
Comparison of indoor fungal spore levels before and after professional home remediation

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Background: Methods for assessing and controlling fungi in the indoor environment have been well documented, but the role of fungal allergen avoidance and respiratory disease control is just beginning to be studied.

Objective: To investigate indoor fungal spore levels to determine if remediation produced reduction of these levels.

Methods: The study was performed on homes remediated for excessive fungal load during 2000 to 2002. Homes were included in the study if they had professional fungal remediation. Airborne spore samples were taken both before and after remediation. Slides were mounted with glycerin jelly that contained Calberla's solution. Spores were identified and counted microscopically at a magnification of $\times 1,000$. Counts were represented as the number of spores per cubic meter of air.

Results: Preevaluations and postevaluations were conducted for 17 structures. There were 92 individual collections before remediation and 99 collections after remediation. Mean counts were 131,687 (median, 9,461) before remediation and 1,291 (median, 409) after remediation. *Aspergillus* and *Penicillium* spores (which were counted together) occurred with the highest frequency in preremediation structures (88%). *Stachybotrys* spores were present in 53% of structures before remediation. *Cladosporium* spores were found in highest frequency in postremediation collections. Preremediation houses contained at least a 1-log increase in *Aspergillus*/*Penicillium* spores over outside collections. In postremediation houses, indoor spore counts averaged 18% of outdoor counts.

Conclusions: Remediation for indoor fungal spore contamination can significantly reduce spore counts. Indoor collections in preremediation buildings are generally much higher than outdoor counts for critical spore types, including *Aspergillus*/*Penicillium* and *Stachybotrys*. Remediation provides indoor spore levels substantially lower than outdoor counts.

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INTRODUCTION

Allergen avoidance, although difficult to achieve, is known to be an important aspect of respiratory disease control.^{1–3} The role of avoidance has been well documented for house dust mites and is being established for cats and cockroaches.^{3,4} Methods for assessing and controlling fungi in the indoor environment have been well documented, but the role of fungal allergen avoidance and respiratory disease control is just beginning to be studied.^{5,6} Since allergen avoidance should be the first-line treatment of allergic disease, we examined the extent of fungal exposure reduction that is possible with professional remediation.

When fungal contamination occurs in private homes, the impact can be immediate.⁷ Concerns of indoor fungal contamination in residential buildings are increasing,^{5,8–12} perhaps as the result of current construction methods that produce tighter buildings and a greater awareness of mold-related problems. Alternatively, such concerns may be attributed to modern building materials that have high cellulose content and are not resistant to fungal growth.¹³ Common household appliances, such as washing machines, dishwashers, and showers, may contribute to increased indoor humid-

ity.¹³ Changes in lifestyle may also affect the growing concern about indoor fungal contamination. Children and adults currently spend most of their time indoors,¹⁴ perhaps because of an increase in sedentary leisure time activities such as video games or an increase in parental safety concerns, especially in inner-city urban settings.^{15–17} To investigate indoor fungal spore exposure and to see if remediation resulted in a reduction of indoor spore levels, the following studies were conducted.

MATERIALS AND METHODS

Materials

Allergenco MK-3 collectors were obtained from Allergenco (CIH Equipment Company Inc, Odsmar, FL; <http://www.cihequip.com/default.htm>). Hexane and Lubraseal high-temperature vacuum grease were obtained from VWR Scientific (West Chester, PA). Microscope slides and coverslips were obtained from Fisher Scientific (Hampton, NH). Calberla's stain was obtained from Surveillance Data Incorporated (Plymouth Meeting, PA; www.sdi.com).

Experimental Protocol

All residential home air collections from the greater Kansas City area taken from 2000 to 2002 and evaluated by our laboratory were examined for inclusion in the study. Homes were included if airborne fungal spore sampling was performed using similar methods both before and after professional remediation to remove visible fungal growth and re-

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Table 1. General Descriptive Statistics for the 2 Study Groups*

Variable	Preremediation	Postremediation
No. of structures	17	17
No. of collections	92	99
Mean No. of collections per structure	5.4	5.8
Mean count for structures	131,687	1,291
Mean count for collections	163,320	1,260
Median count for structures	9,461	664
Median count for collections	4,692	409
Minimum count for structures	231	56
Minimum count for collections	67	0
5th percentile for structures	231	56
5th percentile for collections	128	14
25th percentile for structures	4,331	161
25th percentile for collections	597	96
50th percentile for structures	9,461	664
50th percentile for collections	4,692	409
75th percentile for structures	50,496	1,419
75th percentile for collections	15,532	1,536
95th percentile for structures	158,678	4,373
95th percentile for collections	85,595	5,400
Maximum for structures	1,648,898	5,026
Maximum for collections	12,893,867	11,845

* Data are presented for both preremediation and postremediation collections. Data are grouped by counts for all collections in a structure (structures) and counts for all collections for all structures (collections). All values are spores per cubic meter unless otherwise indicated.

Table 2. Preremediation and Postremediation Airborne Spore Counts for Specific Fungal Genera

Variable	<i>Alternaria</i>		<i>Aspergillus/Penicillium</i>		<i>Chaetomium</i>		<i>Cladosporium</i>		<i>Stachybotrys</i>	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Percent of structures	82	76	88	41	65	29	100	100	53	41
Percent of collections	43	30	61	13	18	10	84	72	23	18
Mean for all collections	97	37	112,327	201	39	3	70,033	319	696	4
Median for all collections	0	0	1,311	0	0	0	266	80	0	0
Minimum for all collections	0	0	0	0	0	0	0	0	0	0
5th percentile for all collections	0	0	0	0	0	0	0	0	0	0
25th percentile for all collections	0	0	0	0	0	0	80	0	0	0
50th percentile for all collections	0	0	1,310	0	0	0	265	0	0	0
75th percentile for all collections	85	13	10,823	0	0	0	927	173	0	0
95th percentile for all collections	347	88	100,693	682	171	27	12,942	1,621	853	27
Maximum for all collections	3,413	1,040	8177,778	10,912	1,706	88	4,622,222	3,813	48,640	93

duce airborne fungal spores. Only the first preremediation sampling and the first postremediation sampling were included in the study. Conditions in the home during the second sampling event were similar but not identical to conditions during the first sampling event. Initial sampling was performed in open areas of the room without any specific measures to dislodge spores such as opening wall or ceiling cavities. Clearance sampling was performed after remediation efforts, including moisture control and construction, had

been completed. If clearance sampling was not satisfactory, additional cleaning was performed, but only the initial clearance sampling results were used in this study. Spore sampling results are presented as means and medians for each structure and for all collections.

Remediation methods were not standard but were specific, depending on the individual circumstances. They generally followed guidelines established by the Environmental Protection Agency.¹⁸⁻²⁰ Typically, they involved identifying and

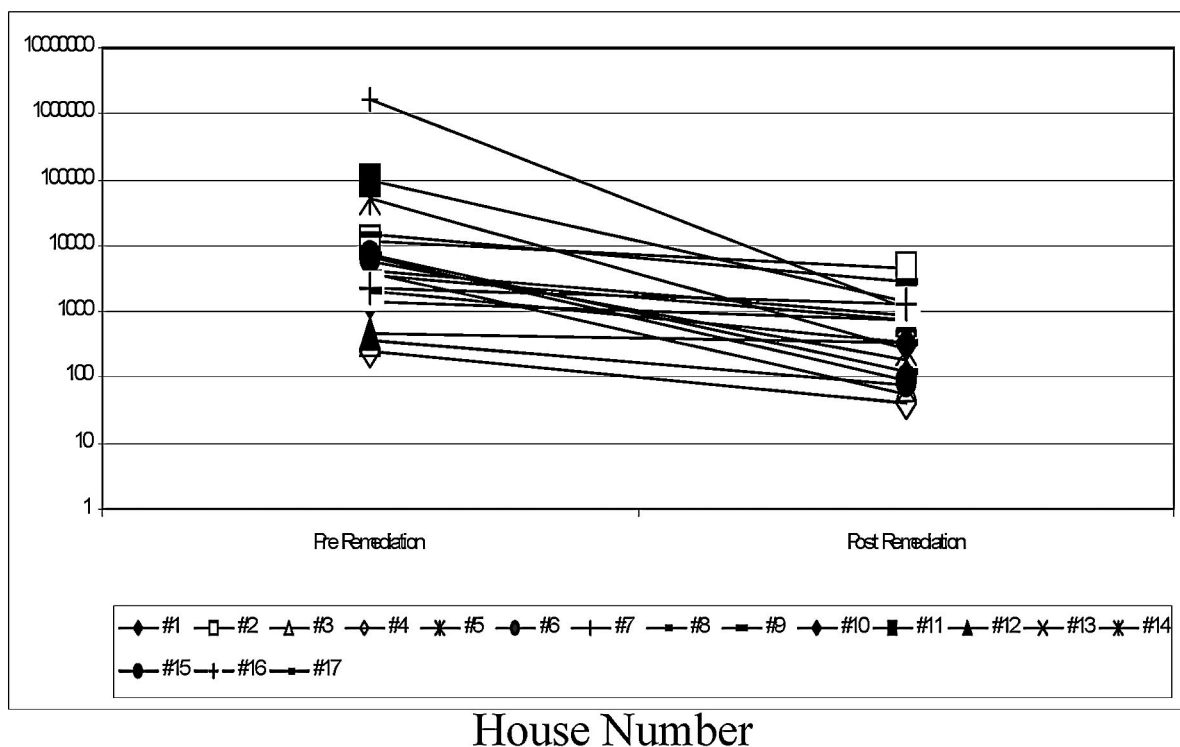


Figure 1. Preremediation and postremediation levels of mean indoor total spore counts per cubic meter of air in 17 homes presented on a logarithmic scale.

fixing the moisture source and removing and replacing contaminated drywall, carpet, ceiling tiles, or other material that was supporting the fungal growth. After removing contaminated materials, the space was cleaned to further reduce spore levels. Cleaning consisted of washing with soap and water for any suitable surfaces and disinfected using a suitable biocide (eg, bleach). Cleaning was also extended to ductwork and HVAC systems if needed. Surfaces that could not be washed and disinfected, including carpet and upholstered furniture, were cleaned with a high-efficiency particulate air (HEPA) vacuum.

Homes in the study underwent professional fungal remediation. Reasons for remediation work varied but most often involved the unsightliness of visible mold that resulted from water intrusion, the potential for property destruction engendered by the presence of fungi, and concerns about potential health consequences due to living in a contaminated environment. To our knowledge, none of the remediations involved legal cases, most were paid by the homeowner, and the typical cost was a few thousand dollars. Collections were made with the Allergenco MK-3 spore trap operating at an inlet velocity of 15 L/min. Collections were either 5 or 10 minutes in duration, depending on the opinion of the operator as to the expected spore load in the area. Collections were taken throughout each structure, including bedrooms, bathrooms, basements, and garage areas. Human activity in the home was typically reduced during the initial and postreme-

diation inspection. No samples taken inside walls or in attic areas were included in this study. Since the remediation events occurred throughout a period of 2 years, outdoor weather conditions varied considerably. For comparison purposes, at least one outdoor collection was taken for each structure at the same time and general location as the indoor collections. Slides were mounted with glycerin jelly that contained Calberla's solution. Spores were identified and counted microscopically at a magnification of $\times 1,000$.⁷ Sufficient percentages of the entire collection (typically 50% for rare taxa and 10% for numerous taxa) were counted to produce statistically valid estimates of airborne fungi present. Collections and estimates were made such that the limit of discrimination was 7 spores per cubic meter of air. Counts were represented as the number of spores per cubic meter of air. Spores of the genera *Aspergillus* and *Penicillium* cannot be properly distinguished in airborne collections and were counted together as *Aspergillus/Penicillium*. Likewise, *Ascospores* and *Basidiospores* were enumerated as collectives instead of identified specifically. The National Allergy Bureau of the American Academy for Allergy, Asthma and Immunology certified the persons who performed the airborne spore identification.

RESULTS

The cohort consisted of 17 structures. Preevaluations and postevaluations were conducted for each structure. There

were 92 individual collections before remediation and 99 collections after remediation. Preremediation and postremediation collections were conducted during all times of the year, with 22% in the winter, 30% in the spring, 13% in the summer, and 35% in the fall. General descriptive statistics for the 2 groups are presented in Table 1. Mean indoor counts for all structures were 131,687 spores per cubic meter of air before remediation and 1,291 spores per cubic meter of air after remediation. Airborne spore counts for specific fungal genera are presented in Table 2. *Aspergillus/Penicillium* spores occurred with the highest frequency in preremediation structures (61% of collections). *Stachybotrys* spores were present in 23% of preremediation collections. *Cladosporium* spores were found in highest frequency in postremediation collections. A comparison of preremediation and postremediation airborne fungal spore counts is presented in Figure 1. The average spore counts decrease more than 1 order of magnitude in most cases, with the greatest decrease being more than 2 orders of magnitude.

Preremediation houses contained as much as a 3-log increase in spores over outside collections, but when outdoor counts were high, the indoor-outdoor ratio was not significantly altered (Fig 2). In postremediation houses, indoor spore counts averaged 18% of outdoor counts. Postremediation airborne *Aspergillus/Penicillium* levels (Fig 3) decreased in 15 of the 17 homes. The largest decrease was nearly 6

orders of magnitude. A similar but less significant decrease was seen for *Stachybotrys* spores (Fig 4).

DISCUSSION

Avoiding exposure to indoor allergens is an important element in the treatment of allergic disease. The results of several studies have demonstrated that avoidance is an effective strategy; however, strategies that optimize allergen reduction in houses have not been determined.^{3,17} We have shown that with careful remediation indoor mold spore counts can be significantly reduced, thereby decreasing at least the potential risk of allergic symptoms.

Such a significant reduction in airborne allergenic material as seen in this study is difficult to obtain with other indoor allergens. Numerous studies have shown that the condition of children with asthma improves when they are in dust mite-free environments.^{1,2} Efforts to remove the child from contact with mite allergen have been rewarded with measurable alleviation of symptoms.² Allergy reduction has not worked as well with cat allergen because of the ubiquitous nature of this protein.²¹ It also has not worked well with cockroach allergen because of the difficulty in removing this insect.²²

Allergen avoidance products (mostly for mites) are widely advertised and can be purchased directly from many sources. Among such products are bed encasings, vacuum cleaners and bags, facemasks, filters for air conditioning systems,

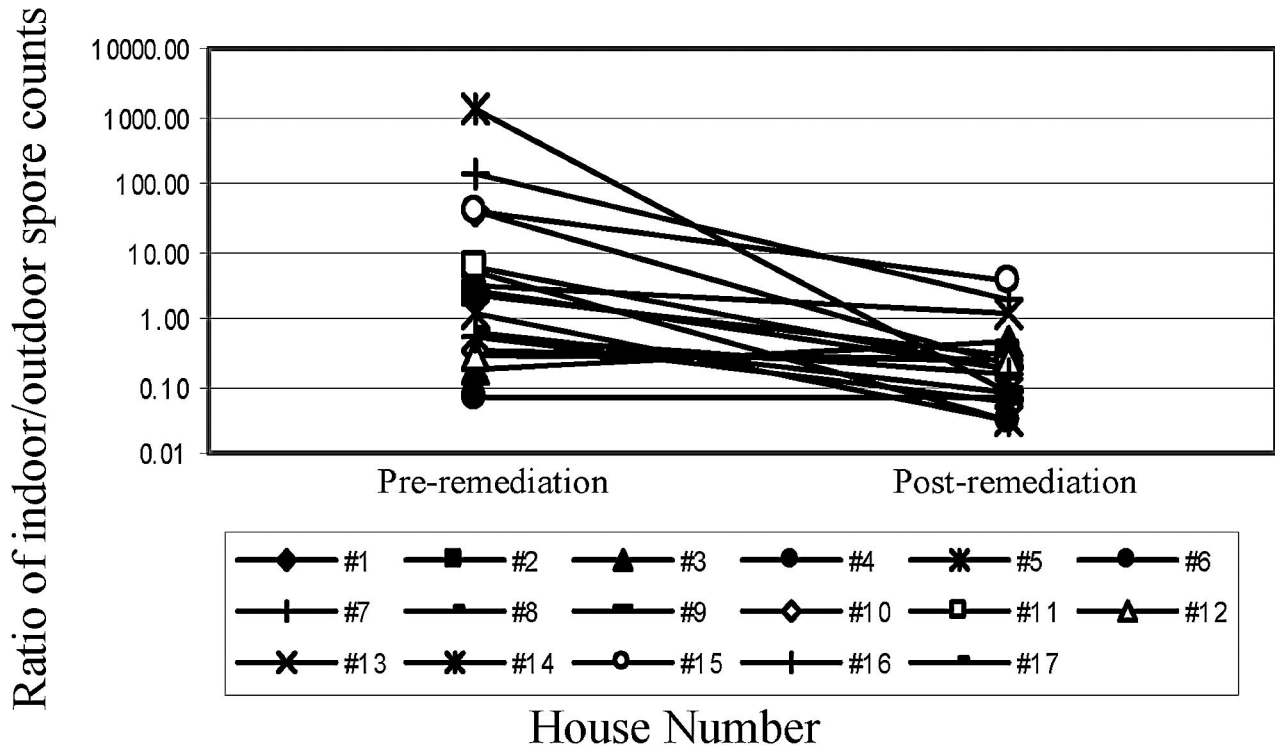


Figure 2. Preremediation and postremediation levels of the ratio of mean indoor total spore counts per cubic meter of air to outdoor total spore counts per cubic meter of air in 17 homes presented on a logarithmic scale.

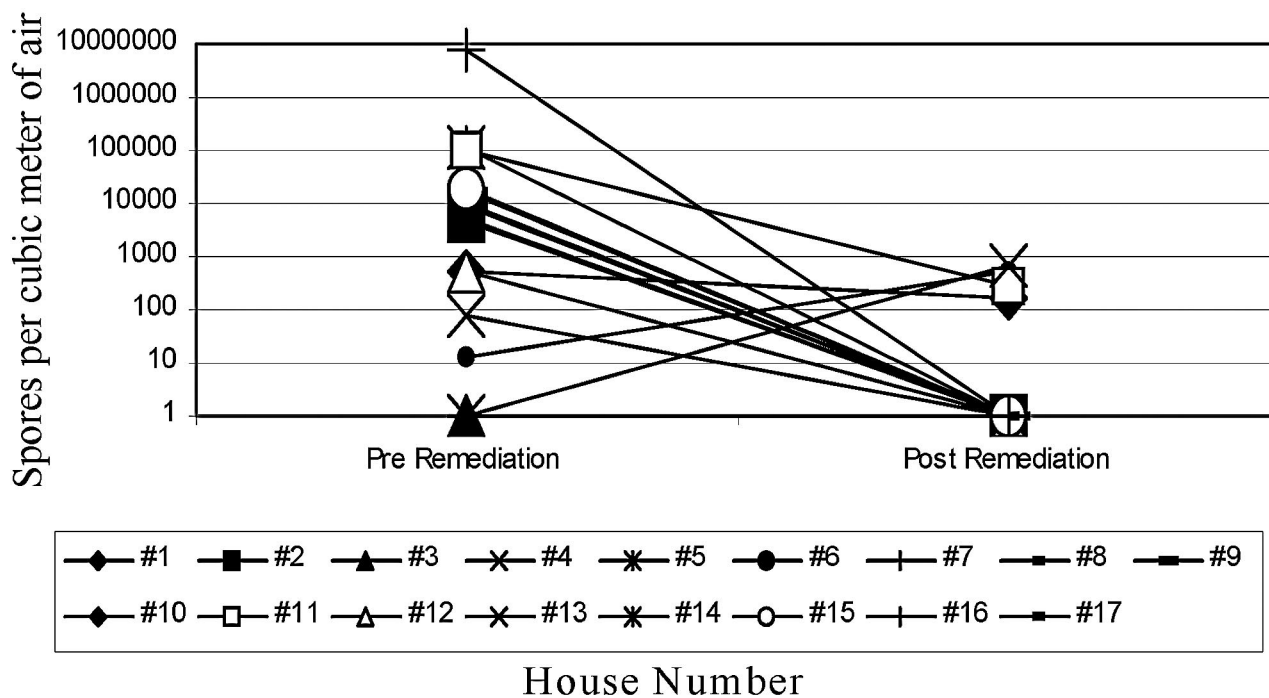


Figure 3. Preremediation and postremediation levels of mean indoor *Aspergillus/Penicillium* spore counts per cubic meter of air in 17 homes presented on a logarithmic scale.

central and room air purifiers, acaricides, and “dust-free” toys. The ability of these products to improve indoor air quality and decrease allergen exposure often has not been scientifically established. Most manufacturers do not document the efficacy, cost-effectiveness, and time-related limitations of their products.²³ Fungal cleanup after water damage resulting from fires and floods has been practiced for a long time and the methods are well established.¹⁸ Primary efforts in fungal remediation must be water control. Herein we demonstrate a substantial reduction in airborne spore concentrations using these methods.

Significant Genera and Reductions

The significant genera seen in this study are the same as those previously reported in homes.^{24,7} The dominance of *Aspergillus/Penicillium* in preremediation homes and that of *Cladosporium* in postremediation homes would have been predicted by any of numerous persons who now perform fungal remediation. The presence of *Stachybotrys* spores in 53% of homes is slightly higher than previous reports of 30% for problem homes⁷ and notably higher than one would expect in homes without fungal problems. When *Stachybotrys* was present in a home, it was often found in only one of several collections and was not normally distributed throughout the home. Although, as in any subjective identification, spore types can be misclassified, our laboratory has much experience growing and identifying *Stachybotrys* spores. Also, these homes all had perceived fungal problems that were deemed to require remediation, and the homeowners

considered the problem significant enough to spend the money for remediation. Since *Aspergillus/Penicillium* spores are small and easily airborne, they can be found at airborne concentrations in the millions per cubic meter of air. Also, since they are often easy to find and remove, significant reductions in these spores are expected. However, overall mean reductions after remediation were largely due to a few structures with high preremediation counts. Some structures with low counts initially changed little. However, these homes fit the inclusion criteria and were included. Not all remediation efforts are successful on the first attempt. In at least 2 homes, both *Aspergillus/Penicillium* and *Stachybotrys* spores were increased after initial remediation, which is not an unusual circumstance. Often removing drywall or opening attic or basement spaces during initial remediation allows increases in airborne spores. Professional remediation companies use plastic sheeting barriers to contain the area under remediation and test to ensure their barrier precautions are working properly. For the purposes of this study, we chose to include only the first preremediation count and the first postremediation count because we wanted to investigate the impact of the remediation itself. Also, sampling subsequent to the initial clearance is often targeted and not as extensive as the initial clearance. In those houses in which the first postremediation count was not satisfactory, additional cleanup was used. Additional cleanup usually took the form of additional HEPA vacuum cleaning. Many

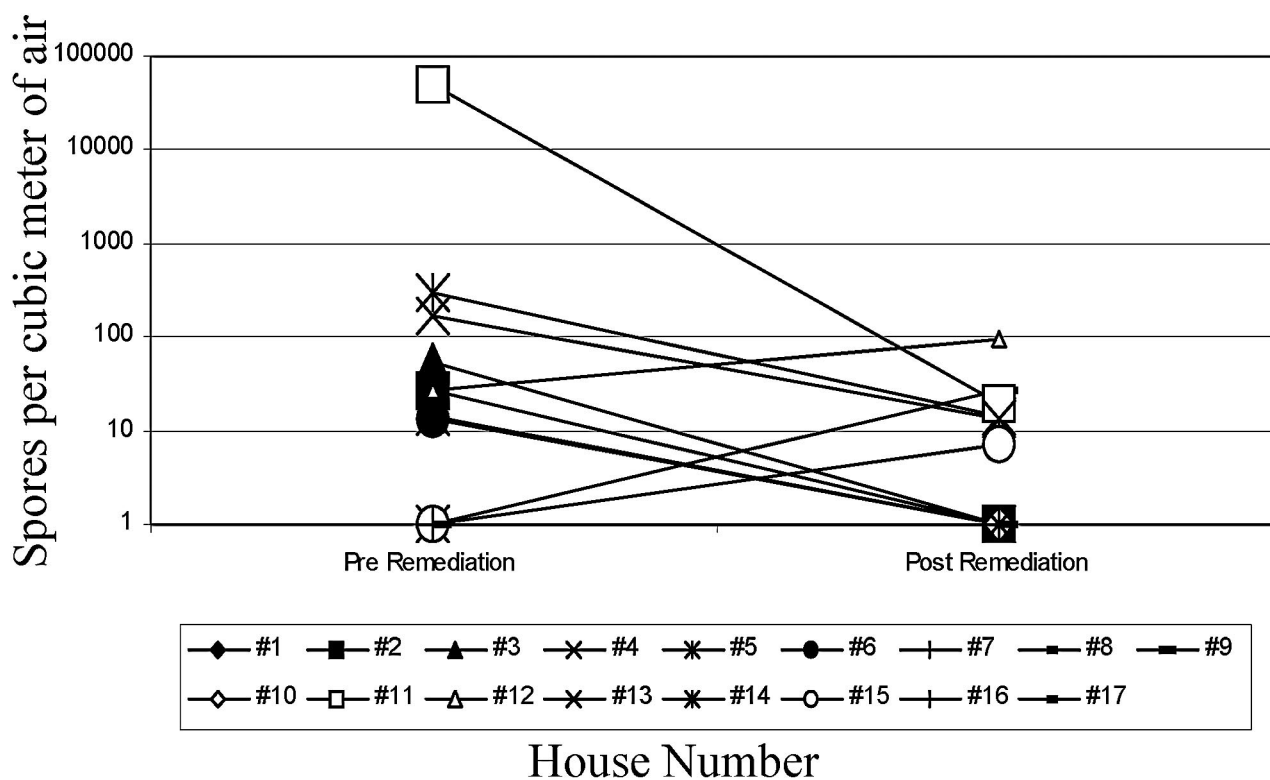


Figure 4. Preremediation and postremediation levels of mean indoor *Stachybotrys* spores per cubic meter of air in 17 homes presented on a logarithmic scale.

remediation firms guarantee reduction of indoor spores to levels below those of outdoor spores for individual species.

Time of Year of Remediation

The remediation projects usually were completed within 2 weeks, although some projects had more than 1 month between the initial inspection and the first clearance sample. The projects were fairly evenly distributed throughout the year, with most in the fall (35%) and fewest in the summer (13%). Time of year seems to have some impact on indoor spore levels. Indoor counts reflect outdoor counts, depending on the infiltration characteristics of the individual structure. It is significant that outdoor counts of 2 significant indoor spore types, *Aspergillus/Penicillium* and *Stachybotrys*, are seldom elevated in this part of the country; however, in some cases fungal spore levels may be elevated in nonproblem structures. The similar percentage of spores reported herein for *Aspergillus/Penicillium* and *Stachybotrys* after remediation suggests that under some conditions these levels may exist naturally.

Problems for Future Research

Several problems concerning indoor fungal-related aeroallergens remain to be solved. First, no quality standards exist for indoor allergen control or for products and services offered to customers by environmental remediation firms. It is crucial to

establish quality standards for indoor allergen control products and procedures so that the consumer may gauge what is effective. Scientific evidence has established such standards for encasings, vacuum cleaners and bags, and filtration systems. Techniques need to be developed for other products or procedures promoted by industry in the name of dust control. For example, no known standards exist to determine whether duct cleaning is effective, and duct cleaning is a multimillion-dollar business.^{23,25}

Second, we need to get a better idea of what if any symptoms are related to indoor fungal aeroallergens and how much effect their removal might have on health symptoms. Studies like these are necessary to eventually establish evidence of the causal effect of mold on health. Finally, the level of improvement in the quality of life that is associated with the removal of fungal spores needs to be documented. Likewise, necessary measures to prevent indoor fungal growth from all sources need to be better delineated. If this is accomplished, these measures can be incorporated into routine teaching practices in allergy clinics, allowing families to maintain good indoor air quality and improve asthma and allergy symptoms.

CONCLUSIONS

We have demonstrated that typical remediation can significantly reduce spore counts in structures with indoor fungal spore con-

tamination. We also observed that indoor collections in preremediation buildings are generally much higher than outdoor counts for critical spore types, including *Aspergillus/Penicillium* and *Stachybotrys*. After remediation, indoor spore levels are substantially lower than outdoor counts at most times of the year. However, much work remains to be done before fungal remediation is established as an effective avoidance mechanism for mold allergic individuals.

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