Fungi in the Built Environment

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ABSTRACT

Fungi are present in normal residential structures from various pathways and reservoirs, such as the migration of outdoor air, dust/debris from foot traffic, indoor reservoirs such as potted plants and foodstuffs, and from other less recognizable sources such as lumber mold found in the building materials that make up the structure. Collection and analysis of settled dust from surfaces in the built environment has become one of several environmental sampling and analytical techniques used during fungal evaluations by some investigators. Measurements of total culturable fungi exceeding 10^5 colony forming units per gram (CFU/g) of dust collected from carpets or furniture surfaces have been considered by some as evidence that a building has been contaminated by mold. In normal residential settings not affected by unusual mold reservoirs, such as water intrusion, little is known of the normal types and concentration of culturable fungi present.

The objective of this study was to ascertain the specific types and amounts of fungi in settled dust, in normal residential settings and to better understand and define a normal level in residences not subjected to water intrusion or sites of unusual fungal growth. This study represents the results of the collection and analysis of surface dust from 26 residential environments that were prescreened by interview, physical inspection, and air sampling to limit the surface dust collection to typical residences in which there was no history of water intrusion, leaks, floods or other evidence of fungal growth. In these structures, surface dust was vacuumed from prescribed areas on carpet and textile--covered furnishings and then subjected to standard culture assay. The results indicate that the culturable fungi were highly variable in terms of types and amounts of fungi, and at some level, this tec1mique has certain applications in diagnosing the presence of unusual fungi in a residence.

Introduction

Molds, a subcategory of the kingdom Fungi, are part of the natural environment. They play an integral part of nature by breaking down dead organic matter such as plant and animal matter. Mold relies on digesting plant materials, using plants and other organic materials for food. Molds can grow on virtually any organic substance, as long as sufficient amounts of moisture and oxygen are present. Without molds, our environment would be overwhelmed with large amounts of dead plant matter. No one knows how many species of fungi exist but estimates range to upwards of a million different species. Molds grow best in warm and damp conditions, and release spores to aid in dissemination and reproduction.

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Mold spores can survive and remain dormant even in harsh environmental conditions, such as dry conditions, that do not support normal mold growth.

Molds commonly reproduce by spreading microscopic spores. Some molds live in temperatures below freezing, and some like it as warm as 122 degrees F. Molds primarily thrive and become a problem when the relative humidity level is above 60% (and more), with temperatures between 50 and 100 degrees F (10 to 38 degrees C) and a pH from 3 to 8. Molds compete with other microorganisms, and some have evolved to produce chemicals that kill or impede the growth of competitors, such as bacteria. Some molds prefer dark settings, since they do not have to compete with organisms like plants.

Mold spores are present in the indoor and outdoor environments. Mold spores may enter the built environment from the outdoor environment through open doorways, windows, and heating, ventilation, and air conditioning systems with outdoor air intakes. Spores in the outdoor air also attach themselves to people and animals, making clothing, shoes, bags, and pets convenient vehicles for carrying mold indoors.

Many building materials provide suitable nutrients where mold can grow, if there is sufficient moisture present. Wet cellulose materials, including paper and paper products, cardboard, ceiling tiles, wood, and wood products, are particularly conducive for the growth of common molds. Other materials such as dust, paints, wallpaper, insulation materials, drywall, carpet, fabric, and upholstery, commonly support mold growth. Some individuals have allergies to exposure to inhaled mold spores (and other mold particles), and this does not require that the mold spores be viable or alive. Additionally, some concerns exist that mold in the built environment could give rise to toxic health effects in exposed individuals; however there appears to be no scientific basis for concerns of toxic reactions. Mold in the built environment has resulted in considerable litigation, and remains a significant building risk management issue.

There is no practical way to eliminate all mold and mold spores in the indoor environment – these organisms are ubiquitous in both outdoor and the built environment; the way to control indoor mold growth is to limit moisture. Molds need both food and water to survive; since molds can grow on almost all surfaces that have organic materials (including settled dust with plant debris), water is usually the limiting factor. Molds will often grow in damp or wet areas indoors. Common sites for indoor mold growth include bathroom surfaces such as caulking and painted surfaces (e.g. ceilings above showers), basement walls, and areas around windows where moisture condenses, at locations around the building envelope that leak, and near leaky water in plumbing fixtures. Common sources or causes of water or moisture problems include roof leaks, leaks in walls or around windows, deferred maintenance, condensation associated with high humidity or cold spots in the building, localized flooding due to plumbing failures or heavy rains, slow leaks in plumbing fixtures, and malfunction or poor design of humidification systems. Uncontrolled humidity can also be a source of moisture leading to mold growth, particularly in hot, humid climates. In some cases, the indoor mold may be hidden. Possible locations of hidden mold can include pipe chases, utility tunnels (with leaking or condensing pipes), wall cavities, condensate drain pans

inside air handling units, porous thermal or acoustic liners inside ductwork, or roof materials above ceilings. Wallpaper, vinyl wall coverings and wood paneling can act as vapor barriers trapping moisture underneath their surfaces, or may hide developing problems, such as leaks.

Some moisture problems in buildings have been linked to the changes in construction practices. These practices have resulted in buildings that are tightly sealed relying on mechanical means for conditioning the spaces rather than allowing the building to breathe naturally through gaps/air leaks, open doors and windows (EPA, March 2001). Sealing air leaks in the building's exterior and using a mechanical ventilation system to provide fresh filtered air can help to reduce entry of mold spores and make it easier to keep indoor relative humidity below 60%.

Investigation and General Interpretation Guidelines

The value of field observations in the assessment of indoor air quality is often more important as compared to environmental sampling and laboratory analysis. Sampling and laboratory results only present one aspect of the indoor air quality (mold problem). An effective evaluation must take into account site conditions (weather), general cleanliness of the building, delayed or insufficient maintenance, the building condition, HVAC operation and occupant use aspects. Awareness of these issues help in understanding the building function and can help in determining the source of a mold problem. It can also provide valuable information when interpreting results from mold sampling.

There are three general types of mold sampling procedures: collection of air samples (by spore trap or culturable methods); collection of tape lifts or swabs from obvious stained locations (by tape lifts or sterile swabs); and by collection of surface dust from textile surfaces (e.g. vacuum dust from carpet or furnishings). Air samples are typically analyzed by comparing indoor to outdoor types and concentrations. Tape lifts and swabs from stained surfaces are usually analyzed by the presence or absence of microscopically visible fungi structures. Analysis of carpet dust is claimed by some to represent the historic nature of mold spores over a period of time; however the interpretation of quantitative amounts of culturable molds in these samples is controversial.

Some of the issues that can affect the interpretation of air sampling results are activity levels of a particular environment at the time of sampling, weather and cleanliness of the environment. Indoor spore levels can be affected by filtered air, air-conditioned air or air from outside sources. The major factor is the accessibility of outdoor air. A residence with open doors and windows with heavy foot traffic may average 95% of the outdoor level while high-rise office buildings with little air exchange may average 2%. The cleanliness of the environment, i.e. a dusty interior can sometimes exceed the outdoor spore levels. The presence of snow cover can make a strict comparison in indoor levels to outdoor levels problematic, and may mean that indoor levels must be compared to typical outdoor levels (during non-snow cover periods of time) (EMLab).

In general, sunny days will present differing counts and levels of spores. Rain washes the air clean of many spore types while it assists in the dispersion of others (e.g.

mushroom spores). Sampling on rainy, foggy, or very humid days may result in outdoor counts which are low or have a significantly different distribution of spore types. Sampling on days when there are strong winds can affect outdoor counts as well.

Along with field observations, moisture evaluations with tools such as moisture meters and hygrometers provide additional information regarding the condition of the suspect space or materials and it can corroborate results from biological sampling. Use of a moisture meter can aid in evaluating areas of observed or suspected (water) damage by measuring the moisture content in the space and/or the building materials. They can also be used to monitor damaged building materials in the drying process.

Sampling

Biological sampling can assist in determining if microorganisms are present in a particular environment, and if the amounts and types are unusual. It can also aid in locating the source of the mold reservoir and facilitate remediation. Evaluation methods include air sampling, surface sampling and settled dust sampling.

Air sampling data represents a specific moment in time. The objective of spore trap air sampling is to capture a “snap shot” of the air and quantify a broad spectrum of fungal spores (both culturable and non-culturable) present in the air. Some fungal spores can cause problems only when they are alive (culturable), while others are capable of producing allergic reactions regardless of their viability. Quantifying airborne fungal spores allows the investigator to assess whether the levels present suggest a fungal problem in the indoor locations. Due to the snap shot effect, these studies must be carefully planned, and sufficient numbers of indoor and outdoor samples must be collected.

The objective of surface sampling is to determine whether the suspected surface (visible stain, discoloration, etc.) sampled is indicative of mold growth on the sample location. A direct microscopic examination of a surface shows exactly what is there. Surface sampling may also reveal indoor reservoirs of spores that have not yet become airborne. It can determine and identify molds actually growing on the surface sampled, and if there were growth structures present, which would be confirmation of mold growth at specific locations.

There are various methods of surface sampling. Transparent tape samples position the adhesive side of the tape over the suspect area and lifts the suspect area from the affected material. Bulk samples remove a physical specimen of the suspect area for analysis. When the sample area is difficult to reach, a bulk sample is not practical or the surface is very wet and a tape sample will not adhere to the area of concern, a swab sample is an option.

Surface (settled) dust sampling is used to determine whether the surface sampled indicates a skewing in the normal distribution of spore types, i.e. unusual fungal contamination. Intuitively, this type of sampling, in which settled dust is vacuumed into a clean, sterile container, may reflect the presence of mold over a period of time. The

interpretation of the results of settled dust sample is challenged by the observation that culturable mold is normally present – so the question of what is abnormal requires knowledge about what are the normal types and concentrations of culturable molds in the built environment.

Our Study

There is little scientific guidance available with respect to fungi in settled dust. The objectives of this study were to ascertain what types and concentrations of fungi are normally present in the surface dust from residential environments not affected by mold. Collection and analysis of settled dust from surfaces in the built environment has become one of several environmental sampling and analytical techniques used during fungal evaluations by some investigators (Maher, 2001; AIHA 2004; EPA, 2003). Measurements of total culturable fungi exceeding 10^5 colony forming units per gram (CFU/g) is stated by some to indicate that a building has been contaminated by mold, and that remediation decisions are therefore warranted. Some have also suggested that the type of taxa present as dominant is an indicator of fungal contamination and non-problem buildings do not contain a dominant taxon (Hodgson and Scott, 1999). The basis for an Occupational Safety and Health Administration (OSHA) statement that total fungi values above 1,000,000 CFU/g may be an indicator of the presence of unusual levels of fungi dates back to a 1988 article by Brief and Bremath, who focused on Legionnaire's disease, and this value does not appear to have a scientific basis, but was an estimate offered by these investigators.

Study Population

A total of 26 dwellings (18 single-family homes and 8 apartment units) in the northern California area were included in this study. From the 26 dwellings, samples of indoor air, outdoor air, settled dust from carpets, and settled dust from furniture, were collected. These dwellings were selected predominantly from colleagues and volunteers who were willing to participate in the study and whose dwellings had passed specific criteria established to ensure that the residence was highly unlikely to be affected by unusual fungi. The goal of the study was to evaluate fungal types and concentrations from settled dust collected in non-fungal impacted structures. All homeowners or occupants were interviewed to confirm the absence of historical or current water damage, water stains, and signs of possible fungal growth sites.

The dwellings in our study represented a range in construction where the changes in these practices over time have been linked to the moisture problems observed in buildings. In general, the single-family homes used in this study were one or two-stories with wood-frame (Type V) construction, which may be any materials allowed by the Uniform Building Code. The exterior envelope of the various homes consisted of exterior cement plaster (stucco) or wood siding, and the roofing systems included composition shingle, concrete tile, ceramic tile and wood shake. Interior wall and ceiling surfaces were gypsum wallboard, lath and plaster; floor surfaces were carpet, hardwood or resilient floor covering. The approximate age of the homes ranged from 14 to 108

years (the majority of the structures were less than 30 years old). All except one house had central forced air heating and air-conditioning system. One house had a wall-mounted heating furnace and did not have air conditioning.

The apartment units sampled were from two complexes; one constructed approximately 26 years ago and the other in the late 1990s. These complexes were two- or three-story structures with wood frame (Type V) construction. Similar to the single-family homes, the complexes consisted of walls typically constructed of 2- by 4-inch wood members. The exterior envelope of the 26-year old complex (sample from Apt. 1) consisted of T-111 siding and a composition shingle roofing system. For the complex constructed in the late 1990s, the exterior envelope consisted of composite wood siding with a composite shingle roofing system. All of the apartments had central forced air heating and air-conditioning systems.

Selection criteria were applied to eliminate residences that may have indoor fungal reservoirs. The selection process was performed as follows:

- At the time of inspection, occupants must have lived in their residences for at least 5 years and have had historical knowledge of the condition of their dwelling. The occupants of one house included in the study had lived in their home for only 2 years, but at the time of the purchase they had the structure inspected by qualified home, pest and mold inspectors, and no signs of unusual mold growth sites or past water/moisture events were noted. The occupants of all structures were interviewed to determine if there had been any water intrusion or plumbing leaks, water stains, any signs of unusual mold growth, any mold-like odors or any other fungal-related problems. If any of these issues were or had been present, the residence was eliminated from further consideration.
- Each residence was then visually inspected. Each room of the residence was examined. Particular interest was placed on the interior sides of the exterior walls, ceilings, under and around windows, near plumbing service areas (e.g. around and under sinks and hot water heaters, adjacent to showers, toilets and bathtubs, near refrigerators, dishwashers, and washing machines), and the relative number and size of interior plants. Dwellings with minor water stains (e.g. small stains under sinks or adjacent to operating sides of windows that could be opened) were evaluated on a case-by-case basis, and the decision to include or exclude homes was based on the apparent extent of the stains and the absence of obvious fungal growth. If there were visible signs of unusual mold growth, stains suggesting leaks, uncontrolled water intrusion, plumbing leaks, water stains exceeding more than several square inches, or an earthy or musty odor that could suggest areas of fungal growth, the residence was excluded from this study.
- Spore trap air samples collected from multiple indoor locations were compared with multiple outdoor air samples at each residence where there was no visual evidence of water stains or mold growth, and when occupants reported no past moisture, water stains, or signs of visible mold growth. Normal findings were interpreted as lower indoor air concentrations for each identified spore types as compared with the outdoor results for each of the indoor air samples. If any of the indoor air samples revealed fungal spore concentrations at levels higher than

the outdoor concentrations for that specific residence, the residence was rejected from this study. Six homes were rejected from the study due to possible unusual spore trap results.

Sampling Procedure

To ensure the air samples collected inside each dwelling were representative of baseline indoor air conditions, occupants of each residence were asked to close their windows and doors overnight prior to sampling activities. Normal access and egress through exterior doors were permitted during this time period. Indoor air samples were collected from two to four regularly occupied rooms on each floor of the residence (typically, the living room, kitchen, master bedroom, and an additional bedroom). Multiple outdoor air samples (typically two to six) were collected in the vicinity of each residence or apartment unit on the same day indoor samples were taken.

Settled dust samples were collected the same day and from the same rooms that indoor and outdoor fungal spore air samples were collected. However, the settled dust samples were not submitted for fungal spore identification and enumeration until indoor and outdoor air samples were confirmed that no unusual fungal types or concentrations were present in the dwelling. These dust samples were always collected following the collection of the spore trap air samples to avoid disturbing the settled dust in an unusual fashion.

In each residence, settled dust samples were collect from three locations: a high-traffic carpeted area located well away from exterior thresholds (e.g. hallway entrance that leads to bedrooms), a low-traffic carpeted area (e.g. a corner of a room located against an interior wall), and the horizontal surface of either textile-covered furniture (upholstered chair or sofa) or a bedspread. Settled dust samples were collected in Zefon Air-O-Cell cassettes. This method was selected because it is commonly used by industrial hygienists conducting fungal investigations in residences (Macher, 2001). The area from which each sample was collected ranged from 0.09 to 0.70 square meters (1 to 7.5 square feet). The surface area sampled was based on the need to collect a minimum quantity of settled dust approximately 100 milligrams to ensure sufficient dust was available for the culture assay procedure. The size of the area from which the sample was collected was measured and blocked with masking tape.

After the study area was sampled, the interior of the cassette was examined. If there was a visible dust cake within the cassette, the cassette was sealed. If there was no apparent significant dust cake, the sample area was expanded and additional sampling was performed using the original cassette. The cassettes were then capped, sealed, uniquely labeled, and shipped following standard chain-of-custody procedures to the laboratory for fungal culture and enumeration.

Laboratory Analysis

Zefon spore traps were mounted onto glass slides and examined under a light microscope. The slide was scanned at various levels of magnification ranging from 200x to 1000x to assess the numbers of large spore types (e.g. *Alternaria,*

Chaetomium, Bopolaris, Curvularia) and smaller spore types (e.g. *Penicillium/Aspergillus, Cladosporium*, ascospores, basidiospores). The spores were identified and the count for each individual type of spore was determined. The final spore densities were then calculated and reported in spores per cubic meter.

Dust samples were initially weighed, and a 0.025g aliquot was removed for extraction and fungal culture. The resulting plates were incubated at a constant temperature of 25˚C for 7 to 10 days. The plates were then examined by optical methods by an experienced analyst to identify and quantify the fungi growing on the plates. Identification was made according to morphological features of the fungi. The quantity was based on enumeration of discrete colony forming units. The developing cultures from all of the differing media and dilutions were examined and counted. The reported values are those representing the highest colony forming unit count, for each separate organism, from any of the media formulations and dilutions. The final data were normalized to represent colony forming units per gram of dust.

Results

The screening process to select residences that had not experienced water intrusion, plumbing leaks or unusual mold situations resulted in selecting 26 structures (a mixture of single family houses [18] and apartments [8]). Indoor and outdoor air sampling results from two of the 28 residences that passed the initial screening interview and inspections (SFH4-VA and SFH7-SJ) revealed elevated airborne fungi spore concentrations, as compared to outdoor comparison samples collected at the same time period, which suggested unusual mold-related conditions. Settled dust data from these two residences were not included in this study. Indoor baseline samples from the remaining 26 dwellings met the selection criteria.

A total of 74 settled dust samples were collected from the remaining single-family homes (18) and eight units in the two apartment complexes that were unaffected by mold. These samples were collected in high-traffic carpeted areas (those that routinely receive foot traffic), low-traffic carpeted areas (locations exposed to settled dust but not routinely receiving foot traffic), and textile-furniture surface or bedspreads. A summary of descriptive statistical results for the sample set is presented in Table 1.

Samples from high-traffic, carpeted areas

In samples collected from high traffic carpeted areas, fungi levels ranged from 30,400 to 10,144,800 cfu/g. The results of descriptive statistical analysis of these data are presented in Table 2.

Ten of the 26 samples had a dominant fungi species. For this study, a dominant fungi species was defined as one that constituted greater than fifty percent of the total cultured fungi. The most commonly detected dominant species was Cladosporium, followed by Yeasts, Penicillium and Areobasidium. A major fungi species was defined as one that constituted between 20 and 50 percent of the total concentration. Eighteen

of the 26 samples had major fungi. The most commonly detected major fungi species was Cladosporium, followed by Yeasts, Penicillium, and Aureobasidum.

Only three of the 26 samples were dominated by fungi often associated with moist building conditions (i.e., Aspergillus, Chaetomium, Penicillium, and Stachybotrys chartarum) (Table 2).

Samples from low-traffic, carpeted areas

In samples collected from low traffic carpeted areas, fungi levels ranged from 7,200 to 18,145,000 cfu/g. The results of descriptive statistical analyses are presented in Table 2.

Eleven of the 25 samples had a dominant fungi species. The most commonly detected dominant fungi species was Cladosporium, followed by Aspergillus niger and Penicillium. Nineteen of the 26 samples had at least one major fungi species, with the most commonly detected being Cladosporium, Penicilliums, and Yeasts. Fungi typically associated with moist conditions dominated six of the 26 samples.

Samples from Furniture Surfaces or Bedspreads

In samples collected from textile furniture surfaces or bedspreads, fungi levels ranged from 10,400 to 2,935,200 cfu/g. The results of descriptive statistical analyses are presented on Table 2.

For each type of fungi analyzed, the range of concentrations detected, as well as the median, geometric mean, and geometric standard deviation is presented on Table 4. Eight of the 23 samples had a dominant fungi species. The most commonly detected dominant fungi species was Cladosporium, followed by Yeasts and Aureobasidium. Fourteen of the 23 samples had at least one major fungi species. The most commonly detected major fungi types was Yeasts, followed by Cladosporium, Penicillium, Aureobasidium, and Aspergillus niger.

Fractional Analysis of Total Culturable Fungi Analysis

Table 3 presents a fractional analysis of the settled dust data, which have been grouped, into the three sample locations (high traffic, low traffic and furnishings), which is useful to illustrate the general distribution of the results. For high traffic areas, 96% of the samples yielded results below 10^6 cfu/g, and for low traffic areas, 92% of the samples yielded results below 10^6 cfu/g.

Discussion

Surface dust sampling and fungal culture are used by some investigators to determine if unusual fungal contamination is present, possibly indicating the need to conduct some form of fungal remediation. This technique is also used to assess fungal contamination of personal property or content items, and consequently the need for fungal remediation of these surfaces. In some circumstances, fungal dust analysis is used as a surrogate

measure for occupant exposure to fungi. The results from this study indicate that culturable fungi in settled dust from carpets and furnishings within the built environment, in structures where there is no indication of the presence of unusual fungi, is highly variable in terms of the types and amounts of fungi, and furthermore is not necessarily correlated with that from indoor breathing zone. These results are generally consistent with observations made by others (Burge et al., 1993; Ren et al., 1999; Chew et al., 2003). Kemp et al. (2002) and Loan et al. (2003) appear to support this perspective. Kemp et al. (2002) collected dust samples from bedroom carpets and mattresses from residences devoid of mold-related problems. Based on the rate of respiration measured for the fungi present, Kemp et al. concluded that bedroom carpets and mattresses in non-problem dwellings and without moisture damage can provide a habitat with enough moisture to support fungal growth, despite the lack of an obvious moisture source. However, concentrations of total fungi present per gram were not reported. Schober (1991) collected samples of floor, bed, and furniture dust from "dry" homes (i.e., no signs of dampness problems or mold damage) and found that *Aspergillus* and *Penicillium* species were commonly encountered and that furniture can be a major source of *Penicillium* spores.

Hodgson and Scott (1998) state that the taxa present, especially as dominant or major, can also be an indicator of fungal contamination. They call out the presence of *Penicillium* spp. and *Aspergillus* spp. as being typically associated with problem buildings. Hodgson and Scott also state that "non-problem samples do not contain a dominant [taxon] when three or more [taxon] are present, unless the [taxon] is a phylloplane species such as *Cladosporium* or *Alternaria*." In this current study of samples collected from residences not impacted by unusual mold sources, *Penicillium* was a major fungi type in a fraction of all sample types and *Aspergillus* species (particularly *Aspergillus niger*) were present in more than half of the samples. These two organisms were not as commonly the dominant types as compared to *Cladosporium* spp., but did dominate in approximately 7% of the carpet dust samples. In this limited set of data, had the dominance by fungal organisms identified as *Penicillium* or *Aspergillus* been a criterion for indication of unusual contamination, this conclusion would have been erroneous in approximately 7% of the structures evaluated.

For our samples, *Cladosporium* was detected as dominant fungi in all sample types (i.e., high-traffic carpeted area, low-traffic carpeted area, and furniture surface or bedspread). *Penicillium, Cladosporium, Aureobasidium*, yeasts, and *Aspergillus niger* were detected as major fungi in samples from all surface types.

Hodgson and Scott postulated that total fungal concentrations greater than 10^5 cfu/g would most likely be associated with buildings contaminated with fungi. However, the data from their control (i.e., non-problem) buildings are both limited and suspect. Their samples were all collected from office buildings, which likely have fungal populations within settled dust very different from those in residential environments, in part because of the way in which outside air enters the structure (e.g., intake of filtered outdoor air through the air handling system for office spaces, as compared to infiltration of unfiltered air through opened doors and windows, or from other leakage pathways, in residential settings). Commercial office buildings are likely to be cleaned at different frequencies and by different methods than residential settings, and the sources of fungi-

containing dusts from occupant activities are likely to be different from residential settings.

Of the five control buildings studied in the Hodgson and Scott paper, three had been problem buildings previously and had been subsequently remediated. It is unclear what this means for surface dust, but it seems likely that some type of treatment or remediation of surfaces would have been conducted. In addition, the study reports that "seven control building culture plates and two problem building culture plates did not contain fungal growth." This finding is unusual, given the ubiquitous nature of fungal spores and the expectation that horizontal surfaces in normal buildings should contain some detectable levels of culturable fungi. However, some control samples were from new carpet and, in two cases, the samples was collected after the application of biocidal treatment to the carpets. It is likely that the samples from control buildings in the Hodgson and Scott study are not representative of the typical surface dust found in residences, or in office buildings or other common building environments.

Based on the results from this current study, it does not appear reasonable that a total fungi concentration of $>10^5$ cfu/g is definitive evidence that a residential surface is contaminated with unusual amounts of culturable fungi. Had this criterion been applied to the data from this current study, it would suggest that 54% of the samples were "mold contaminated," and when examined on a per structure basis, this criterion could suggest that almost 90% of the structures were mold contaminated, whereas other evidence (occupant reported history, visual inspections, spore trap air sampling results) indicates that the structures are not. If a numerical value of 10^6 cfu/g of total culturable fungi were used as a contamination criterion, the data from this study would indicate that an erroneous conclusion would be drawn for 4% of the samples.

A comparison of results from this study to those from Hodgson and Scott appears to support the notion that one should not draw conclusions regarding reasonable background fungi levels for residences using data from other types of buildings (e.g., commercial), where the carpets are regularly cleaned (Beguin and Nolard, 1996 and 1999).

Limitations

One possible study limitation is size of some of the sample aliquots (i.e., < 0.01 g), which could result in widely varying results and bias high the reported concentration values. However, within this study, most sample aliquots were of uniform size (i.e., 0.025 g), and only a limited number of dust samples from low-traffic areas were less than 0.01 g.

Fungal growth media used in the culture process can also bias results if the media selected excludes or suppresses some types of fungi; hence, the amount of fungi detected in a culture may be only loosely related to that in the environment (Chew et al., 2003). We attempted to limit this possible bias by using three popular, common and diverse growth media, in an attempt to maximize fungal growth.

Another possible confounding factor is that there is no standardized equipment or method used to both collect and analyze settled dust samples for culturable fungi. The methods employed varied among the studies reviewed in this paper. Thus, while others, such as Spurgeon (2003), have reported results from carpet dust samples collected from areas known to be subject to water intrusion, comparing such data with those from other studies remains challenging (Wickens et al., 2004).

Conclusions

These data will continue to be supplemented with additional data with the intent of establishing a database of typical background fungi levels in homes unaffected by unusual mold sources. The study results suggest that total fungi levels from carpet dust or furniture surfaces exceeding 10^6 cfu/g is definitive evidence that a residential surface is contaminated with unusual amounts of culturable fungi. While settled dust sampling may be appropriate for determining the mold status of a localized area, such as a mattress, or as a gross screening tool, the use of settled dust results alone to establish the mold status of a structure appears to be inappropriate, unless highly unusual findings are found, such as a set of samples dominated by elevated levels of an unusual fungal type typically associated with water damage (e.g., *Aspergillus*, *Chaetomium*, and *Penicillium* fungi species). Moreover, reported settled dust results should not be used to determine a building's status with regard to mold contamination until standardized collection and analytical methods are established.

Traditional investigative procedures, such as visual inspections, measurement of surface moisture levels, and collecting representative surface samples from stained locations, are more reliable and straightforward for assessing the built environment for unusual fungal contamination.

Tables

TABLE 1. Descriptive Statistics for Total Culturable Fungi, and 95% Confidence Intervals by Sample Type (concentrations listed in cfu/g)

Sample Type	Number of Samples	GM	GSD	95% Lower Confidence Interval	95% Upper Confidence Interval
High-Traffic Carpet	26	125,000	2.7	17,500	897,000
Low-Traffic Carpet	25	171,000	3.1	22,700	1,290,000
Bedspreads/Furniture Surfaces[A]	23	63,300	3.1	6,410	624,000

TABLE 2. Settled Dust Sampling Results Presented by Structure

	Sample Locations		
	High-Traffic Carpet	**Low-Traffic Carpet**	**Bedspreads/Furniture Surfaces**
Structure ID	**Total Fungi (cfu/g)**	**Total Fungi (cfu/g)**	**Total Fungi (cfu/g)**
1	123,000	217,000	46,100
2	58,500	38,100[A]	10,900[A]
3	55,600	102,000[A]	46,900
4	41,700	106,000[A]	39,300
5	142,000	161,000	26,900
6	68,400	157,000[A]	5,280
7	53,200	49,300[A]	40,400
8	77,600	81,500	55,200
9	140,000	363,000	440,000
10	71,800	420,000	253,000
11	1.69×10^{6}	529,000	75,700
12	446,000	1.29×10^{6}	89,700
13	428,000	221,000	47,900
14	156,000	260,000	31,400
15	30,900[A]	127,000	41,500
16	223,000	73,200[A]	15,200
17	327,000	1.26×10^{6}	42,900
18	267,000	55,500	183,000
19	31,300	108,000	136,000
20	203,000	--	--
21	236,000	37,400	44,800
22	45,300	40,200	258,000[A]
23	336,000	392,000[A]	208,000
24	33,200	306,000	490,000
25	154,000	226,000	--
26	144,000	420,000	--
Mean	215,000	228,000	114,000
Maximum	1.69×10^{6}	1.29×10^{6}	490,000
Minimum	30,900	37,400	5,280
Variance	1.05×10^{11}	1.10×10^{11}	1.79×10^{10}
SD	325,000	331,000	134,000
Median	141,000	161,000	46,900
GM	125,000	171,000	63,300
GSD	2.7	2.7	3.1

[A] Sample contains > 50% water-related fungi organisms (i.e., *Aspergillus*, *Chaetomium*, and *Penicillium* fungi species); "--" indicates that no sample was collected.

TABLE 3. Percentage Distribution of Total Fungi Concentrations by Concentration Range (cfu/g) (number of samples listed in parentheses)

Sample Type	<100,000	100,000 to <500,000	500,000 to <1,000,000	1,000,000 to <5,000,000	Total
High-traffic carpet	42 (11)	54 (14)	0 (0)	4 (1)	1.00
Low-traffic carpet	28 (7)	60 (15)	4 (1)	8 (2)	1.00
Bedspreads/Furniture Surfaces	70 (16)	30 (7)	0 (0)	0 (0)	1.00

Table 4. Summary Statistics by Taxon and Sample Type

	High-Traffic Carpet			Low-Traffic Carpet			Bedspread/Furniture Surfaces		
Fungi	Range of Concentrations Detected	Median	GM (GSD)	Range of Concentrations Detected	Median	GM (GSD)	Range of Concentrations Detected	Median	GM (GSD)
Acremonium	ND	ND	ND (1.0)	ND	ND	ND (1.0)	ND-400	ND	23 (1.9)
Alternaria	ND-36,000	3850	703 (19.6)	ND-45,000	3300	1030 (16)	ND-12,000	1800	582 (14.6)
Aspergillus flavus	ND-400	ND	22 (1.8)	ND-32,000	ND	37 (6.3)	ND-4000	ND	29 (3.5)
Aspergillus fumigatus	ND-6700	ND	34 (4.9)	ND-8000	ND	74 (10.9)	ND-4000	ND	37 (4.3)
Aspergillus glaucus	ND-8000	ND	39 (5.4)	ND-8300	ND	74 (9.2)	ND-8000	ND	31 (4.3)
Aspergillus nidulans	ND	ND	ND (1.0)	ND-13,000	ND	26 (3.7)	ND	ND	ND (1.0)
Aspergillus niger	ND-60,000	1450	536 (16.3)	ND-72,000	4000	1920 (12.8)	ND-56,000	400	326 (15.9)
Aspergillus sydowii	ND	ND	ND (1.0)	ND-17,000	ND	26 (3.9)	ND	ND	ND (1.0)
Aspergillus ustus	ND	ND	ND (1.0)	ND-20,000	ND	40 (6.9)	ND	ND	ND (1.0)
Aspergillus versicolor	ND-27,000	ND	32 (5.6)	ND-160,000	ND	54 (11.9)	ND-530	ND	34 (3.3)
Aspergillus, other	ND-400	ND	25 (2.3)	ND	ND	ND (1.0)	ND	ND	ND (1.0)
Aureobasidium	ND-200,000	7600	3760 (18.0)	ND-67,000	4400	1650 (15.9)	ND-68,000	4300	2030 (15.3
Beauveria	ND	ND	ND (1.0)	ND-6700	ND	25 (3.2)	ND	ND	ND (1.0)
Bipolaris/Drechslera group	ND	ND	ND (1.0)	ND	ND	ND (1.0)	ND-1400	ND	24 (2.4)
Botrytis	ND-4000	ND	25 (2.8)	ND-3300	ND	39 (5.0)	ND-5000	ND	29 (3.6)
Chaetomium	ND	ND	ND (1.0)	ND-14,000	ND	32 (5.2)	ND	ND	ND (1.0)
Cladosporium	ND-350,000	25,000	17,900 (8.7)	400-1,200,000	48,000	41,400 (6.0)	ND-180,000	22,000	15,300 (8.
Curvaularia	ND-6700	ND	31 (4.5)	ND-400	ND	23 (1.8)	ND-4000	ND	25 (3.0)
Epicoccum	ND-100,000	3350	644 (23.2)	ND-50,000	4000	863 (20.5)	ND-12,000	800	375 (15.8)
Fusarium	ND-4800	ND	51 (7.4)	ND-8300	ND	46 (7.4)	ND-5000	ND	43 (4.7)
Mucor	ND-4000	ND	52 (5.2)	ND-11,000	ND	117 (12.8)	ND-5000	ND	58 (5.6)
Non-sporulating fungi	ND-12,000	800	354 (8.3)	ND-8300	400	224 (9.0)	ND-1400	800	199 (6.7)
Paecilomyces	ND-9500	ND	31 (4.8)	ND-25,000	ND	51 (9.3)	ND-190	ND	27 (2.7)
Penicillium	200-100,000	9000	8760 (5.6)	ND-430,000	20,000	11,700 (8.4)	ND-120,000	4000	2830 (8.7)
Periconia	ND	ND	ND (1.0)	ND-8300	ND	25 (3.3)	ND-4000	ND	25 (3.0)
Phoma/coelomycetes	ND-8000	ND	61 (8.3)	ND-16,000	ND	74 (11.8)	ND-10,000	ND	70 (7.5)
Rhizopus	ND-4000	ND	117 (7.8)	ND-11,000	400	226 (10.8)	ND-4000	ND	91 (7.7)
Stachybotrys chartarum (atra)	ND-4000	ND	62 (6.2)	ND-8300	ND	25 (3.3)	ND	ND	ND (1.0)
Trichoderma	ND-4000	ND	31 (3.6)	ND-8300	ND	29 (3.8)	ND-4000	ND	25 (3.0)
Ulocladium	ND-9100	ND	105 (12.8)	ND-29,000	3300	730 (18.8)	ND-16,000	ND	213 (14.7)
Wallemia	ND-16,000	ND	69 (10.7)	ND-12,000	ND	33 (5.6)	ND	ND	ND (1.0)
Yeasts	ND-1,400,000	8250	5660 (16.3)	ND-140,000	8300	8360 (9.1)	ND-200,000	8800	4180 (11.1

Notes: ND = not detected; concentrations in CFU/g; GM = geometric mean; GSD = geometric standard deviation; CFU/g = colony forming units per gram

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