

Comparison of multiple environmental factors for asthmatic children in public housing

Abstract Nine families of a public housing development in Boston were enrolled in a pilot asthma intervention program designed to gather dense environmental data and generate hypotheses about the relative importance of different contaminants and the viability of interventions. Despite formidable challenges working with this inner-city population, the project team succeeded in gaining active support for the project by forming a partnership with a community-based organization and by building positive relationships between the field team and the residents. Families were provided with physical interventions such as air filters, industrial cleaning and mattress covers to each apartment. Indoor temperature was high and relative humidity low during winter. Insulation of exposed steam pipes did not lower temperature. Cockroach, mouse and pet antigen levels were variable and frequently high in settled dust. Viable fungal spore levels were variable and high in some apartments. Dust-mite allergen levels were below the level of concern. Industrial cleaning led to transient reduction in mouse and cockroach antigen burden. Mattress and pillow covers lowered dust-mite antigen in bedrooms, but not living rooms. Nitrogen dioxide (NO₂) levels exceeded ambient concentrations due to use of gas stoves and concentrations of particulate matter with aerodynamic diameter <2.5 µm (PM_{2.5}) were above ambient levels because of smoking. Air filtering systems did not reduce PM levels. Several volatile organic compounds (VOCs) were above adverse risk concentrations. We hypothesize that our findings are consistent with a multifactorial model for exacerbation of asthma in this population and that no single problem dominates.

**D. Brugge¹, J. Vallarino²,
L. Ascolillo¹, N.-D. Osgood³,
S. Steinbach⁴, J. Spengler²**

¹Department of Family Medicine and Community Health, Tufts University School of Medicine, Boston, MA, USA, ²Department of Environmental Health, Harvard School of Public Health, Boston, MA, USA, ³Committee for Boston Public Housing, Roxbury, MA, USA, ⁴Department of Pediatrics, Boston Medical Center, Boston, MA, USA

Key words: Asthma; Indoor environment; Housing conditions; Intervention; Public housing; Children's health.

Dogu Brugge
Department of Family Medicine and Community Health,
Tufts University School of Medicine, 136 Harrison Ave.,
Boston, MA 02111, USA
Tel: +617 636 0326
Fax: +617 636 4017
e-mail: dbrugge@aol.com

Received for review 26 April 2001. Accepted for
publication 10 May 2002.
© Indoor Air (2003)

Practical Implications

There are many indoor environmental problems in the housing of low income children. It is suggested that remedial interventions in such homes will need to address, at a minimum, smoking, gas stoves, cockroaches, mice, mold, and heating systems. Further, some of these factors require institutional intervention, some require personal changes, and some require both.

Introduction

Asthma demography

Asthma is one of the most important chronic illnesses in the US today. According to the Centers for Disease Control [Centers for Disease Control (CDC), 1998], the self-reported prevalence of asthma increased by 75% from 1980 to 1994. The largest increases were among children 0–14 years of age. From 1975 to 1993–95, office visits for asthma doubled. Hospitalization and emergency room visit rates were higher among black peoples than among non-Hispanic white peoples.

Mortality from asthma, which decreased from 1960 to 1977, has risen steadily since. Between 1993 and 1994, an estimated 13.7 million persons with asthma lived in the US and rates were higher in the northeastern US than in other regions. Direct and indirect costs associated with asthma were reported to be over 12.7 billion (Weiss and Sullivan, 2001). Asthma is in the top tier of diseases targeted for disease management by managed care organizations because of high cost, prevalence and the potential to address the disease through therapy and modification of environmental factors (Kamer, 1997; Carranza et al., 2001).

African Americans have been reported to have marginally higher asthma rates and dramatically higher hospitalization rates (Centers for Disease Control, 1998). There is also mounting evidence that low-income and inner-city urban populations are mostly at risk (Gottlieb et al., 1995; Sarpong et al., 1996; Apter et al., 1997, 1999; Persky et al., 1998; Ray et al., 1998; Aligne et al., 2000). Particularly high rates of asthma have been reported in small populations (schools) with mostly Black and/or low socioeconomic status (SES) in Chicago [about 20% ever having asthma and about 39% ever having wheeze (Persky et al., 1998)]. A recent study found that racial differences among black people and white people in asthma prevalence could be attributed to living in an urban setting (Aligne et al., 2000).

Environmental factors

The candidates for key factors affecting asthma morbidity and mortality can be broken down into treatment-oriented factors (e.g., medication) and environmental factors (e.g., housing conditions and air pollution). Many environmental factors are associated with exacerbating or causing asthma (Easterlow and Smith, 1997). In urban centers, the role of ambient air pollution as a risk factor, particularly ozone, nitrogen dioxide (NO₂), sulfur dioxide, and particulate matter (PM), has been widely investigated (Neas et al., 1996; Schwartz, 1996; Jones, 1998). Studies suggest that emissions from motor vehicle traffic may exacerbate asthma in children (English et al., 1999). The role of ambient air pollution in causing increases in asthma is in question, however, as many pollutants have declined over the same period asthma has increased (Centers for Disease Control, 1998; Raizenne et al., 1998, US Environmental Protection Agency, 2000). Recently, attention has shifted to the role of indoor environmental risk factors, especially in the home, schools and, in the case of occupational asthma, the workplace. Well-documented risk factors in the home include moisture and mold growth, pest infestation, high dust levels, improper heating, inadequate ventilation and exposure to secondhand cigarette smoke (Spengler et al., 1994; Henderson et al., 1995; Malveaux and Fletcher-Vincent, 1995; Platts-Millis, 1995; Bascom 1996; Becher et al., 1996; Sockrider, 1996; Rosenstreich et al., 1997; Nafstad et al., 1998; Institute of Medicine, 2000). All of these factors are associated with lower SES and/or with deteriorating housing conditions.

Intervention studies

Attempts to show that broad, population-based intervention can reduce asthma severity are in their early stages and have met with limited success thus far. Early

attempts to see effects from interventions relied largely on educational efforts that were reported to have little or no impact (Clark et al., 1986; Wissow et al., 1988; Shields et al., 1990; Hill et al., 1991; Taggart et al., 1991). To the extent that these studies could show reductions in morbidity from asthma, they mainly showed reductions in emergency room use among more severe asthmatics (Taggart et al., 1991).

A case control study compared asthmatics who had been hospitalized with those who had not (Lieu et al., 1997). Hospitalized cases were less likely to have an asthma management plan, or to report washing bed sheets in hot water for dust-mite control. A clinic-based intervention reported that training for clinic staff led to more education and better use of medications by patients (Evans et al., 1997). Cowie et al. (1997) reported that providing a peak flow meter as part of an asthma management plan that emphasized proper use of medication led to significantly reduced emergency room visits. Another study suggests that enrollment of asthmatic patients in an 'Asthma Nurse Practice' program that provided education and adjustment of medication doses reduced asthma symptoms (Lindberg et al., 1999).

The National Cooperative Inner-City Asthma Study has reported intervention results that are particularly relevant to this study. Evans et al. (1999) applied an intervention in a randomized clinical trial. They had masters-level social workers administer the intervention, which included providing information to the physician of enrolled participants, education of the participants based on the A+ Program (Schneider et al., 1997), referral to smoking cessation programs, and provision of pillow and mattress covers. Over 1 year, the intervention group reported about half a day less of symptoms per month than did the controls, which was statistically significant. Among children with more severe asthma, there was a larger improvement (1.5 symptom days/month). A second Inner-City Asthma Study paper reported on attempts, largely unsuccessful, to reduce cockroach antigen by use of pesticide extermination (Gergen et al., 1999).

Public housing

The residents of Boston public housing have a median income that is 17% of the Boston rate. The Franklin Hill Housing Development, in which we conducted this study, was 43% black people, 55% Hispanic, and 2% Asian and white people. Fifty-four percent of the residents were under the age of 18 (Boston Housing Authority, 2000, pers. commun.). Because they were at the lowest end of the SES and consisted largely of minorities, public housing residents may be at risk for exposure to many factors associated with housing that can affect health (Feldman and Westphal, 1994; Malmgren et al., 1996; Sobottka and Thriene, 1996;

de Blay et al., 1997; Easterlow and Smith, 1997; Challans et al., 1998; DuBois, 1998; Polednak, 1998). Previous community-based survey research has found high levels of both poor housing conditions and asthma in this (Brugge et al., 2001a), and another Boston public housing development (Hynes et al., 2000). These studies documented widespread overheating in winter alternating with use of gas ovens for heating during transitional weather. Moisture and water damage, mold growth, lack of fresh air, pest infestation, and damage to walls and ceilings, and high smoking rates were reported.

We sought to conduct an intensive environmental evaluation of a small number of inner-city public housing apartments in which asthmatic children lived. Our goal was to generate hypotheses about the relative importance of a wide range of environmental exposures to these children based on a dense set of measurements rather than the diffuse records obtained by studies of larger populations. Interventions were tailored to each apartment after baseline assessment in order to also test their applicability to the public housing setting. Methods and baseline data have been reported previously in conference proceedings (Brugge et al., 2000). The methodological lessons and findings reported below are being used in a larger scale intervention study currently underway in the same public housing development.

Methods

Recruitment

A single housing development was studied. The development was built in 1952 (Vale, 2000) and has not undergone major renovations since it was built. The development has 364 apartments, most of which are occupied, in nine buildings situated close to each other and housing about 980 residents. It has no mechanical source of ventilation other than fans in some bathrooms. Apartments have windows on one or at the most two sides. Heating is by steam carried to radiators through piping that runs indoors along interior walls and is not insulated.

Each Institutional Review Board affiliated with Tufts University School of Medicine, Harvard University School of Public Health, and Boston Medical Center approved the protocol for the study independently. The outreach staff of the Committee for Boston Public Housing and the residents enrolled in their Action Against Asthma Health Advocate Training Certificate Program recruited nine families.

Families had to meet the following criteria:

1. At least one child, 3–17 years old with physician-diagnosed asthma.
2. The child must live in the apartment at least 5 days/week.
3. Willingness and ability to stay in the study for 6 months.
4. Willingness and ability to allow researchers access to the apartment once or twice per month.
5. Verbal commitment to follow the asthma protocol as assigned, including keeping asthma diaries.
6. One or more risk factors for asthma in the apartment.
7. Verbal commitment to prohibit smoking in the apartment during the study.

Diagnosis

The index asthmatic children underwent a clinical evaluation performed by a pediatric pulmonologist (author SS). The evaluation included administration of a symptom frequency questionnaire modified from the National Institutes of Health (NIH) Expert Panel Report 2 (NIH EPR-2), review of medication use, and a physical examination. Pulmonary function testing was carried out on children >4 years of age using a computerized pneumotachometer (MultiSpiro). Based on the combined observations, an NIH EPR-2 asthma severity level was assigned.

Allergy skin testing was performed using the Multi-test device (Center Laboratories, Port Washington, NY, USA) with saline and histamine controls and 14 allergen extracts: cat, mouse, dog, cockroach, two dust-mite (*Der farinae* and *Der pteronyssinus*), horse, three fungi (*Alternaria*, *Aspergillus fumigatus*, and *Cladosporium*), mixed tree pollens, mixed grass pollens, mixed weed pollens, and ragweed. Test results were read after 15 min by measuring and comparing the wheal for each antigen and for the controls. A test was considered positive if the wheal size elicited was at least 2 mm greater than the negative saline control.

Environmental observation and monitoring

Monthly visits were made to seven homes from January to June 2000, and two homes were visited from April to June 2000. Of scheduled visits to apartments, 92% were completed. During the visit to each of the nine homes, the study team made a visual inspection for mold, wetness, cockroaches, rodent droppings, and any other visual indicators. The first visit established baseline conditions in the apartment, and interventions were begun before the second monthly assessment. All chemical and particulate measurements were collected in the living room.

Twenty-four-hour time-integrated samples were passively collected for NO₂ using Yanagisawa Badges and were analyzed by light spectrophotometry (Yanagisawa and Nishimura, 1982). Volatile organic compounds (VOCs) were collected passively on thermal desorption tubes packed with carbotrap B.

PM_{2.5} measurements were collected on pre-weighed Teflon-coated filters, using Harvard impactors attached to Harvard Black Box pumps. The samples were analyzed gravimetrically. Visual examination of each filter identified smoking in apartments. Filters with a yellow tinge were coded as smoking. Two authors (JV and LA) examined the filters independently. The results were compared, and any discrepancies were resolved by re-examination of the filters.

During monthly visits to each apartment, three vacuum samples of dust were collected using a vacuum cleaner, modified to collect dust in a 19 × 90 mm cellulose extraction thimble. The first sample was a composite sample from a child's room. The bedroom composite sample consisted of all surfaces of the bed including the bedcovers, pillows, and sheets followed by the area directly around the bed. If beds just had sheets and pillows, only these were included in that sample. Other beds were fully made.

The bedroom dust sample was analyzed for dust-mite antigens Der p 1, Der f 1; cat antigen Fel d 1; and dog antigen Can f 1. A second dust sample collected from the general living area was analyzed for the same antigens. It was a composite of upholstered seating and carpeting. A final vacuum sample consisting of kitchen cabinets was analyzed for rodent antigen Mus m 1; and cockroach antigen Bla g 1 and, in a subsample, Bla g II. Antigens were analyzed using enzyme-linked immunosorbent assay (ELISA) methods. Each antigen required 25 mg of fine dust, and the amount of dust in some cases limited the number of analyses that could be performed.

To assay for molds, an aliquot of recovered dust was sifted (425 μ m sieve) and 25 mg of fine dust was suspended in 2 ml 0.02% Tween 20 in distilled water. This suspension was serially diluted to 0.1, 0.01, and 0.001 ml of full strength and each dilution was spread-plated onto duplicated malt extract agar. Colony recoveries from the dilution that could be most easily counted (between three and 102 colonies/plate) were summed and differentiated. Concentrations were calculated and reported as colony-forming units per gram (cfu/g) of dust.

Onset computer miniaturized data loggers were used to measure temperature and relative humidity in the bedrooms and the general living areas. The lower limit of detection for relative humidity varies with temperature and, for the range of temperatures that we encountered, varied from 22 to 25%.

Samples were pooled in three ways for analysis. The first was longitudinal averages, in which measurements in all apartments were averaged for each month. The second was global averages in which measurements over the entire study period were averaged. The third was pre- and post-intervention comparisons in which measurements prior to and after intervention were averaged and compared.

Intervention strategies

Apartments were assigned intervention regimes based on the apparent needs in each apartment as assessed in the initial visual inspection of each apartment.

Three types of air filtration equipment were used in this study, electronic polarization, clean room filtration, and high-efficiency particulate arresting (HEPA). (1) The electronic polarization system consisted of an electrically charged glass fiber/activated charcoal filter, sandwiched between two screens. The unit's removal efficiency was estimated at 80% (coarse particles). (2) The clean room filtration system consisted of wall-to-ceiling mounted units operating at 300 cfm. The units were equipped with a HEPA-filter and an ozone lamp followed by an activated charcoal filter. We did not assess ozone release from the filter in the field. The system was designed to draw in room air at floor level and discharge filtered air at ceiling level. Two or three units were installed in each apartment. (3) The HEPA filtration system was a commercially available small console, 300 cfm HEPA-filter unit.

Filtration equipment remained operational throughout the study; however, participants had access to the controls and could temporarily shut off or change fan speed. Maintenance was performed on the clean room filtration system and the electronic polarization systems. For the clean room filtration system, we replaced the prefilter (40% efficiency standard size furnace filter 12 × 12 × 1 in., \$2/filter) at 3-month intervals. For the electronic polarization systems, we vacuumed the filter every month with a HEPA vacuum cleaner, and replaced the filter every 2 months with a manufacturer-supplied filter. For the standard unit, there was no maintenance as the manufacturer's maintenance period was longer than the study period.

HEPA vacuum cleaners had on-off sensors placed in their inner workings that were retrieved at the end of the study, they showed that one participant used the vacuum cleaner and the other did not. Tenants were asked to vacuum the floors, upholstery, and bedding throughout the house at least once a week. Bags were replaced when full, indicating at least some use. HEPA vacuum bag replacement was once every 3 months or more frequently when requested by participants.

An industrial cleaning machine applied an atomized water-based solution at 200 psi and was designed to extract the residues, leaving little liquid in fabric, upholstery, and carpeting. It was used on floors, upholstered furniture, rugs, walls, windowsills, windows, interior of kitchen cabinets, and pantries. An attempt was made to clean stairwells; however, the stairwells remained clean for only a period of hours, and the effort required on stairwells was considerable. In addition, cracks in walls of apartments were repaired and cockroach nests were physically eradicated without use of pesticide. Bedding covers or pest control

devices were supplied as needed. The research staff HEPA-vacuumed the mattress covers and pillowcases prior to installing covers and cases. Participants were asked to place their own linens on top of both covers and cases and to change linens weekly. However, it was observed that some pillowcases were being used without exterior linens.

Asthma diaries

We pilot-tested asthma diaries in order to learn how effective they would be with this population. Based on this being a first-stage evaluation and small sample size, we did not expect to gain health information of use for statistical comparison. Parents and children (if the child was old enough to keep a diary) were asked to evaluate the child's health daily with respect to asthmatic symptoms for three time periods: (1) between when they woke up and left the home in the morning, (2) between when they arrived at home and went to bed, and (3) the overnight hours. They were to subjectively rate their health for the three time periods on a scale from 0 for no symptoms to 5 for severe symptoms. If they rated the time period something other than 0, they were asked to make a note of the symptoms. They were also asked to indicate how many hours were spent in the home.

Focus group/survey

On March 30, 2000, parents of seven of the children attended a focus group headed by one of the authors (DB). The same person interviewed parents of the other two children separately. Prior to conducting the focus group, we had each parent fill out a short questionnaire, on which they did not include their name or any other identifier. The focus group was designed to elicit a well-rounded description of experiences, difficulties, and recommendations. The discussion was audiotaped and transcribed.

Results

Characteristics of enrolled children

In the children old enough to perform pulmonary function tests, the mean values for FEV-1 were 66.7% and the mean values for FEF 25–75 were 54.1%, indicating mild large airway obstruction and moderate small airway obstruction, consistent with the designation of moderate persistent asthma within the NIH asthma severity classification. There was improvement in spirometric results after inhalation of bronchodilator, confirming bronchial responsiveness and the diagnosis of asthma. Despite therapy, the children continued to experience a symptom level indicating considerable asthma morbidity, and they were reported

to experience, on average, 4.9 symptom days/week. The prevalence of positive allergy skin test responses among the children exceeded that found in comparable populations previously National Cooperative Inner City Asthma Study (NCICAS), predicting that sensitizing levels of environmental allergens are likely present in their homes. Eight children were positive for dust-mite allergen, six for cockroach, three for mouse, four for fungi, and five for pollen.

Observational lessons

We found that multiple beds had to be addressed if we were to prevent cross-contamination from dust-mite. The main pests observable from visual inspection were roaches and mice. As a result of the thorough cleaning of the units, cockroach nests inside the apartment were removed and the infestation in the apartments overall appeared to be reduced. Most steam-heating pipes in the apartments were not insulated. Surface temperature measurements of these pipes were between 140 and 180°F. This posed a risk of burns for the occupants, particularly children. In addition, the lack of insulation on the piping made it impossible to manually control the heat inside the apartments. As a result, tenants would open windows in winter, resulting in very low (dry) indoor relative humidity.

Mattresses and upholstered furniture in the apartments were very old, and thus had the potential to carry significant historical biological contamination. There is little in the cleaning capacity of the residents that would allow them to restore these furnishings to clean, should they even understand the problem and its potential relation to asthma. Hallways had strong chemical or other odors. We suspect that some of the chemical buildup was from cleaning solutions applied to attempt to deal with dirt and other contamination brought into the hallways. The outer walls were uninsulated brick with a plaster skim coat. The uninsulated outer walls were seen to be prone to condensation and mold growth in at least some apartments. Tenants reported using their gas stoves for heating as well as cooking. Use of ovens for heating appeared to occur primarily during the transitional weather in the spring and fall when central heating was sometimes turned on or off after or before the last cold spell.

Environmental conditions

Temperature and relative humidity. Average daily temperature in the apartments ranged from 73 to 82°F. There was a slight decline in temperature in May and June after the end of the heating season. Recorded relative humidity inside the apartments ranged from 24 to 39% for the period of December through April. The lowest values were at the limit of detection and should,

therefore, be considered likely to be higher than actual relative humidity.

Particulate matter. Mean PM_{2.5} levels were elevated compared with values at the two ambient monitoring stations closest to the Franklin Hill Housing Development. Six apartments had signs of smoking while three did not. Smoking apartments had higher levels of PM_{2.5} (mean = 33.8 µg/m³), while non-smoking apartments (mean = 12.3 µg/m³) did not differ from ambient records (means = 13.1 and 9.0 µg/m³).

Mold. Maximum values of total viable fungi were 320,000 and 820,000 cfu/g for the bedrooms and living rooms respectively, and median concentrations were 14,400 cfu/g for both bedrooms and living rooms. Numerous fungal genera have been associated with asthma in the literature. For fungi identified in our study and associated with asthma (*Alternaria*, *Aspergillus*, *Penicillium*, *Cladosporium*, *Mucor*, *Rhizopus*, and *Ulocladium*) in the literature (Flannigan, 1992; Verhoeff and Burge, 1997; Institute of Medicine, 2000), maximum values were 136,000 and 32,000 cfu/g and median values were 7,200 and 2,400 cfu/g for bedrooms and living rooms respectively. The genera present in the largest percent of samples were *Cladosporium*, *Penicillium*, yeast, and non-sporulating fungi. The highest concentrations were found for yeast in bedrooms and *Zygomycetes* in living rooms. There was considerable range in concentrations from apartment to apartment.

Antigens. Median antigen levels in settled dust in bedrooms were 154.1 international units per gram (IU/g) for dog (Can f1), 0.03 and 0.38 µg/g for dust-mite (Der f1 and Der p1), and 0.092 µg/g for cat (Fel d1). In living rooms, median levels were 420 IU/g for dog (Can f1), 0.05 and 0.21 µg/g for dust-mite (Der f1 and Der p1), and 0.098 µg/g for cat (Fel d1). In kitchens, mean levels were 141.4 and 2.5 units per gram (U/g) for cockroach (Bla g1 and Bla g II) and 12.24 mg/g for mouse (mus 1). Values are over the entire study period and all apartments. Minimum levels were below the level of detection for all antigens. Maximum levels were 42.5 IU/g for Can f1, 12 µg/g for Der f1, 78 µg/g for Fel d 1, 1.9 U/g for Bla g I, and 170 mg/g for Mus 1. Despite a wide range of values, maximum dust-mite antigen levels rarely exceeded 2 µg/g, whereas median cockroach antigen levels were several orders of magnitude above 1 U/g, the standard level of concern for sensitization for these two exposures. Animal antigen levels of concern are not so well defined. However, the demonstration of mouse antigen in the apartments combined with resident reports of visually observing mice show that mouse infestation is present in at least some of the apartments.

Nitrogen dioxide (NO₂). Mean NO₂ levels, with the exception of June, were either close to or exceeded the US EPA National Ambient Air Quality Standard of 50 ppb. Levels of NO₂ were higher and more variable in May (approaching 80 ppb), but fell off in June to ambient levels. The arithmetic mean of 1 h NO₂ concentrations for the air monitoring station closest to housing development was lower, 31 ppb (Massachusetts Department of Environmental Protection, 2000, pers. commun.).

Volatile organic compounds. Less than 4% of samples exceeded the US EPA IRIS program RfD for 1,4-dichlorobenzene, 1,2-dichloropropane, methyl-t-butyl ether, and acrylonitrile. Less than 12% of samples exceeded a 10⁻⁶ cancer risk for 1,1,2,2-tetrachloroethane, 1,1,2-trichloroethane, carbon tetrachloride, 1,2-dichloroethane, and acrylonitrile. The cancer risk level was exceeded for benzene in 32% of samples and for chloroform in 38% of samples. The compound present at the highest mean and maximum concentrations was 1,4-dichlorobenzene, followed by toluene.

Asthma diaries. Four of nine families in the study completed the assigned diaries. For those diaries that were filled out, there were records for every day during the study; however, we know that some entries were back-filled rather than filled out on the same day. Symptom severity was none to mild in all entries (scale 1–5 with 1 being no symptoms and 5 severe) with no indication of improvement over the course of the study.

Effect of interventions. There was no observed effect on apartment temperature from insulating exposed steam pipes. For four apartments for which there was pre- and post-insulation data, the average temperature was 25.6 °C prior to adding insulation, and 26.2 °C after adding insulation. There was also no change in pre- and post-intervention RH.

For both PM_{2.5} and PM₁₀ the mean concentrations did not change following installation of filtering equipment.

The effect of industrial cleaning on cockroach antigen concentrations in settled dust in two apartments is shown in Figure 1. Apartment 1 was cleaned in months 1 and 4, while apartment 5 was cleaned only in month 1. Antigen levels were reduced immediately after cleaning in both apartments, but rose again by month 4. In apartment 1, the second cleaning reduced levels of both antigens, while in apartment 5, which did not receive a second cleaning, antigen levels continued to rise until the end of the study. Similar findings were observed for mouse antigen.

Average levels of dust-mite antigen were below levels of concern, but were nonetheless lower in bedrooms

following cleaning and installation of covers. Levels of dust-mite antigen in living rooms did not decline following cleaning and use of covers.

Resident satisfaction/participation. Responses by parents to an evaluation questionnaire suggested a general level of satisfaction with participation in the study. The focus group confirmed a general sense of satisfaction with the program. This was expressed most strongly as a desire, felt by all of the participants, that the program be extended and disappointment that it would not after funding expired. Parents were largely convinced that the interventions they received were helping their asthmatic children. They were happy that an effort was being made to address their children's health. When asked whether the program requirements – installation of the intervention, having monitoring done in the apartment each month (including sampling household dust), maintaining asthma diaries – were a problem, only the asthma diaries were considered problematic. While noise from the monitoring equipment bothered some parents, they viewed it as a small inconvenience.

Creating jobs for residents. Despite the limited nature of our pilot study, we considered this an opportunity to test whether or not we could hire persons out of the community to assist with various parts of the project. In this spirit, Harvard School of Public Health hired one resident to work in their laboratory for the duration of the study.

Discussion

The apparent lack of effect of installing insulation on interior steam pipes on interior air temperature is not easy to explain. It could be a function of small sample size, but that would suggest that whatever effect we had was extremely modest. It is more likely that uninsulated radiators and heat from adjacent apartments played a role. In our full-scale study we will examine the impact of replacement of the steam heating system with a hot water system as well as a renewed effort to insulate piping.

The gas stoves are the primary source of NO_2 in these apartments. Consistent with our assessment, kitchen levels of NO_2 during cooking have been reported in the literature to be as high as 400 ppm (Institute of Medicine, 2000). We suggest that solving the heating problem would be beneficial as it would reduce the use of gas ovens for heating.

Smoking is widespread among Boston Public Housing residents (Hynes et al., 2000; Brugge et al., 2001b). Our findings suggest that smoking was the primary cause of levels of $\text{PM}_{2.5}$ that exceeded ambient concentrations. We are proposing a full smoking awareness/cessation program for the full-scale inter-

vention study. Further, the filtration interventions that we employed appeared to have no effect on reducing $\text{PM}_{2.5}$. Others have reported that filtration is largely ineffective in reducing contaminants from tobacco smoke because tobacco smoke produces such high concentrations of contaminants and room-filtering devices circulate only modest amount of air (Repace and Lowrey, 1993).

While the panel of VOCs that we measured included only a fraction of possible contaminants and levels were generally low, numerous samples exceeded comparison values for cancer or acute health risk. Some of these compounds are known to be present in air fresheners and mothballs (e.g. 1,4-dichlorobenzene) or other consumer items. Other chemicals are present in cigarette smoke (e.g. benzene), ambient pollution (e.g. methyl-t-butyl ether, a gasoline additive) or pesticides (e.g. toluene as a carrying agent) (Ashford and Miller, 1991; Senturia et al., 1998; National Cancer Institute, 1999).

There is not yet a generally agreed upon standard against which to measure levels of fungi in the home with respect to development or exacerbation of asthma (Flannigan, 1992; Institute of Medicine, 2000). Measurement of viable spores may underestimate allergen exposure, and measurement of settled dust does not necessarily reflect airborne respirable burden (Institute of Medicine, 2000). Further, there may be considerable variation in viable spores over short periods of time (Verhoeff and Burge, 1997). Both of these factors limit the interpretation of our measurements. Further study should focus on whether or not control of moisture, followed by industrial cleaning, can reduce levels of fungal growth for protracted periods of time.

It has been suggested that cockroaches and mice may be more significant than dust-mite for inner-city children, including those in the Boston area (Rosenstreich et al., 1997; Barrett et al., 2000). The values that we report here are broadly consistent with values reported elsewhere for similar populations (Rosenstreich et al., 1997; Verhoeff and Burge, 1997; Phipatanakul et al., 2000), albeit we found cockroach antigen to be high. While we saw reductions in dust-mite antigen after installing covers, the levels were less than the level of concern to begin with. Industrial cleaning did reduce cockroach and mouse antigen, but the effect was transient as a result of pests not being effectively eliminated. Nevertheless, our findings suggest that there may be the potential for greater impact from the combined use of building-wide integrated pest management (instead of our apartment-by-apartment approach) followed by industrial cleaning to reduce mouse and cockroach antigen that remains after live pests are removed.

We hypothesize, based on our combined findings and the growing literature cited above, that one needs to take a multifactorial approach to understanding the

environmental determinants of asthma for children living in public housing. At least in the population that we studied, there were numerous environmental factors present in levels likely to affect asthmatic children.

Finally, studies involving inner city, low SES, and minority populations have frequently proven to be challenging for university researchers (Senturia et al., 1998). Our approach followed the general method described by Hynes et al. (2000). We propose one key factor contributed to positively engaging residents. We collaborated with a community partner, the Committee for Boston Public Housing (CBPH), which had strong ties to residents in the development. By creating a partnership with the community, we diffused some of the wariness and skepticism that residents would normally have for outside parties. This pilot study also built a relationship that made possible a larger study with the same partners that is currently underway.

Even so, recruitment was slow. Some of the reasons for this are beyond our control. Many residents of public housing face complex circumstances that limit their ability to join a research study or even to participate in a non-research program aimed at addressing asthma. To cite one example, a parent approached us during the recruitment phase with strong interest in participating, but ultimately could not do so because she was under emergency orders for relocation due to a domestic violence situation.

We think that the style and attitude of our lead field researcher (author JV) also contributed to acceptance. He had an ability to explain the project clearly in lay terms and to relate easily to the residents. The residents value relationships above most other considerations, so, making a personal connection with them improves the dynamic. For example, we knew that the residents would be resistant to suggestions that their cleaning methods were a problem. The lead field researcher diffused this potentially charged issue by separating routine cleaning from industrial cleaning, which he called decontamination. He spoke about levels of contamination (in e.g. old upholstered furniture) that could not be removed by any method at the disposal of the residents. He also built a level of trust by using his bilingual skills and by being responsive to the concerns of the residents.

Conclusions

We were largely successful in engaging residents of public housing in an asthma intervention study. Even so, it is important to note that our success came at the price of expending considerable time and resources. The community partner, their resident Asthma Advocates, and the university partners had to work hard at

generating interest and participation. Relationship building and partnering with the community were key features of our effort that led to resident support for the project. As a result of successfully engaging these nine public housing families, we have been able to gather more dense environmental data and install more extensive interventions than have other studies of inner-city populations. The range of environmental factors assessed, combined with the density of measurements allowed for cross comparison within a single study. The data collected show that many environmental factors are present above levels of concern and that none can be easily dismissed. The environmental factors that we showed with greatest certainty to be of concern were overheating, low RH, fungi, cockroaches, mice, smoking, and NO₂. Most of the interventions that we tried were not successful; however, industrial cleaning showed a strong but transient ability to reduce antigen levels. Coupling industrial cleaning with building-wide pest eradication should be tried. It is also notable that the environmental problems identified arise from personal factors (e.g. smoking), institutional factors (e.g. mold, gas stoves, and heating systems) and combinations of the two (e.g. cockroaches).

Acknowledgements

The authors wish to thank Patricia Terry, Lenora Howard, Joyce Best, and Linda Henson of the Action Against Asthma Health Advocate Training Certificate Program run by the Committee for Boston Public Housing (CBPH) and the families that enrolled in the study. We also thank CBPH for its diligent work and willingness to collaborate. Mary Beth Smuts and Elizabeth Howard of the US EPA provided invaluable advice and guidance. We would like to thank Drew Wood of Life Protective Systems for lending three electrostatic air cleaners, and Thomas Griffin of Griffin Environmental Systems Inc. for donating two HEPA-filtration units and an air-to-air heat exchanger that was evaluated for use in the study, but was not feasible in the public housing context. We would also like to thank Peter Harris of B and V Testing for donating two clean-room technology air filtration systems, Jim Studeny of CFR Corporation for donating the extraction system, and Maynard Johnson of Industrial Wiper and Paper Corporation for providing training in use of the extraction system. Two Tufts undergraduates helped us. Christina Hill transcribed the focus group, and Sabine Jean-Louis assisted with preparing the manuscript. Will Rand and Elena Namova of Tufts University provided helpful advice on our analytical approach. This project was funded by US EPA Cooperative Agreement CR 827232-01.

References

- Aligne, C.A., Auinger, P., Byrd, R.S. and Weitzman, M. (2000) Risk factors for pediatric asthma: contributions of poverty, race, and urban residence. *Am. J. Respir. Crit. Care Med.*, **162**, 873–877.
- Apter, A.J., Reisine, S.T., Affleck, G., Barrows, E. and ZuWallack, R.L. (1999) The influence of demographic and socioeconomic factors on health-related quality of life in asthma. *J. Allergy Clin. Immunol.*, **103**, 72–78.
- Apter, A.J., Reisine, S.T., Kennedy, D.G., Cromley, E.K., Keener, J. and ZuWallack, R.L. (1997) Demographic predictors of asthma treatment site: outpatient, inpatient, or emergency department. *Ann. Allergy Asthma Immunol.*, **79**, 353–361.
- Ashford, N.A. and Miller, C.S. (1991) Chemical Exposures: Low Levels and High Stakes. NY, Van Nostrand Reinhold.
- Barrett, T. K., Chew, C., Burge, H.A., Muilenberg, M.L., Weiss, S.T., Plattsmills, T.A.E., et al. (2000) Socioeconomic predictors of high allergen levels in homes in the greater Boston area. *Environ. Health Perspect.*, **108**, 301–307.
- Bascom R. (1996) Environmental factors and respiratory hypersensitivity: the Americas. *Toxicol. Lett.*, **86**, 115–130.
- Becher, R., Hongso, J.K., Jantunen, M.J. and Dybing, E. (1996) Environmental chemicals relevant for respiratory hypersensitivity: the indoor environment. *Toxicol. Lett.*, **86**, 155–162.
- de Blay, F., Sanchez, J., Hedelin, G., Perez-Infante, A., Verot, A., Chapman, M., et al. (1997) Dust and airborne exposure to allergens derived from cockroach (*Blattella germanica*) in low-cost public housing in Strasbourg (France). *J. Allergy Clin. Immunol.*, **99**, 107–112.
- Brugge, D., Vallarino, J., Osgood, N., Steinbach, S. and Spengler, J. (2000) An Asthma Intervention Pilot Study in Public Housing: Lessons and Baseline Data. *Proceedings of Engineering Solutions to Indoor Air Quality Problems*, Air and Waste Management Association and US EPA, 154–169.
- Brugge, D., Carranza, L., Stienbach, S., Wendell, A. and Hyde, J. (2001a) Environmental management of asthma at Massachusetts MCOs. *J. Public Health Manag. Pract.*, **7**, 37–46.
- Brugge, D., Rice, P., Terry, P., Howard, L. and Best, J. (2001b) Housing conditions and respiratory health in a Boston public housing community. *New Solutions*, **11**, 149–164.
- Centers for Disease Control. (1998) Surveillance for asthma – United States, 1960–1995. *MMWR*, **47**, 1–28.
- Challans, M., Layzell, J., Burr, M., Webb, E., Evans, M., Karani, G., et al. (1998) The effect of housing renovation on health. *Nurs. Times*, **94**, 38–39.
- Clark, N.M., Feldman, C.H., Evans, D., Levison, M.J., Wasilewski, Y. and Mellins, R.B. (1986) The impact of health education on frequency and cost of health care use by low income children with asthma. *J. Allergy Clin. Immunol.*, **78**, 108–115.
- Cowie, R.L., Revitt, S.G., Underwood, M.F. and Field, S.K. (1997) The effect of a peak flow-based action plan in the prevention of exacerbations of asthma. *CHEST*, **112**, 1534–1538.
- DuBois, D.K. (1998) A community health assessment of a culturally diverse housing project in St Paul. *Minnesota Medicine*, **81**, 49–51.
- Easterlow, D., Smith, S.J. (1997) Fit for the future? A role for health professionals in housing management. *Public Health*, **111**, 171–178.
- English, P., Neutra, R., Scalf, R., Suyllivan, M., Waller, L. and Zhu, L. (1999) Examining associations between childhood asthma and traffic flow using a geographic information system. *Environ. Health Perspect.*, **107**, 761–767.
- Evans, R., Gergen, P.J., Mitchell, H., Kattan, M., Kercsmar, C., Crain, E., et al. (1999) A randomized clinical trial to reduce asthma morbidity among inner-city children: results of the national cooperative inner-city asthma study. *The J. Pediatr.*, **135**, 332–338.
- Evans, D., Mellins, R., Lobach, K., Ramos-Bonoan, C., Pinkett-Heller, M., Wiesemann, S., et al. (1997) Improving care for minority children with asthma: Professional education in public health clinics. *Pediatrics*, **99**, 157–164.
- Feldman, R.M. and Westphal, L.M. (1994) Participation for empowerment: the greening of a public housing development. *Places*, **12**, 34–37.
- Flannigan, B. (1992) *Micro-organisms*. In: Brown, R.H., Curtis, M., Saunders, K.J. and Vandendriessche, S. (eds.) *Clean Air at Work: New Trends in Assessment and Measurement for the 1990s*. Royal Society of Chemistry Special Publication No. 108, Melksham, Wiltshire, UK, Redwood Press Ltd.
- Gergen, P.J., Mortimer, K.M., Eggleston, P.A., Rosenstreich, D., Mitchell, H., Ownby, D., et al. (1999) 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.*, **102**, 501–506.
- Gottlieb, D.J., Beiser, A.S. and O'Connor, G.T. (1995) Poverty, race, and medication use are correlates of asthma hospitalization rates: a small area analysis in Boston. *Chest*, **108**, 28–35.
- Henderson, F.W., Henry, M.M., Ivins, S.S., Morris, R., Neebe, E.C., Leu, S.Y., et al. (1995) Correlates of recurrent wheezing in school-age children. *Am. J. Respir. Crit. Care Med.*, **151**, 1786–1793.
- Hill, R., Williams, J., Britton, J. and Tattersfield, A. (1991) Can morbidity associated with untreated asthma in primary school children be reduced?: a controlled intervention study. *BMJ*, **303**, 1169–1174.
- Hynes, P., Brugge, D., Watts, J. and Lally, J. (2000) Public health and the physical environment in Boston Public Housing: a community based survey and action agenda. *Plann. Pract. Res.*, **15**, 31–49.
- Institute of Medicine. (2000) *Clearing the Air: Asthma and Indoor Air Exposures*. Washington, DC, National Academy Press.
- Jones, A.P. (1998) Asthma and domestic air quality. *Soc. Sci. Med.*, **47**, 755–764.
- Kamer, A.S. (1997) Disease management activities at US HMOs: 1997 survey results, as cited in Disease Management: Strategic Approaches and Program Analysis. Spectrum Report., A Decision Resources Inc.
- Lieu, T.A., Quesenberry, C.P., Capra, A.M., Sorel, M.E., Martin, K.E. and Mendoza, G.R. (1997) Outpatient management practices associated with reduced risk of pediatric asthma hospitalization and emergency department visits. *Pediatrics*, **100**, 334–341.
- Lindberg, M., Ahlner, J., Moller, M. and Ekstrom, T. (1999) Asthma nurse practice – a resource-effective approach in asthma management. *Respir. Med.*, **93**, 584–588.
- Malmgren, J.A., Martin, M.L. and Nicola, R.M. (1996) Health care access of poverty-level older adults in subsidized public housing. *Public Health Reports*, **111** (May/June), 260–263.
- Malveaux, F.J. and Fletcher-Vincent, S.A. (1995) Environmental risk factors of childhood asthma in urban centers. *Environ. Health Perspect.*, **103** (Suppl. 6), 59–61.
- Nafstad, P., Oie, L., Mehl, R., Gaarder, P.I., Lodrup-Carlson, K.C., Botten, G., et al. (1998) Residential dampness problems and symptoms and signs of bronchial obstruction in young Norwegian children. *Am. J. Respir. Critical Care Med.*, **157**, 410–414.
- National Cancer Institute. (1999) *Health Effects of Exposure to Environmental Tobacco Smoke: The Report of the California Environmental Protection Agency*. Monograph 10. Bethesda, MD. US Department of Health and Human Services, National Institutes of Health, National Cancer Institute, NIH Pub. No. 99-4645.

- Neas, L.M., Dockery, D.W., Burge, H., Koutrakis, P. and Speizer, F.E. (1996) Fungus spores, air pollutants, and other determinants of peak expiratory flow rate in children. *Am. J. Epidemiol.*, **143**, 797–807.
- Persky, V.W., Slezak, J., Contreras, A., *et al.* (1998) Relationships of race and socioeconomic status with prevalence, severity, and symptoms of asthma in Chicago school children. *Ann. Allergy Asthma Immunol.*, **81**, 266–271.
- Phipatanakul, W., Eggleston, P.A., Wright, E.C. and Wood, R.A., (2000) The national cooperative inner-city asthma Study. Mouse allergen. I. The prevalence of mouse allergen in inner-city homes. *J. Allergy Clin. Immunol.*, **106**, 1070–1074.
- Platts-Millis, T. (1995) Is there a dose-response relationship between exposure to indoor allergens and symptoms of asthma? [Editorial]. *J. Allergy Clin. Immunol.*, **96**, 435–440.
- Polednak, A.P. (1998) Mortality among blacks living in census tracts with public housing projects in Hartford, Connecticut. *Ethn. Dis.*, **8**, 36–42.
- Raizenne, M., Dales, R. and Burnett, R. (1998) Air pollution exposures and children's health. *Can. J. Public Health*, **89**, S43–S48.
- Ray, N.F., Thamer, M., Fadillioglu, B. and Gergen, P.J. (1998) Race, income, urbanicity, and asthma hospitalization in California: a small area analysis. *Chest*, **113**, 1277–1284.
- Repache, J.L. and Lowrey, A.H. (1993) An enforceable indoor air quality standard for environmental tobacco smoke in the workplace. *Risk Anal.*, **13**, 463–475.
- Rosenstreich, D.L., Eggleston, P., Kattan, M., Baker, D., Slavin, R.G., Gergen, P., *et al.* (1997) The role of cockroach allergy and exposure to cockroach allergen in causing morbidity among inner-city children with asthma. *N. Engl. J. Med.*, **336**, 1356–1363.
- Sarpong, S.B., Hamilton, R.G., Eggleston, P.A. and Adkinson, N.F. (1996) Socioeconomic status and race as risk factors for cockroach allergen exposure and sensitization in children with asthma. *J. Allergy Clin. Immunol.*, **97**, 1393–1401.
- Schneider, S.L., Richard, M., Huss, K., Huss, R.W., Thompson, L.C., Butz, A.M., *et al.* (1997) Moving health care education into the community. *Nurs. Manage*, **28**, 40–43.
- Schwartz, Joel. (1996) Air pollution and hospital admissions for respiratory disease. *Epidemiology*, **7**, 20–28.
- Senturia, Y.D., Mortimer, K.N., Baker, D., Gergen, P., Mitchell, H., Joseph, C. and Wedner, H.J. (1998) Successful techniques for retention of study participants in an inner-city population. *Control. Clin. Trials*, **19**, 544–554.
- Shields, M.C., Griffen, K.W. and McNabb, W.L. (1990) The effect of a patient education program in emergency room use for inner-city children with asthma. *AJPH*, **80**, 36–38.
- Sobottka, A. and Thriene, B. (1996) Sanitation programmes for living spaces and health risks involved. *Toxicol. Lett.*, **88**, 365–368.
- Sockrider, M. (1996) The respiratory effects of passive tobacco smoking. *Curr. Opin. in Pulm. Med.*, **2**, 129–133.
- Spengler, J., Neas, L., Nakai, S., Dockery, D., Speizer, F., Ware, J., *et al.* (1994) Respiratory symptoms and housing characteristics. *Indoor Air*, **4**, 72–82.
- Taggart, V.S., Zuckerman, A.E., Sly, R.M., Steinmueller, C., Newman, G., O'Brien, R.W., *et al.* (1991) You can control asthma: evaluation of an asthma education program for hospitalized inner-city children. *Patient Educ. Couns.*, **17**, 35–47.
- US Environmental Protection Agency. (2000) Latest findings on national air quality: 1999 status and trends. US EPA, August 2000 (EPA-454/F-00-002).
- Vale, L.J. (2000) From the Puritans to the projects: public housing and public neighbors. Cambridge, MA, Harvard University Press.
- Verhoeff, A.P. and Burge, H.A. (1997) Health risk assessment of fungi in home environments. *Ann. Allergy Asthma Immunol.*, **78**, 544–554.
- Weiss, K.B. and Sullivan, S.D. (2001) The health economics of asthma and rhinitis: assessing the economic impact. *J. Allergy Clin. Immunol.*, **107**, 3–8.
- Wissow, L.S., Warshow, M., Box, J. and Baker, D. (1988) Case management and quality assurance to improve care of inner-city children with asthma. *AJDC*, **142**, 748–752.
- Yanagisawa, Y. and Nishimura, H. (1982) A badge type personal sampler for measurement of personal exposure to NO₂ and NO in ambient air. *Environ. Int.*, **6**, 235–242.