Journal of Urban Health: Bulletin of the New York Academy of Medicine, Vol. 88, No. 1
doi:10.1007/s11524-010-9527-4

Are Building-Level Characteristics Associated with Indoor Allergens in the Household?

Lindsay Rosenfeld, Ginger L. Chew, Rima Rudd, Karen Emmons, Luis Acosta, Matt Perzanowski, and Dolores Acevedo-García

ABSTRACT *Building-level characteristics are structural factors largely beyond the control of those who live in them. We explored whether building-level characteristics and indoor allergens in the household are related. We examined the relationship between building-level characteristics and indoor allergens: dust mite, cat, cockroach, and mouse. Building-level characteristics measured were presence of pests (seeing cockroaches and rodents), building type (public housing, buildings zoned commercially and residentially, and building size), and building condition (building age and violations). Allergen cutpoints were used for categorical analyses and defined as follows: dust mite: >0.25 μg/g; cat: >1 μg/g; cockroach: >1 U/g; mouse: >1.6 μg/g. In fully adjusted linear analyses, neither dust mite nor cat allergen were statistically significantly associated with any building-level characteristics. Cockroach allergen was associated with the presence of cockroaches (2.07; 95% CI, 1.23, 3.49) and living in public housing (2.14; 95% CI, 1.07, 4.31). Mouse allergen was associated with the presence of rodents (1.70; 95% CI, 1.29, 2.23), and building size: living in a low-rise (<8 floors; 0.60; 95% CI, 0.42, 0.87) or high-rise (8+floors; 0.50; 95% CI, 0.29, 0.88; compared with house/duplex). In fully adjusted logistic analyses, cat allergen was statistically significantly associated with living in a high-rise (6.29; 95% CI, 1.51, 26.21; compared with a house/duplex). Mouse allergen was associated with living in public housing (6.20; 95% CI, 1.01, 37.95) and building size: living in a low-rise (0.16; 95% CI, 0.05, 0.52) or high-rise (0.06; 95% CI, 0.01, 0.50; compared with a house/duplex). Issues concerning building size and public housing may be particularly critical factors in reducing asthma morbidity. We suggest that future research explore the possible improvement of these factors through changes to building code and violations adherence, design standards, and incentives for landlords.*

KEYWORDS *Asthma, Buildings, Building size, Indoor allergens, Public housing*

INTRODUCTION

The relationships between both individual and household characteristics and indoor allergens in the household are well known.[1–3] Yet, there are gaps in our understanding of the relationship between building-level characteristics and allergens. Previous literature has demonstrated a relationship between building

Rosenfeld and Acevedo-García are with the Institute on Urban Health Research, Bouvé College of Health Sciences, Northeastern University, Boston, MA, USA; Chew, Acosta, and Perzanowski are with the Department of Environmental Health Sciences, Mailman School of Public Health, Columbia University, New York, NY, USA; Rosenfeld, Rudd, Emmons, and Acevedo-García are with the Department of Society, Human Development, and Health, Harvard School of Public Health, Boston, MA, USA; Emmons is with the Dana-Farber Cancer Institute, Boston, MA, USA.

Correspondence: Lindsay Rosenfeld, Institute on Urban Health Research, Bouvé College of Health Sciences, Northeastern University, Boston, MA, USA. (E-mail: l.rosenfeld@neu.edu)

materials and associated chemical or biological agents (e.g., volatile organic compounds and fungi) and building-related symptoms/illness,[4–7] supporting the idea that building characteristics are related to health symptoms. In addition, housing type and building age have been examined.[8–11] We explored the relationship between a set of building-level characteristics (presence of pests, building type, and building condition) and common urban indoor allergens (dust mite [Der f 1], cat [Fel d 1], cockroach [Bla g 2], and mouse urinary protein [MUP]) in a cohort of Puerto Rican residents in New York City.

Asthma and Indoor Allergens

Asthma, affecting millions of Americans, is a critical and potentially fatal lung disease.[12] It is associated with physical, social, and environmental issues.[13–22] Over the past two decades, asthma morbidity and mortality within the USA have increased to epidemic proportions among all age, race, and gender groups in every region of the country.[23]

High levels of indoor allergens are associated with asthma morbidity.[11,24–26] Asthma and sensitization to cockroach allergen are widely known to be associated.[27–29] High exposure to cockroach allergen is a risk factor for both asthma medication use and asthma-related hospitalizations.[26] In addition, the presence of dust mite, cat, cockroach, and mouse allergen in the home have been found to be related to airway hyperresponsivesness[30] and sensitization to dust mite and cat allergen are related to wheezing.[31] Mouse allergen's contribution to asthma has also been studied,[9,32–35] and significantly more asthmatic children have been shown to be allergic to mice (assessed by skin prick) when mouse allergen levels reach a certain cutpoint.[36] In all, increased exposure to allergens, particularly dust mites and cockroaches, is related to an increased risk for the development of asthma.[37–39]

Building Level

While researchers have established that asthma is an ever-growing burden, more so for some USA communities than others, they have not yet firmly delineated the issues that put people at highest risk for being exposed to indoor allergens, and/or developing asthma. Most asthma research in the USA focuses on in-unit and other individual-level triggers, with a few exceptions.[40,41] Such triggers include household environmental exposures, high parental stress, poor medication adherence, child behavioral or emotional concerns, and poor medical care.[3,16,21,22,24–26,42–47]

An emerging literature does suggest that indoor allergens associated with asthma are related to the buildings in which people live.[10,11,48–52] Considerable literature firmly establishes that the presence of cockroaches and rodents (i.e., pests) is associated with higher levels of asthma morbidity.[5,10,24,51,53–57] Likewise, recent literature has highlighted the relationship between asthma morbidity and building types such as public housing;[54,58] mixed-use buildings, i.e., property containing both residential and commercial space;[59–61] and building size.[9–11,62,63] Lastly, indoor allergens and asthma morbidity have also been linked to building conditions; in particular older buildings and building violations in or near the residential building have been associated.[8,10,48,49,51,52] However, little explicit examination by building type and condition has occurred, especially in the USA.

We explored the relationship between building characteristics and indoor allergens in the Puerto Rican Asthma Project cohort.[64] Puerto Ricans are among the racial/ethnic groups most widely affected by asthma in the USA.[24,65–74] We hypothesized that specific building-level characteristics—presence of pests and building type and conditions—were associated with levels of indoor allergens.

METHODS

The Puerto Rican Asthma Project (PRAP) is a prospective birth cohort of Puerto Rican children born in New York City (NYC) to mothers who had asthma and/or inhalant allergy. Full study details have been discussed previously.[64] Briefly, 274 mothers and their newborns completed the initial baseline home visit within a few weeks after the birth of the child. Participant mothers answered questions on behalf of their household and child in either Spanish or English. A team of two technicians, one of whom was bilingual (Spanish/English), collected dust samples and administered a questionnaire to the mother. During this baseline visit, the surface of the mother's bed was vacuumed for 3 minutes and samples were analyzed for Der f 1, Bla g 2, Fel d 1, and MUP allergens as previously described.[64]

Building characteristics data were collected from the New York City Open Accessible Space Information System Cooperative (OASIS) database (www.oasisnyc.net) from March to April 2007.[75] OASIS is a web-based Geographic Information Systems mapping resource for NYC. It is a partnership of more than 30 federal, state, and local agencies, private companies, academic institutions, and nonprofit organizations, creating a one-stop, interactive mapping and data analysis application via the Internet. Each participant address was entered into the OASIS mapping system a minimum of three different times to collect building characteristics data. If the address still could not be located, the participant was dropped from the analysis. All study participant addresses were geocoded by the commercial geocoding firm Mapping Analytics.[76] At baseline, 12 participants were excluded from the building-related statistical analysis because they were not available in OASIS. Eight lived outside the five NYC boroughs and four addresses could not be located in OASIS. Thus, at baseline, 261 participants remained for analysis. The Human Subjects Committees at the Harvard School of Public Health and at Columbia University Medical Center approved this study.

Measures

PRAP outcome, pest, and sociodemographic data were collected from September 2002 to August 2005.

Allergen Outcome Measures. We examined four indoor allergens as independent outcomes of building-level characteristics, including Der f 1, Fel d 1, Bla g 2, and MUP. Samples were collected from mothers' beds. Allergen levels were ln-transformed to approximate normality. Logistic regression was also used to explore previously published allergen level thresholds for allergic sensitization, when possible (cockroach, >1 U/g [1 unit=40 ng] and mouse, >1.6 μg/g); and if this was not possible, the detection limits of the relevant immunoassay were used (dust mite, >0.25 μg/g; cat, >1 μg/g).[9,26,28,37,77,78]

Building Exposure Measures. Presence of pests (e.g., cockroaches and rodents) was reported by mothers on the baseline interview survey. Building type was assessed by research staff and characterized as duplex, house, or multistory, with a follow-up question to the resident about the total number of floors. For this analysis, building type was categorized as follows: house/duplex, low-rise apartment (<8 floors), and high-rise apartment (8+ floors).

We measured building type and condition data for each participant's baseline address from information gathered from the OASIS database. Building-level data were collected from the OASIS database (www.oasisnyc.net) from March to April 2007 using participants' addresses.[75] We collected building-level data on public housing and commercial/residential zoning to determine building type and data on building age and building violations cited as Environmental Control Board (ECB) violations to determine building condition. Each participant's address was characterized as public housing or not public housing, and being either a purely residential building or a building with both commercial and residential properties. Building age was calculated by subtracting the year the building was built from the year data were collected. Addresses for all study participants were geocoded by the commercial geocoding firm Mapping Analytics.[79] Building violations for each address were collected by linking to the NYC Department of Buildings (DOB) Property Profile Overview to obtain the number and type of violation for each address.[80] An ECB violation is a notice that a property does not comply with a provision of the NYC Building Code and/or NYC Zoning Resolution, and such violations are resolved at the Environmental Control Board, an administrative law court where a violator must (a) pay a civil penalty and correct the violating condition and (b) file a Certificate of Correction with the DOB.[81] Violations were standardized by building age and number of units in the building, and then multiplied by 100 for ease of interpretability. The OASIS database and the NYC Department of Buildings, Property Profile Overview are publicly available data repositories.

Covariates. Mother's education and household income were measured in the baseline interview survey and were dichotomized: *education* (≤high school graduate (referent) or ≥some college); *household income* (≤\$39,999 (referent) or ≥\$40,000+).

Sociodemographic Variables. During the baseline interview survey, information was collected about marital status (married, divorced, separated, widowed, never been married), birth place (Mainland USA, Puerto Rico, Dominican Republic, Mexico, Other), and how long they had lived in the USA (number of years).

ANALYSIS

We evaluated the association ($p<0.05$) between building exposures and household indoor allergen levels, using bivariate and multivariable linear regression as well as logistic regression for allergen cutpoint levels, as specified earlier. Possible confounders (income and education) were included in all subsequent analyses.

We first examined the distributions of sociodemographic variables, potential confounders (income and education), building exposures, and the outcomes of interest (indoor allergens). The natural log was used for modeling allergens, as well as reporting the geometric mean.[33,82] We then evaluated the association between building exposures and indoor allergens, using bivariate and multivariable linear and logistic regression ($p<0.05$). Possible confounders (income and education) determined to be related to building exposures and outcomes a priori were maintained in all subsequent multivariable analyses. Bivariate models examined the relationship of one building exposure at a time to each outcome. The first set of multivariable models examined the same relationships, while also adjusting for income and education. The next set of multivariable analyses examined fully adjusted linear models, where each parameter estimate is adjusted for all other exposures in the model, including income and education. The next set of multivariable analyses examined fully adjusted logistic models, where each parameter estimate is adjusted for all other exposures in the model, including income and education. For multivariable linear analyses, all ratios and 95% confidence intervals were back-transformed to represent the original allergen scales instead of log scales. All analyses were performed in SAS 9.1 and JMP 7.0.[83,84]

RESULTS

Sample. Most mothers in the sample have never been married (64.8%) and were born on the Mainland USA (73.6%). One fifth (20.7%) were born in Puerto Rico. In addition, 56.3% of mothers had a high school education or less, and 80.8% lived in households where the combined family income was less than $39,999/year.

About 15% of the participants lived in public housing, and 16.9% lived in a building zoned both commercially and residentially. About 59% lived in low-rise apartment buildings, and 17.8% lived in high-rise apartment buildings (referent= duplex/house). The average age of buildings where participants lived was 68.9 years. The average number of standardized ECB violations per unit was 0.2. (Table 1) Mothers reported seeing cockroaches (74.3%) and rodents (42.9%) in their homes in the past 4 months (household-reported sightings). Baseline median and geometric mean allergen levels in participants' homes (bedroom dust sample) are listed in Table 2.

Bivariate and Multivariable Analysis

We examined the association of household indoor allergens and building-level characteristics in a cohort of Puerto Ricans in the Bronx.

Dust Mite Allergen. Table 3 shows a bivariate, statistically significant association between the household-reported presence of rodents and the presence of dust allergen (1.34; 95% CI, 1.02, 1.77). In fully adjusted linear models, this relationship became borderline statistically significant (1.37; 95% CI, 0.99, 1.90). In fully adjusted logistic models, there was a (borderline) statistically significant association between the household-reported presence of rodents and the existence of dust allergen (>1.6 μg/g) (OR, 2.18; 95% CI, 1.01, 4.68).

Cat Allergen. Table 3 displays there were no statistically significant associations in any bivariate or multivariable linear models between building-level characteristics and cat allergen. In fully adjusted logistic models, there was a statistically significant relationship between living in a high-rise apartment vs. a house/duplex and the existence of cat allergen (>1 μg/g; OR, 6.29; 95% CI, 1.51, 26.21). There was also a borderline statistically significant relationship between building age and the existence of cat allergen (>1 μg/g; OR, 1.03; 95% CI, 1.01, 1.05). This relationship remained borderline statistically significant when we stratified for owning a cat (OR, 1.04; 95% CI, 1.01, 1.06).

Cockroach Allergen. Table 3 displays the household-reported presence of cockroaches (2.72; 95% CI, 1.80, 4.12), living in public housing (3.28; 95% CI, 2.02, 5.32), and living in a high-rise apartment building (3.42; 95% CI, 1.82, 6.44) were statistically significantly associated with the existence of cockroach allergen in bivariate linear models. In fully adjusted linear models, the household-reported presence of cockroaches (2.07; 95% CI, 1.23, 3.49) and living in public housing

TABLE 1 Demographic and building-level characteristics at baseline (*n*=261)

Building exposures	Number	Mean	Percentage (%)	SD	Missing
Presence of pests					
Cockroaches					–
No	67		25.67		
Yes	194		74.33		
Rodents					–
No	149		57.09		
Yes	112		42.91		
Building type					
Public housing					–
No	221		84.67		
Yes	40		15.33		
Commercial/Residential housing					–
No (residential housing only)	217		83.14		
Yes	44		16.86		
Building size					47
House/Duplex	50		23.36		
Low-rise (<8 floors)	126		58.88		
High-rise (8+ floors)	38		17.76		
Building condition					
Building age		68.86		21.97	1
Environmental control board violations		0.19		0.95	1
Mother's demographic characteristics					
Mother has health insurance	250		95.79		–
Mother ever had asthma	168		64.37		–
Mother ever had hay fever	91		34.87		–
Mother ever had other allergies	202		77.39		–
Marital status					–
Married	75		28.74		
Divorced	7		2.68		
Separated	9		3.45		
Widowed	1		0.38		
Never been married	169		64.75		
Mother's birth place					–
Mainland USA	192		73.56		
Puerto Rico	54		20.69		
Dominican Republic	10		3.83		
Mexico	2		0.77		
Other	3		1.15		
Education					–
High school grad or equivalent, or less	147		56.32		
Some college or more	114		43.68		
Income					–
≤$39,999	211		80.84		
$40,000+	50		19.16		
Mother years in the USA		23.44		7.12	–

TABLE 2 Indoor allergens at baseline

	Number	Median	Missing	Geometric mean	Geometric SD
Der f 1 mg/g (dust mites)	245	0.13	16	0.20	2.98
Fel d 1 mg/g(cat)	253	0.48	8	0.64	7.66
Bla g 2 U/g (40 ng/g) (cockroach)	221	0.50	40	1.46	4.10
MUP mg/g (mouse)	241	0.38	20	0.63	2.81

(2.14; 95% CI, 1.07, 4.31) remained statistically significantly associated with the existence of cockroach allergen. In fully adjusted logistic models, there was a statistically significant relationship between the household-reported presence of cockroaches and the existence of cockroach allergen (>1 U/g; OR, 2.82; 95% CI, 1.10, 7.19).

Mouse Allergen. Table 3 shows the household-reported presence of rodents (1.72; 95% CI, 1.33, 2.22) was statistically significantly associated with the existence of mouse allergen in bivariate linear models. In fully adjusted linear models, the household-reported presence of rodents was positively statistically significantly associated with the existence of mouse allergen (1.70; 95% CI, 1.29, 2.23); however, living in a low-rise apartment building (0.60; 95% CI, 0.42, 0.87) and living in a high-rise apartment building (0.50; 95% CI, 0.29, 0.88), compared with the referent group (duplex/house), was negatively associated with the existence of mouse allergen. In fully adjusted logistic models, there was also a statistically significant relationship between the household-reported presence of rodents and the existence of mouse allergen (>1.6 μg/g). (OR, 4.79; 95% CI, 1.69,13.61). Likewise, there was a statistically significant association between the existence of mouse allergen (>1.6 μg/g) and living in public housing (6.20; 95% CI, 1.01, 37.95), and between the existence of mouse allergen (>1.6 μg/g) and building size: living in a low-rise apartment (0.16; 95% CI, 0.05, 0.52) or high-rise apartment (0.06; 95% CI, 0.01, 0.50) vs. a duplex/house.

DISCUSSION

Our principal goal was to determine if there was any relationship between building characteristics and measured indoor allergens, since this has not been previously reported. While our study comprised lower levels of cat and dust allergens and higher levels of cockroach and mouse allergens compared to national studies, our allergen levels were comparable to other New York City studies examining indoor allergens.[9,54] Our levels are likely less comparable to national data, because these data are generally less representative of the urban context; for example, they contain few high-rise buildings.[10,51,77,85]

From this examination, we begin to understand how building-level characteristics may be related to allergen levels. We did not find associations between building-level characteristics and Der f 1 or Fel d 1 allergen in bivariate or fully adjusted linear models. In previous studies, a relationship has been found between older homes and single family homes as independent predictors of higher levels of dust mite allergens.[85] To examine this, we dichotomized building age to explore the

TABLE 3 Bivariate and multivariable associations of building characteristics and indoor allergens: Puerto Rican Asthma Project (n=261)

	Dust mite allergen (Der f 1)			Cat allergen (Fel d 1)			Cockroach allergen (Bla g 2)			Mouse allergen (MUP)		
	Bivariate[a]	Multivariable[ab]	Logistic[b]	Bivariate[a]	Multivariable[ab]	Logistic[b]	Bivariate[a]	Multivariable[ab]	Logistic[b]	Bivariate[a]	Multivariable[ab]	Logistic[b]
Presence of pests												
No cockroaches (reference)												
Cockroaches	1.08 (0.79, 1.49)	1.02 (0.67, 1.56)	1.05 (0.39, 2.80)	0.99 (0.55, 1.78)	0.52 (0.25, 1.10)	0.44 (0.19, 1.02)	2.72 (1.80, 4.12)	2.07 (1.23, 3.49)	2.82 (1.10, 7.19)	1.24 (0.92, 1.67)	1.33 (0.94, 1.89)	2.64 (0.68, 10.27)
No rodents (reference)												
Rodents	1.34 (1.02, 1.77)	1.37 (0.99, 1.90)	2.18 (1.01, 4.68)	0.68 (0.41, 1.12)	0.62 (0.35, 1.09)	0.82 (0.43, 1.55)	1.11 (0.77, 1.62)	0.88 (0.59, 1.31)	1.01 (0.51, 1.97)	1.72 (1.33, 2.22)	1.70 (1.29, 2.23)	4.79 (1.69, 13.61)
Building type												
Not public housing (reference)												
Public housing	0.91 (0.63,1.32)	1.00 (0.57, 1.76)	0.86 (0.21, 3.53)	1.00 (0.50, 1.99)	0.69 (0.25, 1.91)	0.38 (0.10, 1.38)	3.28 (2.02, 5.32)	2.14 (1.07, 4.31)	2.78 (0.83, 9.30)	0.83 (0.58, 1.19)	1.31 (0.79, 2.15)	6.20 (1.01, 37.95)
Residential housing (reference)												
Commercial/Residential housing	0.82 (0.57, 1.19)	0.79 (0.52, 1.20)	0.65 (0.23, 1.87)	1.20 (0.62, 2.35)	1.28 (0.61, 2.69)	1.82 (0.82, 4.03)	0.81 (0.50, 1.31)	0.67 (0.41, 1.10)	0.74 (0.33, 1.70)	1.32 (0.94, 1.86)	1.01 (0.71, 1.44)	1.42 (0.47, 4.29)
Building size												
House/Duplex (reference)												
Low-rise	0.91 (0.62, 1.34)	0.81 (0.52, 1.25)	0.51 (0.19, 1.34)	1.17 (0.59, 2.30)	1.40 (0.65, 3.03)	1.29 (0.54, 3.08)	1.44 (0.88, 2.36)	0.92 (0.55, 1.56)	1.04 (0.42, 2.56)	0.86 (0.61, 1.22)	0.60 (0.42, 0.87)	0.16 (0.05, 0.52)
High-rise	0.75 (0.46, 1.22)	0.76 (0.40, 1.44)	0.44 (0.09, 2.13)	1.13 (0.48, 2.70)	2.34 (0.73, 7.54)	6.29 (1.51, 26.21)	3.42 (1.82, 6.44)	1.48 (0.67, 3.27)	2.36 (0.59, 9.39)	0.82 (0.52, 1.29)	0.50 (0.29, 0.88)	0.06 (0.01, 0.50)
Building condition												
Age of building	1.00 (1.00, 1.01)	1.00 (1.00, 1.01)	1.00 (0.98, 1.02)	1.00 (1.00, 1.01)	1.01 (1.00, 1.03)	1.03 (1.01, 1.05)	1.00 (0.99, 1.01)	1.01 (1.00, 1.02)	1.02 (1.00, 1.04)	1.01 (1.00, 1.01)	1.00 (1.00, 1.01)	1.02 (1.00, 1.05)
Environmental control board violations	1.01 (0.87, 1.16)	1.02 (0.88, 1.19)	1.00 (0.67, 1.48)	0.91 (0.70, 1.19)	0.96 (0.73, 1.26)	0.56 (0.21, 1.50)	0.91 (0.75, 1.09)	1.02 (0.86, 1.21)	1.00 (0.55, 1.82)	0.96 (0.84, 1.09)	0.99 (0.87, 1.12)	0.63 (0.14, 2.81)

Mean roadway length: (1) 396.4, (2) 556.2, and (3) 713.3. Housing code violations/1,000 rental units: (a) 39.0 (n=70), (b) 78.8 (n=91), and (c) 179.3 (n=99)

[a]Ratios and the 95% confidence intervals were back-transformed to original scale instead of log scale

[b]Multivariable and logistic results: each parameter estimate is adjusted for all other variables in the model, including income and education

relationship with older homes (pre-1945 and post-1945 construction), but we did not see a relationship (data not shown). This may be the result of small sample size or very low levels of dust mite allergen within our study sample. Although, when we examined a cutpoint by using the detection limits of Der f 1, we observed an association between Der f 1 and the household-reported presence of rodents. There is little literature to guide us on this finding. One possible explanation for the observed association may concern the presence of water: rodents are attracted to water, and water produces more humidity, which is related to dust mites. However, it may be in this instance that the household-reported presence of rodents is a proxy for some other factor (water or something else) not controlled for in "fully adjusted" analyses.

Concerning cat allergen, we stratified by cat ownership to further elucidate the relationship between building-level characteristics in homes that might have higher levels of cat allergen because of the presence of a cat. Yet, there were no further relationships found upon stratification among cat owners. Results of the National Survey of Lead and Allergens in Housing noted that essentially all USA homes contain Fel d 1 (whether the home actually contains a cat or not), and that the majority of these homes had levels that exceeded the proposed cutpoint for sensitization to these allergens.[77] While the majority of the literature just discusses whether or not a cat is present, a 2007 abstract by Panjwani and colleagues does discuss the existence of Fel d 1 in homes where "cat non-owners" reside.[86] Concerning cutpoint effects for Fel d 1 observed at the limits of detection, we found a strong association with high-rise apartment buildings and a slight association with the age of the building. Using the clinically relevant cutpoint, there seems to be an increased risk for the presence of cat allergen (>1 U/g) in a high-rise apartment building compared to a house/duplex (OR, 6.29; 95% CI, 1.51, 26.21).

For Bla g 2 and MUP allergen levels, building-level characteristics were associated in bivariate and fully adjusted linear models. In these models, cockroach allergen was statistically significantly associated with the household-reported presence of cockroaches and living in public housing. Previous research by Chew et al. supports this finding with which our results are consistent; they reported that seeing cockroaches and living in public housing in New York City are both highly associated with the existence of cockroach allergen.[54] Interestingly, in our study, building size, specifically living in a high-rise apartment vs. a house/duplex, was statistically significant in the bivariate model, but not in the fully adjusted linear model. When building size alone was removed from the fully adjusted model, both the presence of cockroaches reported by household and living in public housing remained statistically significant, and the ratios were stronger. Therefore, removing building size from the model increased the effect of these predictors, suggesting that building size is important for understanding levels of cockroach allergen. This may be linked to the transport and staying power of allergens and pests in, as well as to the condition of, different size buildings, especially in urban areas. Just as in linear regression analyses, the relationship between Bla g 2 at a clinically relevant level of >1 U/g and the household-reported presence of cockroaches was statistically significantly associated in logistic regression analyses. That is, Bla g 2 seems to be related to a household report of the presence of cockroaches in/of the same unit from which the Bla g 2 sample was taken. These results are consistent with prior literature.[25,58]

The household-reported presence of rodents and building size were positively statistically significantly associated with MUP allergen in bivariate and fully adjusted linear models. The household-reported presence of rodents, living in public housing, and building size were statistically significantly associated with MUP allergen at a clinically relevant level of >1.6 μg/g. Whether modeled continuously or at a clinically relevant cutpoint (>1.6 μg/g), there is an evident relationship between the household-reported presence of rodents and mouse allergen. That is, the presence of MUP seems to be related to a household report of rodents in/of the same unit from which the MUP sample was taken. This finding is consistent with previous literature.[9,54] There is also a relationship between mouse allergen and building size, which becomes stronger when a clinically relevant cutpoint is employed (>1.6 μg/g). However, the relationship between building size and mouse allergen turns out to be a complex association. While our results indicated that living in a multistory building is associated with a decrease in the existence of mouse allergen, Chew et al. and Cohn et al. suggested that higher levels of mouse allergen were associated with living in multistory buildings, low-rise buildings (<8 floors)[9] and high-rise apartments (≥5 floors),[10] respectively.

However, previous work by Bradman et al. and Berg et al. reported results similar to ours: an association between higher levels of mouse allergen and detached housing.[62,63] When we dichotomized building size as the relationship between living in a house/duplex (vs. living in a multistory), this suggested a 69% (1.69; 95% CI, 1.18, 2.41) increase in the existence of mouse allergen (data not shown). Bradman et al. hypothesized that detached homes provided more points of easy entry on the ground floors.[62] In addition, we might hypothesize that other neighborhood-level factors, such as proximity to restaurants or grocery stores, or large-scale urban planning projects, could influence the amount of infestation. Area-level predictors may be an especially interesting characteristic to explore in terms of mouse allergen; such that an issue like housing dilapidation at the neighborhood-level could play an important role in explaining this phenomenon. The question is, why do some types of housing have different or higher rates of allergens than others? Here, houses/duplexes seem to have more mouse allergen among a sample of mainly Puerto Ricans in the Bronx. Lastly, we found that those living in public housing are at an increased risk of being exposed to clinically relevant levels of mouse allergen (>1.6 μg/g; OR, 6.20; 95% CI, 1.01, 37.95). However, studies in NYC and Boston have found low levels of mouse allergen in public housing.[54,58]

Limitations

This study has limitations. Firstly, the sample size of this prospective birth cohort at baseline was small (N=261). Concerning cutpoint examinations (logistic regression analyses), some wide confidence intervals are present, although the findings are statistically significant. Secondly, this sample was limited to a cohort of Puerto Rican participants, all with a history of mother-reported inhalant allergy or asthma. While such a cohort might help elucidate the relationships under study within this population, we cannot generalize beyond this small, relatively homogeneous group. Next, the season in which allergen samples were taken is not available. Lastly, many building-level exposures were also proxy variables (e.g., household-reported pest presence) while still other relevant variables were unavailable (e.g. number of building violations related to pests).

Implications

This work helped to more clearly examine allergens in relation to building characteristics; a level not yet fully explored. In particular, we focused on ways to measure physical places at the building level since it is evident that structural issues need to be considered in order to reduce health disparities. Building issues in urban spaces are often controlled by landlords, city codes, and urban developers, and therefore understanding the influences of the structural building on allergen levels may help locate responsibility in spheres still considered unrelated to the prevention of asthma.[87]

Future Research

Future studies should incorporate a city-wide, or nationally, representative sample of USA participants to further clarify the relationship between building characteristics and indoor allergens. While a focus on Puerto Ricans is warranted due to the high asthma burden in this population, a representative sample will provide us with a better idea of the relationship between building-level factors and asthma morbidity in the general population. Likewise, a longitudinal study would be important to capture exposures across the life span, beginning during the prenatal period and following the cohort forward. This would help us to determine at what period building exposures may be important for allergic sensitization and asthma development/morbidity.

In addition, future studies concerning the building level might aim to collect data on building characteristic variables that might more precisely capture issues of interest. The data as we might ideally like to have it is not currently available. In the future, we might want to ask participants, for example, about pest presence in other areas in and around the building; allergen measurements could be taken in these spaces outside of the household unit. In addition, odor, heating, and ventilation systems could be assessed, as suggested by previous studies.[4,48,49,52] Furthermore, a well-powered future study might statistically account for the fundamental multilevel nature of this work, examining participants, buildings, neighborhoods, and regional issues.[49,88]

Altogether, substantial further research remains to be done, but this study, and the work that precedes it, demonstrated that the association between building characteristics and asthma morbidity merits attention. The continuing asthma epidemic suggests that household physical triggers alone do not paint a complete picture. We will have to seek a broader understanding of what influences asthma morbidity and mortality—and shape policies on multiple levels of influence and across the life span.

ACKNOWLEDGMENTS

We thank the Puerto Rican Asthma Project research participants and staff for their time and effort. We also thank Jeff Blossom for creating variables and maps in ArcGIS 9.2 and Amy Cohen for her SAS programming expertise. This work was supported by NIEHS grants R01 ES 10922 and P30 ES 009089.

REFERENCES

1. Matsui EC, Eggleston PA, Buckley TJ, et al. Household mouse allergen exposure and asthma morbidity in inner-city preschool children. *Ann Allergy Asthma Immunol*. 2006; 97(4): 514–520.
2. Platts-Mills T, Vervloet D, Thomas WR, Aalberse RC, Chapman MD. Indoor allergens and asthma: report of the Third International Workshop. *J Allergy Clin Immunol*. 1997; 100: S1–S24.

3. Custovic A, Simpson BM, Murray CS, Lowe L, Woodcock A, for NAC Manchester Asthma and Allergy Study Group. The National Asthma Campaign Manchester Asthma and Allergy Study. *Pediatr Allergy Immunol*. 2002; 13(Suppl 15): 32–37.
4. Engvall K, Norrby C, Bandel J, Hult M, Norbäck D. Development of a multiple regression model to identify multi-family residential buildings with a high prevalence of sick building syndrome (SBS). *Indoor Air*. 2000; 10(2): 101–110.
5. Wang C, Abou El-Nour MM, Bennett GW. Survey of pest infestation, asthma, and allergy in low-income housing. *J Community Health*. 2008; 33(1): 31–39.
6. Marmot AF, Eley J, Stafford M, et al. Building health: an epidemiological study of "sick building syndrome" in the Whitehall II study. *Occup Environ Med*. 2006; 63(4): 283–289.
7. Engvall K, Norrby C, Norbäck D. Sick building syndrome in relation to building dampness in multi-family residential buildings in Stockholm. *Int Arch Occup Environ Health*. 2001; 74(4): 270–278.
8. Arbes SJ Jr, Sever M, Archer J, et al. Abatement of cockroach allergen (Bla g 1) in low-income, urban housing: a randomized controlled trial. *J Allergy Clin Immunol*. 2003; 112 (2): 339–345.
9. Chew GL, Perzanowski MS, Miller RL, et al. Distribution and determinants of mouse allergen exposure in low-income New York City apartments. *Environ Health Perspect*. 2003; 111(10): 1348–1351.
10. Cohn RD, Arbes SJ Jr, Yin M, Jaramillo R, Zeldin DC. National prevalence and exposure risk for mouse allergen in US households. *J Allergy Clin Immunol*. 2004; 113(6): 1167–1171.
11. Gruchalla RS, Pongracic J, Plaut M, et al. Inner City Asthma Study: relationships among sensitivity, allergen exposure, and asthma morbidity. *J Allergy Clin Immunol*. 2005; 115 (3): 478–485.
12. ALA Epidemiology and Statistics Unit, Research and Program Services. *Trends in Asthma Morbidity and Mortality*. New York: American Lung Association; 2006.
13. Bell JF, Zimmerman FJ, Almgren GR, Mayer JD, Huebner CE. Birth outcomes among urban African-American women: a multilevel analysis of the role of racial residential segregation. *Soc Sci Med*. 2006; 63(12): 3030–3045.
14. Mostashari F, Kerker BD, Hajat A, Miller N, Frieden TR. Smoking practices in New York City: the use of a population-based survey to guide policy-making and programming. *J Urban Health*. 2005; 82(1): 58–70.
15. Breysse P, Farr N, Galke W, et al. The relationship between housing and health: children at risk. *Environ Health Perspect*. 2004; 112(15): 1583–1588.
16. Chaudhuri N. Interventions to improve children's health by improving the housing environment. *Rev Environ Health*. 2004; 19(3–4): 197–222.
17. Bush RK, Portnoy JM, Saxon A, Terr AI, Wood RA. The medical effects of mold exposure. *J Allergy Clin Immunol*. 2006; 117(2): 326–333.
18. Sandel M, Wright RJ. When home is where the stress is: expanding the dimensions of housing that influence asthma morbidity. *Arch Dis Child*. 2006; 91(11): 942–948.
19. Payne-Sturges D, Gee GC. National environmental health measures for minority and low-income populations: tracking social disparities in environmental health. *Environ Res*. 2006; 102(2): 154–171.
20. Morello-Frosch R, Lopez R. The riskscape and the color line: examining the role of segregation in environmental health disparities. *Environ Res*. 2006; 102(2): 181–196.
21. Gold DR, Wright R. Population disparities in asthma. *Annu Rev Public Health*. 2005; 26: 89–113.
22. Liu AH. Hygiene theory and allergy and asthma prevention. *Paediatr Perinat Epidemiol*. 2007; 21(Suppl 3): 2–7.
23. ALA. Asthma in Adults Fact Sheet, September 2007. Available at: http://www.lungusa.org/site/apps/nl/content3.asp?c=dvLUK9O0E&b=2058817&content_id={39966A20-AE3C-4F85-B285-68E23EDC6CA8}&notoc=1. Accessed on: March 2008

24. Findley S, Lawler K, Bindra M, et al. Elevated asthma and indoor environmental exposures among Puerto Rican children of East Harlem. *J Asthma*. 2003; 40(5): 557–569.
25. Rauh VA, Chew GR, Garfinkel RS. Deteriorated housing contributes to high cockroach allergen levels in inner-city households. *Environ Health Perspect*. 2002; 110(Suppl 2): 323–327.
26. Rosenstreich DL, Eggleston P, Kattan M, et al. The role of cockroach allergy and exposure to cockroach allergen in causing morbidity among inner-city children with asthma. *N Engl J Med*. 1997; 336(19): 1356–1363.
27. Arruda LK, Vailes LD, Ferriani VPL, et al. Cockroach allergens and asthma. *J Allergy Clin Immunol*. 2001; 107(3): 419–428.
28. Call R, Smith TF, Morris E, Chapman MD, Platts-Mills TAE. Risk factors for asthma in inner-city children. *J Pediatr*. 1992; 121: 862–866.
29. Gelber LE, Seltzer LH, Bouzoukis JK, et al. Sensitization and exposure to indoor allergens as risk factors for asthma among patients presenting to hospital. *Am Rev Respir Dis*. 1993; 147(3): 573–578.
30. Tepas E, Litonjua AA, Celedón JC, Sredl D, Gold DR. Sensitization to aeroallergens and airway hyperresponsiveness at 7 years of age. *Chest*. 2006; 129: 1500–1508.
31. Erwin EA, Wickens K, Custis NJ, et al. Cat and dust mite sensitivity and tolerance in relation to wheezing among chidlren raised with high exposure to both allergens. *J Allergy Clin Immunol*. 2005; 115: 74–79.
32. Phipatanakul W, Cronin B, Wood RA, et al. Effect of environmental intervention on mouse allergen levels in homes of inner-city Boston children with asthma. *Ann Allergy Asthma Immunol*. 2004; 92(4): 420–425.
33. Chew GL, Correa JC, Perzanowski MS. Mouse and cockroach allergens in the dust and air in northeastern United States inner-city public high schools. *Indoor Air*. 2005; 15: 228–234.
34. Phipatanakul W, Eggleston PA, Wright EC, Wood RA. Mouse allergen. I. The prevalence of mouse allergen in inner-city homes. The National Cooperative Inner-City Asthma Study. *J Allergy Clin Immunol*. 2000; 106(6): 1070–1074.
35. Phipatanakul W, Litonjua AA, Platts-Mills TA, et al. Sensitization to mouse allergen and asthma and asthma morbidity among women in Boston. *J Allergy Clin Immunol*. 2007; 120(4): 954–956.
36. Phipatanakul W, Eggleston PA, Wright EC, Wood RA. Mouse allergen. II. The relationship of mouse allergen exposure to mouse sensitization and asthma morbidity in inner-city children with asthma. *J Allergy Clin Immunol*. 2000; 106(6): 1075–1080.
37. Sarpong SB, Hamilton RG, Eggleston PA, Adkinson NF Jr. Socioeconomic status and race as risk factors for cockroach allergen exposure and sensitization in children with asthma. *J Allergy Clin Immunol*. 1996; 97(6): 1393–1401.
38. Eggleston PA, Rosenstreich D, Lynn H, et al. Relationship of indoor allergen exposure to skin test sensitivity in inner-city children with asthma. *J Allergy Clin Immunol*. 1998; 97 (4 Pt 1): 1393–1401.
39. Huss K, Adkinson NF Jr, Eggleston PA, et al. House dust mite and cockroach exposure are strong risk factors for positive allergy skin test responses in the Childhood Asthma Management program. *J Allergy Clin Immunol*. 2001; 107(1): 48–54.
40. Corburn J, Osleeb J, Porter M. Urban asthma and the neighbourhood environment in New York City. *Health Place*. 2006; 12(2): 167–179.
41. Rosenfeld L, Rudd R, Chew GL, Emmons K, Acevedo-Garcia D. Are neighborhood-level characteristics associated with indoor allergens in the household? *J Asthma*. 2010; 47(1): 66–75.
42. Lanphear BP, Kahn RS, Berger O, Auinger P, Bortnick SM, Nahhas RW. Contribution of residential exposures to asthma in US children and adolescents. *Pediatrics*. 2001; 107 (6): E98.

43. Malveaux FJ, Fletcher-Vincent SA. Environmental risk factors of childhood asthma in urban centers. *Environ Health Perspect*. 1995; 103(Suppl 6): 59–62.
44. Eggleston PA, Buckley TJ, Breysse PN, et al. The environment and asthma in US inner cities. *Environ Health Perspect*. 1999; 107(Suppl 3): 439–450.
45. Warman K, Silver EJ, Wood PR. Asthma risk factor assessment: what are the needs of inner-city families? *Ann Allergy Asthma Immunol*. 2006; 97(1 Suppl 1): S11–S15.
46. Gergen PJ, Mortimer KM, Eggleston PA, et al. Results of the National Cooperative Inner-City Asthma Study (NCICAS) environmental intervention to reduce cockroach allergen exposure in inner-city homes. *J Allergy Clin Immunol*. 1999; 103(3 Pt 1): 501–506.
47. Platts-Mills TA, Sporik RB, Chapman MD, Heymann PW. The role of indoor allergens in asthma. *Allergy*. 1995; 50(22 Suppl): 5–12.
48. Norbäck D, Björnsson E, Janson C, Palmgren U, Boman G. Current asthma and biochemical signs of inflammation in relation to building dampness in dwellings. *Int J Tuberc Lung Dis*. 1999; 3(5): 368–376.
49. Engvall K, Norrby C, Norbäck D. Asthma symptoms in relation to building dampness and odour in older multifamily houses in Stockholm. *Int J Tuberc Lung Dis*. 2001; 5(5): 468–477.
50. Vojta PJ, Friedman W, Marker DA, et al. First National Survey of Lead and Allergens in Housing: survey design and methods for the allergen and endotoxin components. *Environ Health Perspect*. 2002; 110(5): 527–532.
51. Cohn RD, Arbes SJ Jr, Jaramillo R, Reid LH, Zeldin DC. National prevalence and exposure risk for cockroach allergen in US households. *Environ Health Perspect*. 2006; 114(4): 522–526.
52. Emenius G, Svartengren M, Korsgaard J, et al. Building characteristics, indoor air quality and recurrent wheezing in very young children (BAMSE). *Indoor Air*. 2004; 14(1): 34–42.
53. Hynes HP, Brugge D, Osgood ND, Snell J, Vallarino J, Spengler J. "Where does the damp come from?" Investigations into the indoor environment and respiratory health in Boston public housing. *J Public Health Policy*. 2003; 24(3–4): 401–426.
54. Chew GL, Carlton EJ, Kass D, et al. Determinants of cockroach and mouse exposure and associations with asthma in families and elderly individuals living in New York City public housing. *Ann Allergy Asthma Immunol*. 2006; 97(4): 502–513.
55. Brugge D, Rice PW, Terry P, Howard L, Best J. Housing conditions and respiratory health in a Boston public housing community. *New Solut*. 2001; 11(2): 149–164.
56. Hynes HP, Brugge D, Osgood ND, et al. Investigations into the indoor environment and respiratory health in Boston public housing. *Rev Environ Health*. 2004; 19(3–4): 271–289.
57. Levy JI, Brugge D, Peters JL, Clougherty JE, Saddler SS. A community-based participatory research study of multifaceted in-home environmental interventions for pediatric asthmatics in public housing. *Soc Sci Med*. 2006; 63(8): 2191–2203.
58. Peters JL, Levy JI, Rogers CA, Burge HA, Spengler JD. Determinants of allergen concentrations in apartments of asthmatic children living in public housing. *J Urban Health*. 2007; 84(2): 185–197.
59. Norbäck D, Bjornsson E, Janson C, Widstrom J, Boman G. Asthmatic symptoms and volatile organic compounds, formaldehyde, and carbon dioxide in dwellings. *Occup Environ Med*. 1995; 52(6): 388–395.
60. USGS. Volatile Organic Compounds. Toxic Substances Hydrology Program, United States Geologic Survey. Available at: http://toxics.usgs.gov/definitions/vocs.html. Accessed on: January 18, 2008.
61. Godish T. *Indoor Environmental Quality*. Boca Raton: CRC Press; 2001.
62. Bradman A, Chevrier J, Tager I, et al. Association of housing disrepair indicators with cockroach and rodent infestations in a cohort of pregnant Latina women and their children. *Environ Health Perspect*. 2005; 113(12): 1795–1801.

63. Berg J, McConnell R, Milam J, et al. Rodent allergen in Los Angeles inner city homes of children with asthma. *J Urban Health*. 2008; 85(1): 52–61.
64. Acosta LM, Acevedo-García D, Perzanowski MS, et al. The New York City Puerto Rican asthma project: study design, methods, and baseline results. *J Asthma*. 2008; 45(1): 51–57.
65. Beckett WS, Belanger K, Gent JF, Holford TR, Leaderer BP. Asthma among Puerto Rican Hispanics: a multi-ethnic comparison study of risk factors. *Am J Respir Crit Care Med*. 1996; 154(4 Pt 1): 894–899.
66. Carter-Pokras OD, Gergen PJ. Reported asthma among Puerto Rican, Mexican-American, and Cuban children, 1982 through 1984. *Am J Public Health*. 1993; 83(4): 580–582.
67. Carter-Pokras O, Zambrana RE, Poppell CF, Logie LA, Guerrero-Preston R. The environmental health of Latino children. *J Pediatr Health Care*. 2007; 21(5): 307–314.
68. Choudhry S, Burchard EG, Borrell LN, et al. Ancestry-environment interactions and asthma risk among Puerto Ricans. *Am J Respir Crit Care Med*. 2006; 174(10): 1088–1093.
69. Crain EF, Weiss KB, Bijur PE, et al. An estimate of the prevalence of asthma and wheezing among inner-city children. *Pediatrics*. 1994; 94(3): 356–362.
70. Lara M, Morgenstern H, Duan N, Brook RH. Elevated asthma morbidity in Puerto Rican children: a review of possible risk and prognostic factors. *West J Med*. 1999; 170(2): 75–84.
71. Ledogar RJ, Penchaszadeh A, Garden CC, Iglesias G. Asthma and Latino cultures: different prevalence reported among groups sharing the same environment. *Am J Public Health*. 2000; 90(6): 929–935.
72. Rose D, Mannino DM, Leaderer BP. Asthma prevalence among US adults, 1998–2000: role of Puerto Rican ethnicity and behavioral and geographic factors. *Am J Public Health*. 2006; 96(5): 880–888.
73. Homa DM, Mannino DM, Lara M. Asthma mortality in US Hispanics of Mexican, Puerto Rican, and Cuban heritage, 1990–1995. *Am J Respir Crit Care Med*. 2000; 161 (2 Pt 1): 504–509.
74. Diaz T, Sturm T, Matte T, et al. Medication use among children with asthma in East Harlem. *Pediatrics*. 2000; 105(6): 1188–1193.
75. OASIS-NYC. OASIS, New York City Open Accessible Space Information System Cooperative OASIS, Center for Urban Research. The Graduate Center/CUNY. Available at: www.oasisnyc.net. Accessed on: January 24, 2008
76. Krieger N WP, Chen JT, Rehkopf DH, Subramanian SV. Geocoding and monitoring US socioeconomic inequalities in health: an introduction to using area-based socioeconomic measures—the Public Health Disparities Geocoding Project monograph. Harvard School of Public Health. Available at: http://www.hsph.harvard.edu/thegeocodingproject/. Accessed on: February 12, 2008.
77. Arbes SJ Jr, Cohn RD, Yin M, Muilenberg ML, Friedman W, Zeldin DC. Dog allergen (Can f 1) and cat allergen (Fel d 1) in US homes: results from the National Survey of Lead and Allergens in Housing. *J Allergy Clin Immunol*. 2004; 114(1): 111–117.
78. Chew GL, Perzanowski MS, Canfield SM, et al. Cockroach allergen levels and associations with cockroach-specific IgE. *J Allergy Clin Immunol*. 2008; 121(1): 240–245.
79. Krieger N, Waterman P, Lemieux K, Zierler S, Hogan JW. On the wrong side of the tracts? Evaluating the accuracy of geocoding in public health research. *Am J Public Health*. 2001; 91(7): 1114–1116.
80. New York City Department of Buildings. Property Profile Overview, Building Information System. Available at: http://www.nyc.gov/html/dob/html/bis/faq.shtml#property. Accessed on: March 25, 2008.
81. New York City Department of Buildings. Buildings Information System: Environmental Control Board Violations. Available at: http://www.nyc.gov/html/dob/html/violations/ecb_violation.shtml. Accessed on: April 15, 2007.

82. Chew GL, Burge HA, Dockery DW, et al. Limitations of a home characteristics questionnaire as a predictor of indoor allergen levels. *Am J Respir Crit Care Med*. 1998; 157(5 Pt 1): 1536–1541.
83. SAS 9.1 [computer program]. Cary, NC: SAS Institute, Inc.; 2002–2003.
84. *JMP 7.0* [computer program]. Cary, NC: SAS Institute, Inc.; 2007.
85. Arbes SJ Jr, Cohn RD, Yin M, et al. House dust mite allergen in US beds: results from the First National Survey of Lead and Allergens in Housing. *J Allergy Clin Immunol*. 2003; 111(2): 408–414.
86. Panjwani K, Chew GL, Divjan A, et al. Fel d 1 in the bed dust of cat non-owners differs among ethnicities but not neighborhood in two NYC cohorts. *J Allergy Clin Immunol*. 2007; 119(1): S186.
87. Geronimus AT. To mitigate, resist, or undo: addressing structural influences on the health of urban populations. *Am J Public Health*. 2000; 90(6): 867–872.
88. Wright RJ, Subramanian SV. Advancing a multilevel framework for epidemiologic research on asthma disparities. *Chest*. 2007; 132(5 Suppl): S757–S769.