

Airborne fungi in the homes of children with asthma in low-income urban communities: The Inner-City Asthma Study

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Background: Despite growing evidence of the importance of exposure to fungi as an environmental risk factor for asthma, few data have been reported on the exposure to airborne fungi of asthmatic children living in US inner cities.

Objective: We sought to examine the spectrum and concentration of fungi in the air inside and outside of the homes of mold-sensitive children with asthma living in US cities. We also analyzed the relationship of the concentration of fungi in indoor air to home characteristics.

Methods: We performed a home environmental survey and measured the concentrations of culturable airborne fungi inside and outside the homes of 414 mold-sensitive children with asthma in 7 urban communities.

Results: The airborne fungi encountered indoors generally paralleled those found outdoors, and the similarities between communities were more striking than the differences. Indoor fungal concentrations were correlated with outdoor concentrations measured on the same day, suggesting the need to adjust for the outdoor concentration in analyses by using the indoor concentration as an indicator of the relative moldiness of a home. The concentration of fungi in indoor air in excess of outdoor air—that is, the

indoor-outdoor difference—was significantly related to home characteristics, including dampness, having a cat, and cockroach infestation.

Conclusion: Mold-sensitive children with asthma living in urban communities across the US are exposed to airborne fungi in indoor and outdoor air. The concentrations of fungi are higher in homes with dampness problems, cockroach infestation, and cats. The indoor-outdoor difference in the concentration of airborne fungi may provide a valuable metric for investigations of the role of fungal exposure as a risk factor for asthma. (*J Allergy Clin Immunol* 2004;114:599-606.)

Key words: Airborne fungi, indoor mold, home environmental characteristics, indoor air, inner-city pediatric asthma

Exposure to airborne fungi may lead to allergic sensitization and symptoms of allergy and asthma,^{1,2} including fatal asthma episodes.^{3,4} In addition, the non-specific immunologic effects of inhaled fungi have been hypothesized to increase the risk of sensitization to other allergens.^{5,6} Few data have been reported on the exposure to airborne fungi of asthmatic children living in US inner cities, a group with high morbidity and frequent sensitization to mold.^{7,8} Previous studies of exposure to fungi in the home environment have not focused on inner-city homes and have usually involved a relatively small number of homes or been limited to a single geographic region.⁹⁻¹⁶ The only large study of indoor air fungal concentrations in multiple regions across the US was limited almost entirely to nonresidential buildings.¹⁷

We measured the concentrations of airborne fungi inside and outside the homes of 414 mold-sensitive children with moderate to severe asthma in 7 low-income urban communities across the United States. We also analyzed the relation of the concentration of fungi in indoor air to home characteristics and to the outdoor concentration on the day of measurement.

METHODS

Sample

The Inner-City Asthma Study is a multicenter randomized controlled trial of interventions to reduce morbidity among inner-city children with asthma.⁸ From August 1998 through July 1999, we recruited 937 children who lived in low-income census tracts in 7

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Abbreviations used

CFU: Colony-forming units

I-O difference: Difference between indoor and outdoor concentrations

OR: Odds ratio

urban communities, had moderate-to-severe asthma, and had a positive allergy skin test to at least 1 indoor allergen. As part of the Inner-City Asthma Study baseline home evaluation,⁸ we measured indoor and outdoor airborne culturable fungi for children with at least 1 positive skin test to a fungal extract. The institutional review boards of all participating centers approved the study.

Allergy skin testing

Skin testing was performed with the Multi-Test II device (Lincoln Diagnostics, Decatur, Ill), following a standardized protocol at all study sites. Fungal extracts used included *Alternaria alternata*, 1:20; *Cladosporium herbarum*, 1:40; *Aspergillus* mix, 1:20; and *Penicillium notatum*, 1:20 (all from Greer Laboratories, Lenoir, NC). Wheal diameters ≥ 2 mm larger than glycerin control were considered positive. Only subjects with a histamine wheal diameter at least 2 mm larger than glycerin control were included in the study.

Home survey

At the time of the child's initial evaluation, a trained interviewer administered a questionnaire to the primary caretaker to collect home environmental data including housing type; heating system type; history of flooding or water damage; and use of air conditioners, humidifiers, and dehumidifiers. Subsequently, a team of 2 research assistants conducted a home visit that included the collection of air samples and an inspection of the home for visible dampness or water damage, visible mold growth, musty odor, type of floor covering, evidence of pets, evidence of pest infestation, and the use of air cleaning devices.

Air sampling and laboratory analysis

The air samples were obtained by using a single-stage Burkard Portable Air Sampler (Burkard Manufacturing Co, Rickmansworth, United Kingdom), which draws air through a sieve plate with 100 holes of 1 mm diameter and over a petri dish filled with 30 mL dichloran glycerol (DG-18) agar (prepared by Remel, Lenexa, Kan). Each sample was collected over a period of 60 seconds. The flow rate of each air sampler was measured in a central laboratory, and the flow rate for each air sampler (mean, 30.5; range, 28.1–32.0 L/min) was used to convert the number of fungal colonies cultured to colony-forming units (CFU)/m³ air.

Two consecutive samples were collected outside the participant's home, near the door most commonly used to enter the building. Outdoor sampling was not performed if the outdoor temperature was 36°F or lower, temperatures at which freezing of the agar in the culture plates may cause inaccuracy. Two consecutive indoor samples were then collected in the center of the child's bedroom. The culture plates were shipped on the day collected without temperature control by overnight mail to the laboratory.

The covered plates were incubated at room temperature for an average of 40 days. The most common genera of fungi were identified by low-power and high-power microscopy. Colony characteristics, color, evidence of sporulation, and general morphology of sporulating structures were examined at low power directly on the culture plate. Some genera can be recognized by using these characteristics alone. When necessary, slides were made and examined at 400× to

1000× to examine spore-bearing structures and spore morphology, by which most fungi are readily identifiable. The number of CFUs per plate of each fungal genus was counted.

Data analysis

We used a positive hole correction¹⁸ to correct for the finite number of impaction sites on the plate. This conversion scales all positive counts to an estimate of the actual number of CFU that would have been observed with unlimited impaction sites. After this conversion, the count data were converted to CFUs per cubic meter by using the following formula:

$$\text{No. CFU/m}^3 = \frac{\text{Positive hole corrected CFU}}{\text{Time sampled}} \times \frac{1 \text{ minute}}{\text{Sampling rate (L)}} \times \frac{1000 \text{ L}}{1 \text{ m}^3}$$

Next, single indoor and outdoor values were computed for each participant as the mean of the 2 consecutive indoor and outdoor plate values (CFU/m³). The correlations between indoor and outdoor concentrations of airborne fungi were analyzed after log₁₀ transformation (after addition of a small constant in light of 0 values) because of highly skewed distributions of concentrations. A generalized estimating equation approach was used to determine whether subjects' samples collected outdoors had higher odds of a fungus being present than their indoor samples, controlling for site (Table I). The relationships of home characteristics to high indoor concentrations of fungi were assessed by Cochran-Mantel-Haenszel χ^2 analysis (Table II) or by multiple logistic regression analysis (Table III) with adjustment for community. All statistical analyses were performed by using SAS version 8.02 (SAS Institute, Cary, NC).

RESULTS

Among 936 children who underwent allergy skin testing, 469 (50%) had a positive allergy skin test to at least 1 fungal extract.⁸ Positive reactions to *Alternaria*, *Aspergillus*, *Cladosporium*, and *Penicillium* occurred in 36%, 28%, 19%, and 13% of children, respectively. Skin test data for each community are provided in Table E1 in the Journal's Online Repository (www.mosby.com/jaci). Indoor or outdoor fungal concentrations were unavailable for 55 (12%) of these 469 children (air sampling was inadvertently omitted, 18; specimens were lost during shipping, 6; rain or cold weather precluded outdoor sampling, 31). The homes of 414 mold-sensitive children with both indoor and outdoor fungal concentration data were used in subsequent analyses. Skin test data for this subgroup of 414 children are provided in Table E2 in the Online Repository (www.mosby.com/jaci).

Across all 7 cities, the culturable fungi most commonly found in outdoor air samples were *Cladosporium*, *Penicillium*, *Aspergillus*, and *Alternaria* (Table I). Indoor air samples contained a similar spectrum of fungal genera (Table I), although some genera were more common indoors than outdoors, whereas others showed the reverse pattern. *Alternaria*, *Cladosporium*, and *Coelomycetes* were found in indoor air less often than in outdoor air ($P < .01$). In contrast, *Aspergillus* ($P < .01$), *Penicillium* ($P < .05$), and *Wallemia* ($P < .05$) were found in indoor air more often than in outdoor air.

TABLE I. Percentage of air samples with culturable fungi from 414 homes

		Boston n = 44	Bronx n = 40	Chicago n = 54	Dallas n = 95	New York n = 48	Seattle n = 52	Tucson n = 81	Total n = 414
<i>Alternaria</i>	Outdoor	45.5	50.0	63.0	78.9	33.3	11.5	46.9	50.5†
	Indoor	29.5	32.5	33.3	47.4	14.6	13.5	30.9	30.9
<i>Aspergillus</i>	Outdoor	59.1	50.0	63.0	67.4	60.4	32.7	67.9	59.2†
	Indoor	61.4	80.0	70.4	73.7	70.8	57.7	67.9	69.1
<i>Aureobasidium</i>	Outdoor	13.6	27.5	24.1	9.5	31.3	21.2	7.4	17.1†
	Indoor	11.4	12.5	13.0	7.4	16.7	9.6	8.6	10.6
<i>Botrytis</i>	Outdoor	4.5	5.0	3.7	3.2	6.3	25.0	0.0	6.0
	Indoor	4.5	5.0	3.7	0.0	4.2	21.2	0.0	4.6
<i>Cladosporium</i>	Outdoor	84.1	85.0	92.6	95.8	75.0	96.2	86.4	88.9†
	Indoor	70.5	72.5	87.0	94.7	64.6	94.2	72.8	81.2
<i>Coelomycetes</i>	Outdoor	4.5	12.5	11.1	4.2	25.0	0.0	14.8	9.9†
	Indoor	2.3	5.0	5.6	8.4	4.2	0.0	4.9	4.8
<i>Epicoccum</i>	Outdoor	0.0	0.0	0.0	2.1	0.0	0.0	0.0	0.5
	Indoor	0.0	0.0	0.0	0.0	2.1	0.0	0.0	0.2
<i>Fusarium</i>	Outdoor	0.0	2.5	11.1	7.4	2.1	1.9	8.6	5.6*
	Indoor	0.0	0.0	3.7	1.1	0.0	1.9	6.2	2.2
<i>Paecilomyces</i>	Outdoor	0.0	7.5	1.9	3.2	4.2	5.8	0.0	2.9
	Indoor	2.3	12.5	7.4	4.2	4.2	3.8	4.9	5.3
<i>Penicillium</i>	Outdoor	65.9	60.0	79.6	65.3	81.3	88.5	43.2	67.1*
	Indoor	77.3	80.0	79.6	78.9	83.3	92.3	50.6	75.6
<i>Scopulariopsis</i>	Outdoor	0.0	2.5	3.7	1.1	0.0	0.0	1.2	1.2
	Indoor	0.0	2.5	3.7	1.1	0.0	0.0	2.5	1.4
<i>Ulocladium</i>	Outdoor	2.3	2.5	5.6	0.0	0.0	1.9	8.6	3.1
	Indoor	6.8	2.5	0.0	1.1	4.2	5.8	7.4	3.9
<i>Wallemia</i>	Outdoor	0.0	0.0	1.9	3.2	0.0	7.7	2.5	2.4†
	Indoor	9.1	5.0	9.3	14.7	2.1	11.5	7.4	9.2
Yeast	Outdoor	29.5	30.0	48.1	18.9	47.9	23.1	21.0	29.2†
	Indoor	15.9	17.5	40.7	23.2	18.8	19.2	16.0	21.7
<i>Zygomycetes</i>	Outdoor	0.0	2.5	3.7	2.1	6.3	3.8	0.0	2.4
	Indoor	2.3	7.5	7.4	1.1	2.1	3.8	7.4	4.3
Other	Outdoor	81.8	75.0	87.0	87.4	79.2	88.5	70.4	81.4†
	Indoor	61.4	62.5	83.3	67.4	58.3	71.2	58.0	65.9

*Indoor vs outdoor; $P < .05$.†Indoor vs outdoor; $P < .01$.

To assess the reproducibility of fungal concentrations, the correlation between duplicate samples was calculated. For total fungi, the Pearson correlation between duplicate samples was 0.77 for both indoor and outdoor samples. For the 4 most common fungi, the correlation between duplicate outdoor samples ranged from 0.29 for *Aspergillus* to 0.72 for *Cladosporium*. For indoor samples, correlations ranged from 0.38 for *Alternaria* to 0.68 for *Cladosporium*. All of these correlations were highly significant ($P < .0001$).

There was marked day-to-day variation in the outdoor concentrations of fungi. The outdoor counts of *Alternaria* in Chicago over the 12-month period of data collection (Fig 1) provide an illustrative example of this temporal variation. The outdoor *Alternaria* count was measured on 45 different days at different homes in Chicago during this period, with counts ranging from 0 to 391 CFU/m³. The median outdoor *Alternaria* count during this period in Chicago was 35.6, and the 75th percentile of counts was 71.2. Table E3 in the Online Repository (www.mosby.com/jaci) provides the distribution of outdoor and indoor concentrations of fungi measured in each community over the year of home visits.

Using the 75th percentile of concentrations throughout the year to summarize the distributions of concentration of the 4 most common fungal genera, the outdoor air concentrations were highest for *Cladosporium*, followed by *Penicillium* (Fig 2, A-D). Between-city differences in outdoor fungal concentrations were generally not striking, with a few exceptions. Dallas had the highest outdoor levels of *Alternaria* and *Cladosporium*. Seattle had the lowest outdoor levels of *Alternaria* and relatively high levels of *Cladosporium* and *Penicillium*. Tucson, in contrast, had relatively low outdoor levels of *Cladosporium* and *Penicillium*. For *Cladosporium* and *Alternaria*, the outdoor concentrations generally exceeded those indoors (Fig 2, A-D), and the opposite pattern was observed for *Aspergillus* and *Penicillium*.

The 75th percentile of indoor air *Alternaria* concentration for each of the seven communities was positively correlated with the prevalence of skin test reactivity to *Alternaria* in the communities ($r = 0.82$; $P = .03$). A similar relationship was shown for *Cladosporium* ($r = 0.81$; $P = .03$) but not for *Aspergillus* ($r = 0.52$; $P = .2$) or *Penicillium* ($r = -0.06$; $P = .9$). Relationships between outdoor air concentrations and the prevalence of

TABLE II. Relationship between high indoor fungal concentration (I-O difference >75th percentile*) and home characteristics in 414 homes

Home characteristic	Prevalence of characteristic	Community-adjusted OR†				
		<i>Alternaria</i>	<i>Aspergillus</i>	<i>Cladosporium</i>	<i>Penicillium</i>	Total
Detached house	36.0	1.8 (.9-3.3)	1.2 (.7-2.1)	1.3 (.8-2.2)	0.8 (.5-1.4)	1.4 (.8-2.3)
Forced air heating	45.7	0.8 (.4-1.6)	0.6 (.3-1.0)‡	0.8 (.5-1.3)	0.7 (.4-1.2)	0.4 (.3-.7)‡
Air conditioning in child's bedroom	41.3	1.1 (.6-2.3)	0.7 (.4-1.1)	0.8 (.5-1.4)	1.0 (.6-1.8)	1.0 (.6-1.7)
Observed evidence of moisture or leaks in any room	44.8	1.3 (.7-2.3)	1.3 (.8-2.1)	1.4 (.9-2.2)	1.3 (.8-2.2)	1.4 (.9-2.2)
Reported water, dampness, or leaks in any room in past 12 months	46.0	1.9 (1.1-3.4)‡	1.2 (.8-1.9)	1.3 (.8-2.0)	1.4 (.9-2.2)	1.8 (1.2-2.9)‡
Observed evidence of moisture or leaks in child's bedroom	11.4	1.5(.6-3.4)	2.1 (1.1-4.0)‡	2.7 (1.4-5.1)‡	1.3 (.6-2.5)	3.4 (1.8-6.5)‡
Reported water leaks from ceiling or windows in child's bedroom	7.0	1.1 (.4-3.2)	1.1 (.5-2.7)	1.2 (.5-2.7)	1.2 (.5-3.0)	1.9 (.8-4.2)
Humidifier or vaporizer used in child's bedroom	26.6	1.1 (.5-2.2)	0.8 (.5-1.4)	1.0 (.6-1.7)	1.3 (.7-2.2)	1.3 (.8-2.3)
Observed musty smell in child's bedroom	14.5	0.8 (.3-2.0)	2.6 (1.4-4.7)‡	2.0 (1.1-3.7)‡	2.1 (1.2-3.9)‡	2.5 (1.3-4.5)‡
Observed evidence of cockroaches in child's bedroom	22.0	1.7 (.9-3.3)	3.3 (2.0-5.6)‡	1.6 (.9-2.7)	1.5 (.9-2.6)	2.1 (1.2-3.5)‡
Reported dog living in home within past 6 months	24.9	1.0 (.5-1.9)	1.2 (.7-2.1)	0.8 (.4-1.3)	1.2 (.7-2.0)	1.0 (.6-1.8)
Reported cat living in home within past 6 months	16.2	1.3 (.6-2.9)	2.8 (1.5-5.2)‡	1.6 (.9-2.8)	1.9 (1.0-3.4)‡	2.3 (1.3-4.2)‡
Winter month sample	21.3	1.5 (.7-3.2)	0.4 (.3-.7)‡	0.8 (.5-1.4)	0.5 (.3-.8)‡	0.5 (.3-.8)‡
Bedroom temperature at time of sampling (5°F increase)	NA	1.1 (.8-1.3)	0.8 (.7-.96)‡	1.0 (.9-1.2)	0.8 (.7-.99)‡	0.8 (.6-.9)‡
Relative humidity at time of sampling (10% increase)	NA	1.2 (1.0-1.5)	1.0 (.8-1.1)	1.2 (1.0-1.4)	0.9 (.7-1.1)	1.0 (.8-1.2)

*The 75th percentiles of I-O difference were as follows: *Alternaria*, 0 CFU/m³; *Aspergillus*, 35.6 CFU/m³; *Cladosporium*, 0 CFU/m³; *Penicillium*, 63.3 CFU/m³; and total fungi, 62.5 CFU/m³.

†Odds ratios were adjusted by multiple Cochran-Mantel-Haenszel χ^2 except for the continuous variables temperature and relative humidity, for which multiple logistic regression was used.

‡Ninety-five percent confidence interval does not span 1.

TABLE III. Multiple logistic regression models relating high indoor fungal concentration (I-O difference >75th percentile) to home characteristics in 414 homes*

Fungus	Characteristic	OR	95% Wald confidence limits
Total fungi	Temperature in child's bedroom (5°F increase)	0.7	(0.60-0.89)
	Forced air heating	0.4	(0.25-0.76)
	Reported water, dampness or leaks in any room in past 12 months	1.9	(1.15-3.13)
	Observed evidence of moisture or leaks in child's bedroom	2.4	(1.19-4.79)
	Reported cat living in home within past 6 months	3.0	(1.58-5.74)
<i>Alternaria</i>	Reported water, dampness or leaks in any room in past 12 months	1.9	(1.04-3.48)
<i>Aspergillus</i>	Season (winter vs other)	0.5	(0.26-0.80)
	Forced air heating	0.6	(0.32-0.99)
	Observed evidence of cockroaches in child's bedroom	2.9	(1.65-4.96)
<i>Cladosporium</i>	Reported cat living in home within past 6 months	3.1	(1.65-5.89)
	Observed evidence of moisture or leaks in child's bedroom	2.8	(1.43-5.32)
<i>Penicillium</i>	Season (winter vs other)	0.5	(0.27-0.79)
	Observed musty smell in child's bedroom	2.1	(1.14-3.79)

*All models are adjusted for site. ORs are for the independent relationship of the risk factor to a high indoor fungal concentration after adjusting for the other factors in the model.

positive skin tests were generally weaker, although a relationship between outdoor concentration 75th percentile and the prevalence of skin test reactivity was suggested for *Alternaria* ($r = 0.69$; $P = .09$) and *Cladosporium* ($r = 0.60$; $P = .15$).

For these 4 fungi, the indoor concentrations were moderately correlated with the outdoor concentrations measured on the same day, suggesting that the outdoor concentration is an important determinant of the indoor concentration. The community-adjusted Pearson

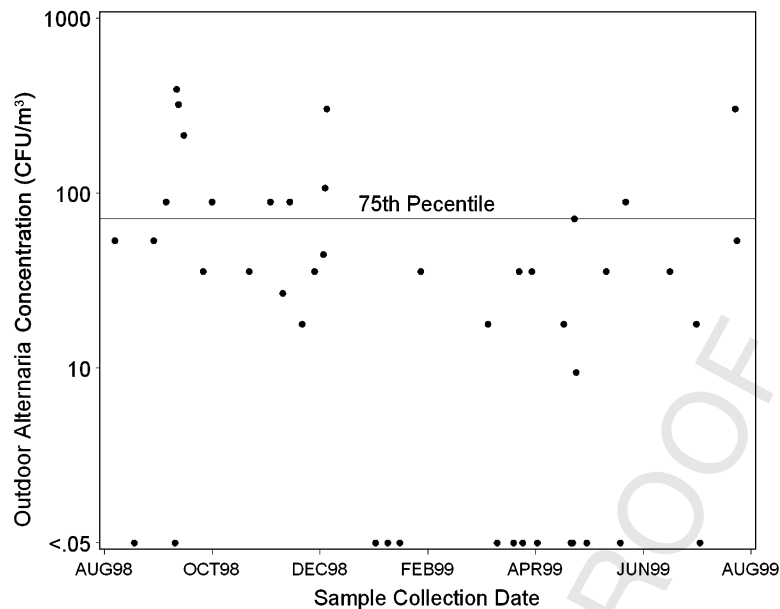


FIG 1. Outdoor concentration of *Alternaria* in Chicago over the sampling period.

correlations between the log-transformed indoor and outdoor concentrations were as follows: *Cladosporium*, 0.56 ($P < .0001$); *Alternaria*, 0.32 ($P < .0001$); *Penicillium*, 0.26 ($P < .0001$); and *Aspergillus*, 0.29 ($P < .0001$).

To classify homes as having relatively high or low indoor concentrations of fungi, we used the difference between indoor and outdoor concentrations (I-O difference) as a metric of indoor fungal concentration in excess of the outdoor concentration on the day of measurement. Combining data from all seven communities, we calculated the 75th percentile of I-O differences for total fungi as well as each of the 4 most common genera, and we considered homes above these cut points to have relatively high indoor concentrations. The 75th percentiles of I-O differences for *Aspergillus*, *Penicillium*, *Alternaria*, *Cladosporium*, and total fungi were 35.6, 63.3, 0.0, 0.0, and 62.5 CFU/m³, respectively.

After adjusting for differences between communities, a relatively high indoor concentration of total fungi (ie, an I-O difference greater than the 75th percentile) was significantly more likely in homes with reported water damage, dampness, or leaks in the past 12 months (odds ratio [OR], 1.8); observed moisture or leaks in the child's bedroom (OR, 3.4); a musty smell in the child's bedroom (OR, 2.5); evidence of cockroach infestation in the child's bedroom (OR, 2.1); or a cat living in the home (OR, 2.3; Table II). A high indoor concentration of total fungi was significantly less likely in homes with forced air heating (OR, 0.4) and in homes with a higher bedroom temperature at the time of sampling (OR, 0.8 per 5°F). In addition, a high indoor concentration of total fungi was less likely to be found in homes sampled in the winter compared with those sampled in other seasons (OR, 0.5). Similar relationships were seen for *Aspergillus*, but fewer statistically significant relationships to home character-

istics were observed for *Penicillium*, *Cladosporium*, and *Alternaria*.

The independent relationship of high indoor fungal concentrations (ie, I-O differences greater than the 75th percentile) with home characteristics was examined by stepwise multivariate logistic regression (Table III). For total fungi, significant independent correlates of a high indoor fungal concentration included caretaker-reported dampness in the home, technician-observed moisture in the child's bedroom, and the presence of a cat in the home. Forced air heating in the child's room and the temperature in the child's bedroom were inversely related to high total indoor fungal concentrations. The presence of a cat and cockroach infestation were associated with a high indoor level of *Aspergillus*, and sampling in the winter and forced air heating were associated with a low indoor level of *Aspergillus*. For *Penicillium*, a musty smell in the child's bedroom was associated with high indoor levels, and sampling in the winter was associated with low indoor levels. High indoor levels of *Alternaria* and *Cladosporium* were significantly associated only with reported or observed dampness.

DISCUSSION

Previous reports from locations in the United States^{9-12,16,17} and elsewhere¹³⁻¹⁵ have indicated that culturable *Alternaria*, *Cladosporium*, *Penicillium*, and *Aspergillus* are common in outdoor air and in many indoor environments. Our data, collected simultaneously in 7 inner-city communities using standardized methods, confirm the nearly ubiquitous nature of these 4 genera of fungi in outdoor and indoor air in cities across the United States. Other fungal genera were less common. The potentially xerophilic fungi *Aspergillus* and *Penicillium*

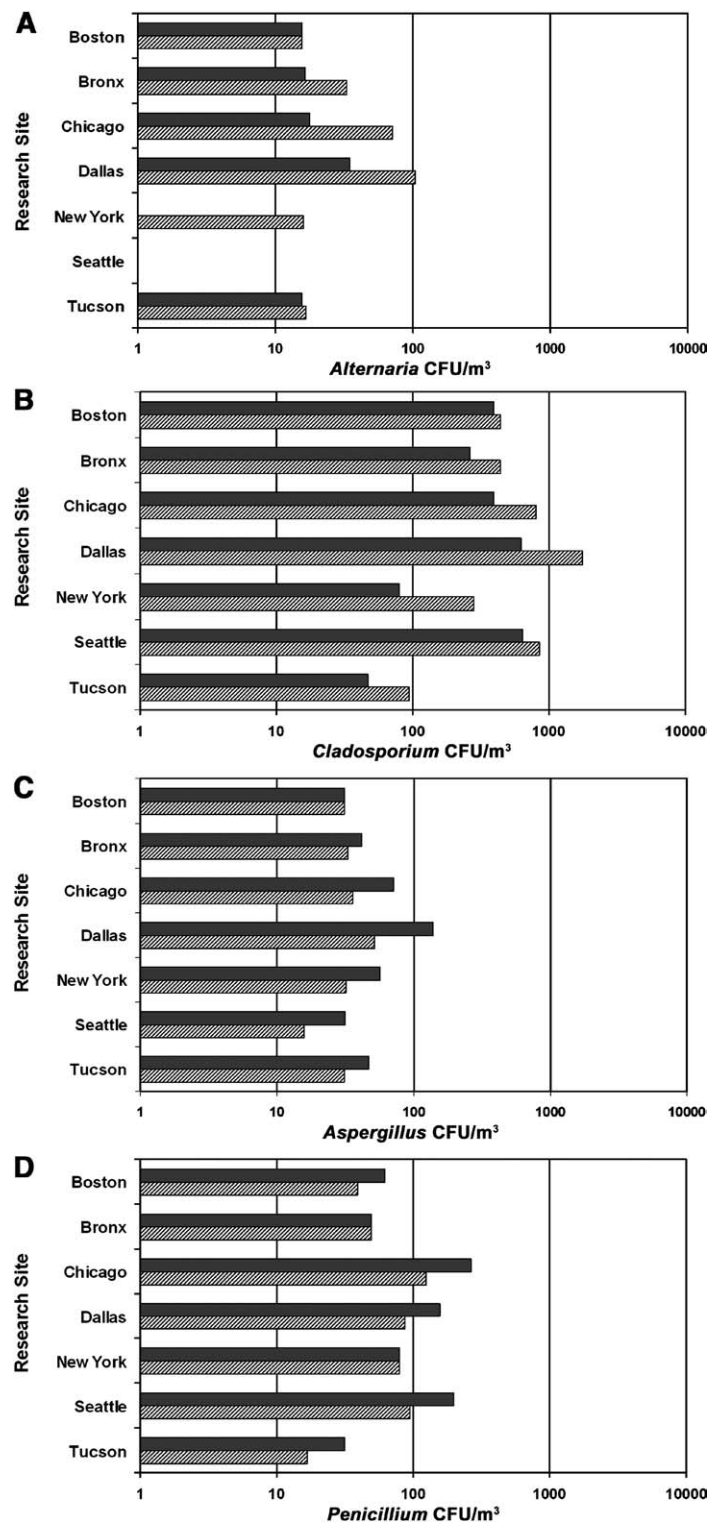


FIG 2. The 75th percentile concentrations of fungi in outdoor and indoor air of 414 homes. The *darker bars* are indoor air and the *lighter bars* are outdoor air. **A**, *Alternaria*. **B**, *Aspergillus*. **C**, *Cladosporium*. **D**, *Penicillium*.

were found more commonly indoors than outdoors, and the opposite pattern was seen for *Alternaria* and *Cladosporium*, fungi that grow on plant stems and leaves, from which they are widely dispersed in outdoor air.

The concentrations of culturable fungi in outdoor air vary over time in relation to many factors, including temperature, humidity, precipitation, and season,¹⁹ and indoor concentrations may be further influenced by temporal variation in air exchange with the outdoors and by the use of machines that alter humidity or filter air.²⁰ This striking temporal variation in concentration (Fig 1) complicates the quantitative analysis of airborne fungi, and there is no universally accepted metric for summarizing airborne fungal concentration in a particular location. As described in the Results section, we have chosen to summarize the fungal concentration by using the 75th percentile of concentrations measured. Although any percentile cut point is by its nature somewhat arbitrary, we chose the 75th percentile in light of the skewed distribution and large number of 0 values.

The classification of an individual home as excessively moldy on the basis of a single sample collection is complicated by the correlation of indoor levels on a given day with the outdoor levels that day, a correlation in part related to the direct penetration of outdoor fungi into indoor air via doors, windows, and other sites of air exchange.⁹ Our data demonstrate such a correlation for each of the 4 most common fungal genera, with correlation coefficients ranging from 0.26 to 0.56. The correlation coefficients are lowest for *Penicillium* and *Aspergillus*, probably reflecting the greater tendency of these 2 fungi to grow indoors. Previous studies have yielded variable results concerning the correlation between indoor and outdoor concentrations of culturable fungi,^{13,14,21-23} likely reflecting geographic differences in climate, housing, and behavior.

Previous reports have revealed relatively weak relationships between home characteristics and objective determinations of home moldiness, but these studies did not account for the outdoor air fungal concentrations on the day that the indoor concentrations were measured.^{13,16} To assess the relative indoor fungal concentration of homes visited on different days, we used the difference between the indoor and outdoor levels to remove the influence of the outdoor level on the day of sampling, and we chose the 75th percentile of the I-O difference as an indicator of a home with a relatively high indoor level of each fungus. The relationships between this metric of indoor fungal concentration and home characteristics (Tables II and III) suggest that this metric is able to identify relatively moldy homes. Parallel analyses using the indoor fungal concentration without subtraction of the outdoor concentration yielded generally similar results (data not shown), although relationships to temperature and season were quite different when the outdoor concentration was ignored.

The association of home dampness measures with relatively high indoor levels of fungi is logical and supports the hypothesis that fungi play a role in the epidemiologic association between home dampness and

respiratory symptoms.²⁴ The significant association of cockroach infestation with a high indoor level of total CFU and *Aspergillus* may derive from cockroach infestation serving as a surrogate for home dampness. The negative associations for forced air heating may relate to the excessive dryness sometimes associated with such heating systems. The association of a cat in the home, but not a dog, with high indoor levels of fungi has also been reported by Ren et al¹⁶ and may be a result of fungal growth in a damp litter box or the large amounts of organic material that cats add to house dust. The relatively low indoor levels of total fungi, *Aspergillus*, and *Penicillium* observed in association with winter sampling may reflect the effect of low relative humidity in the winter. Air conditioning has previously been reported to reduce indoor levels of *Cladosporium*¹²; we did not observe a significant relation between the presence of air conditioning in the home and the indoor levels of fungi, but many of our measurements were made in seasons when air conditioning would not be used.

Because many home characteristics are interrelated, we used stepwise multiple logistic regression models to identify the characteristics with the strongest independent associations with high indoor levels of fungi (Table III). The negative association between temperature in the bedroom and a high indoor level of total fungi may reflect seasonal effects, including keeping windows closed on colder days. For individual fungal genera, temperature did not enter the models as significantly related to a high indoor level, although winter sampling remained associated with high indoor levels of *Aspergillus* and *Penicillium*. Both *Alternaria* and *Cladosporium* were independently associated with moisture or leaks, indicating that indoor sources of these predominantly outdoor fungi may be present in some homes. Nevertheless, the different patterns of association seen for *Aspergillus* and *Penicillium*, compared with *Alternaria* and *Cladosporium*, support the idea that the former 2 genera differ from the latter 2 with respect to their ecologic profile in the indoor environment. The absence of dampness as a correlate of high indoor *Aspergillus* levels in the multivariate model suggests that cockroach infestation or other covariates may be acting as surrogates for dampness in this model.

A potential limitation of this investigation is its reliance on 60-second air samples of culturable fungi, an approach reported to have only moderate reproducibility,¹³ to be unable to provide a time-weighted average of exposure, and to be difficult to interpret in light of the different growth requirements of different fungi.²⁵ Nevertheless, the observed significant correlations between a high I-O difference in airborne culturable fungi and home dampness indicate the utility of this approach for characterizing homes in terms of relative indoor fungal concentrations. A further limitation is the reliance on identification of fungi only to the genus level, which was necessary a result of funding constraints. Especially for *Cladosporium* and *Penicillium*, both of which are large genera with many species, recoveries indoors and outdoors may have

represented different species. Finally, it must be kept in mind that spore counts are only a surrogate for allergen exposure.

In summary, the airborne fungi found in the homes of 414 mold-sensitive children with asthma in 7 inner-city US communities generally paralleled those found in the outdoor air of those communities, and the similarities between communities were more striking than the differences. Indoor fungal concentrations were correlated with the outdoor concentrations measured on the same day, suggesting the need to adjust for the outdoor concentration in analyses by using the indoor concentration as an indicator of the relative moldiness of a home. The I-O difference in fungal concentrations was significantly related to several home characteristics linked to dampness and may provide a valuable metric for future epidemiologic investigations of the role of fungal exposure as a risk factor for disease.

The Inner-City Asthma Study investigators are listed in the Online Repository (www.mosby.com/jaci).

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