 1, Der f 1, Bla g 1, Bla g 2, Fel d 1, and Can f 1, a sandwich enzyme-linked immunosorbent assay (ELISA) was used. For MUP, a competitive inhibition ELISA was used.

The measurements from the air samples are not reported per cubic meter of air because the airflow through the precipitators was not measured during sampling and the collection efficiency of the machine tends to decline as it reaches capacity. Therefore, allergen concentrations in both dust and airborne samples are reported per gram of dust. Concentrations of cockroach allergens are reported in units per gram, and for all the other allergens, concentrations are in microgram per gram.

The lower limits of detection (LLOD) are as follows: Bla g 1 0.20 U/g, Bla g 2 0.40 U/g, dust mite allergens 0.03 μg/g, cat allergen 0.012 μg/g, dog allergen 0.05 μg/g, and MUP 0.25 μg/g.

Statistics

Primary predictive covariates of interest were related to: housekeeping, physical condition of the unit as indicated by the presence of holes in the wall and ceiling, occupant density, duration of occupancy, presence of pets, and renovation status of the development. Other covariates included season, age of caregiver, and ethnicity. Housekeeping and presence of holes in the wall and ceiling (Yes or No) were assessed during visual inspection of the apartments. Housekeeping was given a rating of 1 through 5 on the basis of cleanliness and clutter. For analysis, the five categories were reduced to three: below average (1), average (2–3), and above average (4–5). Information for occupant density determination, age of the primary caretaker, pet ownership, duration of occupancy, and race and ethnicity were determined by surveying residents at the beginning of the study. We created the binary variable of occupant density using the ASHRAE criteria for occupant density of two persons in the first bedroom and one person for each additional bedroom (ASHRAE Standard 62.2-2003) as the cutoff. Because previous studies have shown elevated allergen concentrations given less than 2 years occupancy in the home,[12] we created a binary variable with 2 years as the cut point. The three developments were categorized as having had a major renovation (West Broadway) or not (Franklin Hill and Washington Beech). Age of caretaker was categorized as below or above 30 years of age (25th percentile). Ethnicity was divided into Hispanic and non-Hispanic. Season at sample collection was divided into cold months (October–April) and hot (May–September), which corresponded roughly to the designated heating/nonheating seasons.

Allergen concentrations were used as continuous data or divided into categorical variables. For continuous variable analysis, concentrations were log-transformed to address normality issues. We used Tobit regression, which uses a two-part likelihood, with one part corresponding to classical regression for values above the LLOD and the other involving a discrete distribution of relevant probabilities for nondetects. By using the Tobit regression method, we avoided the biases that would have resulted from using substitution schemes for nondetects such as using the LLOD or LLOD/2, particularly for >10% missing data.[21]

Concentrations were also divided into groups based on critical concentrations associated with asthma exacerbation (upper cut point). The critical level used for cockroach was 8 U/g,[3,22] and for dust mite,[23] dog,[24] and cat,[24] it was 10 μg/g. For mouse, the median value was used as the cut point.[25] This categorization was used to develop a high allergen burden score, which is the sum of the number of allergens in an apartment present in concentrations above critical exacerbation levels or above the median for MUP. An apartment could have a score between 0 and 7. Ordinal logistic regression was used to model allergen score or burden.

Univariate analysis was performed on each of the predictive variables of interest. To determine if specific predictors significantly impacted allergen concentrations beyond the effect of development, multivariate analysis was performed with each variable that was at least marginally significant in any media (air, bed, or kitchen) in the univariate analysis, controlling for development renovation status. Each multivariate analysis also controlled for season. *P* values less than 0.05 were

considered significant, whereas less than 0.1 was considered as marginally significant. All analyses were conducted using SAS software (version 9.1).

RESULTS

Household personal and physical characteristics are outlined by development in Table 1. A higher percentage of apartments in the unrenovated developments had signs of disrepair as indicated by holes in the wall/ceiling. There were a greater number of recent occupancies in the renovated development. Other characteristics of the study population are provided in Levy et al.[26]

Table 2 shows the concentrations and percent above the LLOD for all measured allergens. In air samples, 65% had at least one allergen above a critical exacerbation level or median (for MUP); the highest number of allergens in any one apartment over this level was three. In bed samples, 73% had at least one allergen above the critical exacerbation level or median, with two units having four allergens over this level. Cockroach allergen concentrations above the critical exacerbation level were found in 11% of air samples, 33% of bed samples, and 80% of kitchen samples.

Household Characteristic Determinants of Cockroach-Related Allergen Concentrations

In univariate Tobit analyses (Table 3), the only significant predictor of high airborne cockroach concentrations was below-average housekeeping (clutter and lack of cleanliness), with greater significance and effect for Bla g 1. Units with below-average housekeeping had 10 times higher Bla g 1 than those with average to above-average housekeeping. Below-average housekeeping also significantly predicted high bed cockroach allergen concentrations. Units with below-average housekeeping had eight times higher cockroach allergen than those with average to above-average housekeeping. Season was also a significant predictor of bed Bla g 2.

In the kitchen, there were a greater number of influential factors, likely related in part to the higher levels found in this setting. Below-average housekeeping, unrenovated developments, holes in the wall/ceiling, occupancy of 2 or more years, and hotter months were all univariately associated with higher cockroach allergen concentrations. Having holes in the wall/ceiling was the most influential predictor of kitchen cockroach allergen, having a multiplicative effect nearly twice that of other univariate predictors.

In the multivariate analysis controlling for development renovation status and season, housekeeping remained a significant predictor of high airborne Bla g 1 allergen concentrations and a marginally significant predictor of airborne Bla g 2 concentrations. For bed samples, housekeeping remained a significant predictor for Bla g 1 and Bla g 2. For kitchen samples, housekeeping was significant for Bla g 2, and the effect estimates for holes in the wall/ceiling were significant but attenuated after controlling for development renovation status and season.

Household Characteristic Determinants of Mouse-Related Allergen Concentrations

Looking at the same variables univariately as predictors of MUP concentrations (Table 4), airborne concentrations were marginally associated with high occupant density and unrenovated developments. For bed samples, the magnitude of the effect of density and unrenovated developments was lower and insignificant, but

TABLE 1 Household personal and physical characteristics by development

Household characteristics by development	Franklin Hill	Washington Beech	West Broadway	Total
Number of households	23	7	19	49
Race/ethnicity[a]				
Hispanic	65%	71%	73%	69%
African-American	35%	29%	21%	29%
Caucasian	0%	0%	5%	2%
Caregiver age <30	23%	40%	20%	24%
High occupant density	50%	20%	44%	44%
Occupancy ≥2 years	79%	57%	25%	45%
Holes in walls	96%	83%	33%	73%
Housekeeping practice				
Below average	21%	29%	28%	25%
Average	58%	57%	66%	63%
Above average	21%	14%	6%	12%
Pets	27%	40%	22%	27%

[a]Ethnicity and race were asked separately, so total may be >100%.

there was a positive association with hotter months and having pets. The MUP concentrations were 2.6 times higher in the hotter season and 2.5 times higher in apartments with pets. For kitchen MUP concentrations, the only significant associations were with pets and duration of occupancy (7.6 times higher in homes

TABLE 2 Allergen concentrations in air, bed, and kitchen dust from 49 apartment units, 30 in unrenovated developments (Franklin Hill and Washington Beech), and 19 in a renovated development (West Broadway)

					Median (max.) by development status	
Allergen	Location	*N*[a]	>LLOD (%)[b]	Median (max.)	Unrenovated	Renovated
Bla g 1 (U/g)	Air	44	55	0.26 (9.38)	0.29 (9.38)	<0.20 (4.84)
	Bed	46	70	0.34 (99.6)	0.43 (99.6)	<0.20 (7.15)
	Kitchen	44	96	61.8 (649)	84.5 (649)	14.6 (337)
Bla g 2 (U/g)	Air	41	78	1.50 (67.2)	1.85 (67.2)	0.79 (34.7)
	Bed	46	74	1.99 (71.6)	4.65 (71.6)	0.90 (28.0)
	Kitchen	46	93	198 (11884)	310 (2200)	13.0 (11884)
MUP (μg/g)	Air	44	43	<0.25 (8.09)	0.25 (8.09)	<0.25 (0.38)
	Bed	46	48	<0.25 (3.92)	0.25 (3.92)	0.08 (0.58)
	Kitchen	46	59	0.31 (55.3)	0.38 (55.3)	0.12 (25.0)
Der f 1 (μg/g)	Air	42	43	<0.03 (0.38)	<0.03 (0.38)	<0.03 (0.15)
	Bed	44	68	0.16 (23.3)	0.20 (23.3)	0.13 (2.77)
Der p 1 (μg/g)	Air	39	13	<0.03 (56.8)	<0.03 (56.8)	<0.03 (0.13)
	Bed	44	28	<0.03 (14.1)	<0.03 (8.31)	<0.03 (14.1)
Fel d 1 (μg/g)	Air	45	100	0.28 (73.2)	0.28 (73.2)	0.24 (39.8)
	Bed	45	100	0.44 (335)	0.44 (335)	0.45 (122)
Can f 1 (μg/g)	Air	42	55	0.13 (18.9)	0.20 (18.9)	0.12 (1.29)
	Bed	44	77	0.19 (350)	0.19 (350)	0.20 (7.58)

[a]*N*=Number of households
[b]LLOD=Lower limit of detection

TABLE 3 Parameter estimates (multiplicative effect)[a] from univariate and multivariate analyses of the effects of determinants on cockroach allergen concentrations using Tobit regression

Household characteristics	Air Bla g 1	Air Bla g 2	Bed Bla g 1	Bed Bla g 2	Kitchen Bla g 1	Kitchen Bla g 2
Univariate analyses						
Below-average housekeeping[b]	10.36**	4.15*	8.11**	7.78**	6.66*	14.31**
High occupant density	2.74	2.22	0.76	2.62	0.95	1.62
Unrenovated development	2.28	1.63	4.03*	2.50	6.34**	14.09**
Holes in wall/ceiling[c]	2.41	1.87	5.82*	3.45	11.96**	25.24**
Hot season	1.30	1.17	2.19	3.59**	8.54**	11.38**
Hispanic race/ethnicity	1.45	0.99	1.73	1.95	3.95*	4.62*
Having pets	1.82	1.03	1.84	1.18	0.64	3.30
Occupancy ≥2 years	2.08	2.70*	3.03*	2.33*	4.35**	4.76**
Caregiver age <30	1.22	1.35	1.04	1.35	2.42	2.51
Multivariate analyses[d]						
Below-average housekeeping[b]	9.61**	4.01*	6.92**	7.61**	4.25	10.53**
Holes in wall/ceiling[c]	2.70	2.18	5.76*	3.39	6.49**	11.24**
Occupancy ≥2 years	2.80	2.25	2.87	2.18	1.12	1.16

[a]Parameter estimates represent how many times higher the allergen levels are in households with the listed characteristics.

[b]Below-average housekeeping vs. average/above-average housekeeping

[c]Presence vs. absence of holes in the wall/ceiling

[d]Multivariate parameter estimates calculated with each variable controlling for development and season

*$p<0.1$

**$p<0.05$

with pets and 8.3 times higher for occupancy of 2 or more years). However, the effect estimates were large for housekeeping practices, unrenovated developments, and hotter season.

An earlier study in an inner-city population found mouse allergen concentrations to be associated with evidence of cockroach infestation;[7] therefore, we tested the association between MUP and high Bla g 2 (defined as >8 U/g). We found no significant association with high cockroach allergen in the corresponding location/sample type.

For MUP multivariate analysis, occupant density became a significant predictor of airborne concentrations, and having pets was reduced to a marginally significant predictor of bed and kitchen concentrations (Table 4).

Household Characteristic Determinants of Multiple Allergen Burden

Beyond the individual allergens, it is important to understand factors that predict high allergen burdens across multiple allergens (Table 5). In univariate analysis, the number of allergens per household detected in the air at high concentrations was significantly associated with renovation status and duration of occupancy. Those in unrenovated developments and those with occupancy of 2 or more years were 1.4 and 1.3 times more likely to have a greater number of allergen at high concentration than those in the renovated development and those with occupancy of less than 2 years, respectively. In the multivariate regression, the effect estimate for occupancy increased (from 1.34 to 1.51) and remained significant.

TABLE 4 Parameter estimates (multiplicative effect)[a] from univariate and multivariate analyses of the effects of determinants on mouse urinary protein concentrations using Tobit regression

Characteristics	Air MUP	Bed MUP	Kitchen MUP
Univariate analyses			
Below-average housekeeping[b]	1.87	2.22	7.02
High occupant density	2.94*	1.34	1.89
Unrenovated development	2.93*	2.01	4.56
Holes in wall/ceiling[c]	1.00	2.22	2.27
Hot season	1.26	2.63**	5.13*
Hispanic race/ethnicity	0.69	1.10	0.92
Having pets	1.50	2.51**	7.63**
Occupancy ≥2 years	0.44	1.36	5.42*
Caregiver age <30	0.64	0.99	1.09
High cockroach concentration	0.45	1.88	2.37
Multivariate analyses[d]			
Below average housekeeping[b]	1.62	2.12	6.37
High occupant density	2.98**	1.39	1.92
Occupancy ≥2 years	0.44	1.15	4.93
Having pets	1.59	2.08*	5.76*

[a]Parameter estimates represent how many times higher the allergen levels are in households with the listed characteristics.

[b]Below-average housekeeping vs. average/above-average housekeeping

[c]Presence vs. absence of holes in the wall/ceiling

[d]Multivariate parameter estimates calculated with each variable controlling for development and season

*$p<0.1$

**$p<0.05$

For bed allergen concentrations, univariate analysis showed a significant association with below-average housekeeping and owning pets (2.1 and 2.7 times higher likelihood of having a greater number of allergens at high concentration, respectively). In the multivariate model, housekeeping and having pets remained significant predictors of the likelihood of high allergen burden.

DISCUSSION

This study focused on determinants of allergen concentrations in public housing with a goal of highlighting key risk factors and groups, thereby focusing intervention efforts and recommendations for operation and policy changes. This is particularly important given the financial constraints faced by many public housing authorities and in other low-income settings.

We found that variations in cockroach allergen concentrations in the air and bed were most highly associated with housekeeping practices, whereas holes in the wall/ceiling were significant in the kitchen but not elsewhere. It appears that having a point of entry is a major determinant of whether cockroaches are able to get into a particular apartment to access available food and water, and housekeeping practice is the major determinant of whether the infestation spreads or the allergen is tracked into and builds up in the bedroom. The significant correlation between kitchen and bed cockroach allergen concentrations (Spearman correlation of 0.55 for Bla g 1, 0.72 for Bla g 2) supports this theory.

TABLE 5 Parameter estimates (multiplicative effect)[a] from univariate and multivariate analyses of the effects of determinants on increasing the likelihood of high allergen burden using logistic regression

Characteristics	Air high allergen counts	Bed high allergen counts
Univariate analyses		
Below-average housekeeping[b]	0.98	2.09**
High occupant density	0.98	0.62
Unrenovated development	1.38**	0.88
Holes in wall/ceiling[c]	0.54	1.10
Hot season	0.47	0.67
Hispanic race/ethnicity	0.09	0.79
Having pets	1.27*	2.69**
Occupancy ≥2 years	1.34**	0.13
Caregiver age <30	−0.19	0.08
Multivariate analyses[d]		
Below-average housekeeping[b]	0.69	2.09**
Occupancy ≥2 years	1.51**	0.24
Having pets	1.12	2.71**

[a]Parameter estimates represents how many times more likely for a household with listed characteristics to have a greater number of allergens at high concentration.

[b]Below-average housekeeping vs. average/above-average housekeeping

[c]Presence vs. absence of holes in the wall/ceiling

[d]Multivariate parameter estimates calculated with each variable controlling for development and season

*$p<0.1$

**$p<0.05$

Our finding of a significant contribution of deteriorating housing to high cockroach allergen concentrations is consistent with that found by Rauh et al.[12] They found a significant association between the degree of disrepair and Bla g 2 concentrations in the kitchen after adjusting for income and ethnicity.

We also found a positive (but insignificant in multivariate models) association between kitchen and bedroom cockroach allergen concentrations and duration of occupancy. However, we found lower allergen concentrations in apartments occupied for less than 2 years rather than higher as reported by Rauh et al.[12] In these public housing developments, apartments occupied for less than 2 years may represent apartments in better physical condition. Apartment turnover allows maintenance staff to thoroughly clean, treat, and repair the whole unit. Moreover, short-duration occupancy was greatest in West Broadway, which had major renovations and fewer holes in the wall/ceiling, among other differences, complicating interpretation of this covariate. While this covariate represented "residential stability" for Rauh et al., it may capture a different phenomenon in public housing wherein short-term residents may be more likely to be socioeconomically mobile than long-term residents.

Our study found similar seasonal differences as reported by Mollet et al.[27] and Chew et al.[17] of higher cockroach allergens in the hotter months. However, the seasonal difference in our population could have been affected in part by increased pest awareness due to a housing authority-wide pest program and benefits to early recruits that may have inspired greater interest in the study in the fall and winter sampling period by those with less severe pest problems. In addition, the summer sampling was done in the Franklin Hill development only, whereas the winter

sampling was done in all three developments with the greatest number of winter samples collected in West Broadway.

Our study had comparable median kitchen cockroach allergen concentrations with those reported for the National Cooperative Inner-City Asthma Study (NCICAS),[28] three times the levels observed in a Baltimore inner-city study,[29] and two orders of magnitude above the geometric mean concentration found in the New York City Columbia Center for Children's Environmental Health Study (CCCEHS).[6] The bed levels for our study were comparable to CCCEHS. The NCICAS bedroom values were a combination of bedroom floor and bed,[3] and studies that report both levels often report much higher levels for floor dust than for bed dust.[10,30]

As a whole, mouse allergen does not appear to be a major problem in these developments in terms of allergen concentrations and number of detects. Self-report of mouse problems was also low. Our mouse levels were much lower than those found in other studies in urban environments.[6,7,29,31] Likely due to the lower levels, unlike the NCICAS[25] and the National Survey of Lead and Allergen in Housing (NSLAH)[31] and similar to the CCCEHS,[6] we did not find a significant association between cockroach allergen concentrations and mouse concentrations. We found MUP concentrations to be consistently associated with having pets; however, our analysis did not distinguish among the types of pets, so that the inverse relationship between the presence of cats and mouse allergen concentrations found in the CCCHES[6] was not assessed.

There was low detection of dust mite similar to the pattern found by Chew et al.[32] and Kitch et al.[10] of lower dust mite allergen levels in urban inner-city homes in the Northeast. As in these studies, Der f 1 was more highly detected and had greater percentage above the thresholds. However, in skin-prick tests of our study population, a higher percent of the children showed sensitivity to Der p 1 (59%) than Der f 1 (50%) and an equal percent to cockroach allergen (59%).[26] The dust mite sensitivities may have been related to early childhood exposure in another environment.

High airborne concentrations of allergens were frequently associated with a high occupant density, which is not surprising given that greater disturbance of allergen reservoirs occurs with higher levels of human activity. We also found a subset of airborne cockroach allergen concentrations in the bedroom, which was above the existing critical exacerbation level. However, the critical exacerbation thresholds are based on studies that examined bed and floor dust concentrations. Because measurement in air is more relevant to exposure, it could be that a much lower threshold level would be associated with exacerbation than has been found for bed and floor dust.

There are some limitations in interpreting our findings. We evaluated determinants in 49 homes, which limited our power to detect significant predictors. In addition, data were collected in three housing developments, two of which had not been renovated and one of which had. However, the plausible causal pathways and magnitude of the associations even after controlling for renovation status strengthen our interpretations. In addition, some of the predictive variables had only small numbers in the groups, which could result in unstable estimates, and multiple predictors were correlated with one another. More generally, public housing is unique in its design, structure, and operation, which may not make the results generalizable to other housing types. However, the associations are

consistent in terms of what is known about the influence of building conditions and about pest ecology.

Even though unrenovated developments have higher cockroach allergen concentrations, there are very high concentrations in all three public housing developments we evaluated, which need to be addressed. Residents reported that pest infestation particularly by cockroaches is one of their key issues of concern. Providing physical and educational interventions has been proposed as a means of reducing allergen concentrations. Concerted efforts by the public housing management to keep the basements sealed and clean in these developments have probably already contributed to lower concentrations of mouse allergen. To successfully control the cockroach population, building and unit conditions will need to be addressed, such as holes in the walls and ceiling. Interventions also need to focus on education about the role of housekeeping and strategies for making homes less hospitable to pests.

Our study highlights that even among households with similar housing structures and administration, there is variability in the allergen concentrations and number of allergens at high concentrations. This implies that while some pest remediation activities must be focused on the building, other efforts must address characteristics of the unit and resident.

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