Fungal Levels on Interior Surfaces of Ventilation Ductwork: Closed Cell Foam Insulation Versus Fibrous Glass Insulation and Galvanized Metal

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ABSTRACT

This study compares the fungal populations present on the airstream surfaces of fibrous glass insulation, bare galvanized metal, and closed cell foam insulation, which were all subjected to the same environmental conditions over a five-year period. This study shows that fibrous glass liners have fungal levels thousands of times higher than galvanized metal or closed cell foam insulation when exposed to the same environmental conditions. The porous fibrous glass insulation with its rough surface is more likely to hold onto organic debris from the airstream than bare galvanized metal or closed cell foam insulation. Fungi in high moisture areas can feed on this collected organic debris. Porous fibrous glass insulation in contact with the airstream surface can become a reservoir of fungal organisms, which can be a source of elevated levels of fungal organisms in the occupied space. Elevated levels of fungal organisms can degrade the air quality for building occupants. Galvanized metal and closed cell foam insulation have smooth surfaces, which are less likely to collect debris and encourage fungal growth. Galvanized metal and closed cell foam insulation are better choices for interior ductwork surfaces than fibrous glass insulation, especially in high moisture areas such as near cooling coils and humidifiers.

INTRODUCTION

Fungal contamination of buildings has been related to health concerns in building occupants (ACGIH 1999). Because of fungal related health concerns, fungal abatement is becoming common in commercial office buildings.

After fungal abatement work is completed, it is common to conduct fungal clearance sampling in office buildings to determine whether the fungal abatement was successful. In some cases, where buildings have failed their clearance testing, the primary cause of the failure has been traced to the air conveyance system. It has been found that air conveyance systems, which have internal surfaces in contact with the airstream, which readily collect debris, are more likely to become sources of the fungal organisms found in the occupant space. This paper outlines two buildings with these types of concerns and the solutions that were implemented to solve these problems.

FUNGAL SAMPLING PROTOCOL

To assess the fungal infestations in the two buildings, four types of samples were collected. Sampling procedures followed the guidelines provided by the American Conference of Governmental Industrial Hygienists or the American Industrial Hygiene Association and are summarized below.

Fungal Air Samples

Airborne fungal samples were collected on agar plates using a single-stage bioaerosol sampler at a constant sampling rate of 28.3 liters per minute. Two different media were used—DG-18 and 2% malt extract agar. Air was impacted on the plates for one to three minutes at each site. The samples were taken under normal office conditions. All plates were then incubated at 25°C and examined over a seven-day period. The number of colony-forming units per cubic meter (CFU/m^3) was calculated from the number of CFUs counted and the collected air volumes.

Bulk Samples

Bulk samples of fibrous glass insulation and closed cell foam insulation were collected, usually weighing about one

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gram. The samples were placed in a sealed 0.5 liter plastic bag. Samples were kept near room temperature and arrived at the laboratory within 24 hours of collection. Samples were processed upon arrival. Bulk samples were weighed, suspended in sterile distilled water, diluted serially (three dilutions, minimum 100, 4100, and 60,400X), and inoculated onto 2% malt extract agar (MEA) plates. All plates were then incubated at 25°C and examined over a seven-day period.

Micro-Vacuum Settled Dust Samples

Settled dust samples were collected at a flow rate of 20 liters per minute using an open-face three-piece 37 mm cassette with a 0.8 μm pore size mixed cellulose ester (MCE) filter. The sample area was one-ninth of a square meter of a porous surface. The open-faced filter cassette was pressed with some force onto the porous surface. The same section of porous material was vacuumed at least six times. The filter cassette was closed and then tapped lightly. If debris rolled around in the cassette and had a weight of 0.1 to 0.5 grams, sampling was complete. If insufficient debris was collected, a second section of porous material was vacuumed with the same cassette to collect adequate debris. Filter cassettes arrived at the laboratory within 24 hours of sampling. MCE filters were removed from the cassette holders. The loose debris was weighed, suspended in sterile distilled water, diluted serially (three dilutions, minimum 100, 4100, and 60,400X), and then inoculated onto 2% malt extract agar (MEA). All plates were then incubated at 25°C and examined over a seven-day period.

Wipe Samples

A sterile cotton swab wetted with sterile water was used to wipe an area equal to 25 cm^2. Cotton swabs arrived at the laboratory within 24 hours of sampling. Cotton swabs were suspended in sterile distilled water, diluted serially (three dilutions, minimum 100, 4100, and 60,400X), and inoculated onto 2% MEA plates. All plates were then incubated at 25°C and examined over a seven-day period.

FIELD INVESTIGATION INTO BUILDING-RELATED AIRBORNE FUNGAL LEVELS

A five-year-old two-story commercial office building with one hundred occupants and with two central type air conveyance systems, located in the State of Wisconsin, had numerous indoor air quality complaints. The cause of these complaints was traced to extensive fungal contamination caused by rainwater penetration through the exterior walls. Testing showed fungal colonization of porous wall and floor materials primarily by *Aspergillus* and *Penicillium* fungal species. Extensive fungal remediation occurred in this building, which included the removal of vinyl wallpaper, carpet, and suspended ceiling panels. Landscaping and surface water drainage on the exterior of the building was also improved. After this remediation work was completed, this building failed its fungal clearance air test.

Fungal Clearance Air Monitoring

One outdoor fungal air sample and nine indoor fungal air samples were collected in this building using an Andersen N-6 sampler with DG 18 agar plates at a flow rate of 28.3 liters per minute for one to three minutes.

Outdoor fungal levels were 106 colony-forming units per cubic meter of air (CFU/m^3). The dominant outdoor fungal organism was *Eurotium* (66%). Three other species found were *Aspergillus versicolor, Cladosporium*, and *Wallemia sebi*, all at 11% each.

The indoor fungal levels varied from 35 to 2,600 CFU/m^3, with an average concentration of 502 CFU/m^3. Six of the nine indoor samples had fungal levels above the outdoor level. The average indoor concentrations of fungi were five times the outdoor concentrations. *Eurotium,* which was the outdoor dominant fungus, was not detected in any of the indoor samples. *Aspergillus or Penicillium* species were dominant (greater than 50% of the organisms) in all nine indoor fungal samples. Indoor *Penicillium* and *Aspergillus* fungal concentrations were 37 times higher than the outdoor concentrations. This sampling gives strong indications that major reservoirs of *Aspergillus* and *Penicillium* fungal species still exist in this building.

Investigation of Fungal Reservoirs

Eleven microvacuum settled dust samples were collected from porous materials in this building. Four samples were collected from cloth-covered chairs in the occupant space and seven samples were collected from porous fibrous glass insulation in contact with the airstream surface inside the air conveyance system.

The four samples collected from the cloth-covered chairs had total fungal populations that ranged from 30,000 to 63,000 colony-forming units per gram (CFU/g) with an average population of 47,000. *Penicillium* (7,3,2,36%) and *Aspergillus* (1,0,0,0%) fungal species were dominant in one of the four samples and were present in the other three samples.

The seven samples collected from the air conveyance system had total fungal populations that ranged from 28,000 to 13 million CFU/g with an average fungal population of 2.4 million. Two of the seven samples, which were collected within 3 meters of the cooling coils, had total fungal populations of more than one million CFU/g, which normally indicates active growth of fungal organisms or heavy contamination. *Aspergillus* (0,3,0,3,2,0%) and *Penicillium* (3,5,2,27,16,27,7%) fungal species were dominant in three of the seven samples and were present at significant concentrations in all seven samples. Two samples collected within two meters of the cooling coils had a fungal population of 2.6 and 13 million CFU/g with 89% and 97% of the organisms *Cladosporium* and 2% and 3% *Penicillium*—results like this typically indicate active growth of these organisms. Two samples collected in the supply air ductwork, which is downstream of the air filters, had fungal population of 400,000 and 430,000 CFU/g, with *Penicillium* (27,16%) and *Aspergillus* (0,3%) making up a significant number of these fungal organisms.

Additional Fungal Abatement

Major retrofit/redesign of the air conveyance system was required to eliminate the reservoirs of fungal spores. This major retrofit/redesign included removal of internal fibrous glass liners within three meters downstream of the cooling coils and replacement with a smooth surface, closed cell foam insulation, cleaning of the air conveyance system using standard ductwork cleaning techniques, and the coating of the internal fibrous glass liners with a coating with antifungal properties. All the cloth-covered chairs were vacuumed.

Additional Fungal Air Monitoring, First Set

Three outdoor samples and seven indoor fungal air samples were collected in this building using an Anderson N-6 sampler with 2% malt extract agar plates at a flow rate of 28.3 liters per minute for three minutes.

The three outdoor airborne fungal levels were 300, 176, and 188 CFU/m^3, with an average concentration of 221 CFU/m^3. The dominant outdoor fungal organism was *Cladosporium* (53%, 67%, and 31%). Five other fungal species present were *Aspergillus versicolor* (0%, 0%, 6%), *Eurotium* (6%, 20%, 31%), *Paecilomyces farinosus* (0%, 7%, 0%), *Rhodotorula* (12%, 0%, 0%), sterile fungi (12%, 7%, 13%), and yeasts (18%, 0%, 19%).

The seven indoor airborne fungal samples varied from nondetectable to 72 CFU/m^3, with an average concentration of 27 CFU/m^3. Total fungal levels in all indoor samples were less than one-third of the outdoor levels. The average indoor concentrations of fungi were less than one-fifth of the outdoor concentrations. *Cladosporium*, the dominant outdoor fungi, was dominant (more than 50%) in six of the seven indoor samples; one indoor sample had no growth of fungi. *Aspergillus* and *Penicillium* fungal species were present in three of the seven samples, but only at trace levels. Trace levels of *Aspergillus* species were also found in the outdoor air.

Micro-Vacuum Settled Dust Samples, First Set

Three microvacuum settled dust samples were collected from cloth-covered chairs in the occupant space.

The three samples collected had total fungal populations that ranged from 6,600 to 58,000 CFU/g, with an average concentration of 31,000 CFU/g. *Aspergillus* (3%, 0%, 0%) and *Penicillium* (6%, 0%, 0%) fungal species were present at trace levels in just one of the four samples. Total average fungal levels dropped from an average of 47,000 to 31,000 CFU/g, a reduction of 34%. *Penicillium* and *Aspergillus* species dropped from an average of 12.3% of the organisms found to 3%, which was a reduction of 76%.

Fungal Air Monitoring, Second Set

Six months later, three outdoor and eight indoor samples were collected using an Anderson N-6 sampler with 2% malt extract agar plates at a flow rate of 28.3 liters per minute for three minutes. Total outdoor fungal levels were 4,200; 2,047; and 2,094 colony-forming units per cubic meter of air (CFU/m^3), with an average level of 2,780. Dominant outdoor organisms were *Cladosporium* (95%, 88%, and 90%), *Alternaria* (4%, 2%, and 3%), and Basidiomycetes (<1%, 6%, and 3%). *Penicillium* (0%, 2%, 1%) was present at trace levels in the outdoor air samples.

Eight indoor samples were collected. Total indoor fungal populations varied from 94 to 612 CFU/m^3, with an average population of 248, which is one-tenth the average outdoor level. *Cladosporium*, the dominant outdoor organism, was dominant in all eight indoor samples. *Aspergillus* and *Penicillium* species were not present in the indoor samples.

Micro-Vacuum Fungal Bulk Samples, Second Set

Five settled dust samples were collected from the occupant space. Total fungal levels varied from 17,000 to 68,000 CFU/g, with an average level of 39,000. *Cladosporium* (21%, 20%, 55%, 46%, 47%), *Alternaria* (29%, 10%, 13%, 16%, 27%), and Basidiomycetes (0%, 20%, 0%, 0%, 0%), the dominant outdoor airborne fungal organisms, were dominant in the same order as were present in the outdoor air in all five settled dust samples. *Aspergillus* (4%, 20%, 1%, 0%, 0%) and *Penicillium* (0%, 0%, 1%, 4%, 0%) fungal species were present in four of the five samples, but at relatively low concentrations. Total average fungal levels dropped from an initial average of 47,000 to 39,000 CFU/g, which was a reduction of 17%. *Penicillium* and *Aspergillus* species dropped from an average of 12.3% of the organisms found to 6%, which was a reduction of 51%.

RESULTS AND DISCUSSION

The results of fungal sampling in this building are summarized in Table 1. Initial clearance sampling conducted after the initial fungal remediation occurred in this building gave strong indications that major reservoirs of *Penicillium* and *Aspergillus* fungal species still existed in this building. According to AIHA guidelines (AIHA 1996), "dominance in indoor air samples by species of molds that are not the predominant outdoor species indicate that molds are growing in the building and that air quality is degraded."

In this case, *Eurotium* was the dominant outdoor fungi and *Penicillium* and *Aspergillus* species were the dominant indoor fungal species. Settled dust samples collected from the air conveyance system found elevated levels of *Penicillium* and *Aspergillus* fungal species. Samples collected within three meters of the cooling coils inside the air conveyance system were all above one million CFU/g of settled dust, which likely indicates active growth of fungal organisms at these locations. Settled dust collected in the supply air ductwork downstream of the air filters had fungal population of 400,000 and 430,000 CFU/g, with 19% to 27% of these organisms *Penicillium* and *Aspergillus* fungal species.

TABLE 1
Airborne Fungal Levels

Type of Air Testing	Location	#	CFU/m^3 Range	Mean
Initial fungal clearance sampling -total*	Outdoors	1		106
Initial fungal clearance sampling - total	Indoors	9	35-2,600	502
Initial clearance sampling - penicillium and aspergillus†	Outdoors	1		12
Initial clearance sampling - penicillium and aspergillus	Indoors	9	20-2,500	440
First clearance after ACS remediation - total	Outdoors	3	176-300	221
First clearance after ACS remediation - total	Indoors	7	nd-72	27
First ACS remediation - penicillium and aspergillus	Outdoors	3	nd-12	4
First ACS remediation - penicillium and aspergillus	Indoors	7	nd-12	5
Second clearance after ACS remediation - total	Outdoors	3	2,047-4,200	2,780
Second clearance after ACS remediation - total	Indoors	8	94-612	248
Second ACS remediation - penicillium and aspergillus	Outdoors	3	nd-42	28
Second ACS remediation - penicillium and aspergillus	Indoors	8	nd	nd

* nd—nondetectable: detection limit is 12 CFU/m^3.
† *Penicillium* and *Aspergillus*—*Penicillium* and *Aspergillus* fungal species combined.

Fungal remediation of the air conveyance system then occurred and additional fungal sampling occurred in this building.

Additional Fungal Air Monitoring, First and Second Sets

These fungal air samples were collected immediately after the remediation and then six months later. In both sets of these samples the dominant fungal organisms present outdoors, *Cladosporium* was also the dominant indoor fungal organism. The indoor airborne concentration of *Penicillium* and *Aspergillus* fungal species were comparable to or less than outdoor levels. Using AIHA guidelines, this indicates that fungal organisms are likely at normal levels inside this building.

Micro-Vacuum Settled Dust Samples, First and Second Sets

These fungal samples were collected from cloth-covered chairs in the occupant space. These results give additional evidence that fungal remediation of the air conveyance systems was necessary to bring airborne fungal level back to normal levels. Initial samples collected after the first remediation showed signs of elevated levels in the occupant space. *Penicillium* and *Aspergillus* fungal species were dominant in one of the four samples and were present in significant concentrations in all four samples. The first and second sets of follow-up settled dust samples, collected after the air conveyance system was remediated, showed a significant reduction in both total fungal organisms present in the settled dust (17% to 34% reduction) and in the levels of *Penicillium* and *Aspergillus* fungal species (reduction of 51% to 76%).

Five-Year Study of Air Conveyance Systems

The results of five years of ongoing testing that we have been conducting, comparing the fungal populations in fibrous glass insulation, closed cell foam insulation, and galvanized metal in three air conveyance systems in a 19-year-old, 2-story office building with 75 occupants, located in Minnesota, are summarized in Table 2. Internal surfaces of three air conveyance systems (ACS), which were installed in the Minnesota office building in 1982, consisted of either fibrous glass (FG) or galvanized metal (GM). This testing is being performed on three different air conveyance systems, which are all located in the same building. Each air conveyance system serves a different part of the building.

In 1995, five bulk samples of the fibrous glass in two of the ACS were tested for fungi. The two samples of fibrous glass, within three meters downstream of the cooling coils (CC) in two ACS, had an average fungal population of 6.8 million CFU/g compared to three fibrous glass samples collected more than three meters from the cooling coils, which had an average fungal population of 3,700 CFU/g. With the exception of one square meter of fibrous glass liner in one of the three ACS, all fibrous glass liners within three meters downstream of the cooling coils were replaced in 1996 with a closed cell foam insulation (CCF). The entire air conveyance system was cleaned in 1996.

On March 24, 1999, three bulk samples and three wipe samples were collected from fibrous glass liners and three bulk and three wipe samples were collected from closed cell foam liners installed within three meters downstream of the cooling coils in three ACS. Average fungal populations found in the fibrous glass were 16,600 CFU/g and 620 CFU/cm^2. Average fungal populations found in the closed cell foam were 510 CFU/g and less than 4 (BD—below detection) CFU/cm^2.

TABLE 2
Comparison of Average Fungal Levels

	Fibrous Glass Liner	Closed Cell Foam Liner	Galvanized Metal
1982	Installed	Not applicable	Installed
November 1995	6,800,000 CFU/g (bulk)[*] 3,700 CFU/g (bulk)[†]	Not applicable	Not tested (bulk) Not tested (wipe)
February 1996	ACS cleaned—Closed cell foam liner installed		
March 24, 1999	16,600 CFU/g (bulk)[‡] 620 CFU/cm^2 (wipe)[3]	510 CFU/g (bulk)[**] BD CFU/cm^2 (wipe)[4]	Not tested (bulk) Not tested (wipe)
March 25, 1999	Cooling coils cleaned		
March 31, 1999	2,600,000 CFU/g (bulk)[3] 2,400 CFU/cm^2 (wipe)[3]	317 CFU/g (bulk)[4] BD CFU/cm^2 (wipe)[4]	Not tested (bulk) Not tested (wipe)
August 5, 1999	Not tested (bulk) 122,000 CFU/cm^2 (wipe)[3]	Not tested (bulk) 1 CFU/cm^2 (wipe)[4]	Not tested (bulk) BD CFU/cm^2 (wipe)[4]
August 3, 2000	17,600 CFU/g (bulk)[3] 60,300 CFU/cm^2 (wipe)[3]	640 CFU/g (bulk)[4] 142 CFU/cm^2 (wipe)[4]	Not tested (bulk) 78 CFU/cm^2 (wipe)[4]
August 31, 2000	Cooling coils cleaned		
September 5, 2000	1,470,000 CFU/g (bulk)[3] 553 CFU/cm^2 (wipe)[3]	BD CFU/g (bulk)[4] 1 CFU/cm^2 (wipe)[4]	Not tested (bulk) 3 CFU/cm^2 (wipe)[4]

[*] Average of two bulk samples (located within 3 meters downstream of the cooling coils).
[†] Average of three bulk samples located 3 to 10 meters downstream of the cooling coils.
[‡] Average of three bulk or wipe samples collected from fibrous glass liner overlooked during replacement in February 1996 (located within 2 meters downstream of the AHU-4 cooling coils).
[**] Average test results from three bulk or wipe samples collected from AHU-1, AHU-3, and AHU-4 (located within 3 meters downstream of the cooling coils).
Note: All fungal samples were collected from vertical surfaces. BD—stands for below detection limit. The detection limit for bulk samples varies from 500 to 1, 000 CFU/g, depending on the size of bulk sample processed (0.1 to 0.2 grams). The detection limit for the wipe samples is 4 CFU/cm^2.

On March 25, 1999, the cooling coils were cleaned using detergent and water. On March 31, 1999, all the tests were repeated. The repeat tests were taken within 25 cm of the March 24, 1999, locations but were not taken at the same locations. Average fungal populations found in the fibrous glass were 2.6 million CFU/g and 2,400 CFU/cm^2. Average fungal populations found in the closed cell foam were 317 CFU/g and less than 4 CFU/cm^2.

On August 5, 1999, repeat wipe tests were taken from these same locations. Average fungal populations found in the fibrous glass were 122,000 CFU/cm^2, in the closed cell foam were 1 CFU/cm^2, and in galvanized metal was less than 4 CFU/cm^2.

On August 3, 2000, these same locations were retested. Average fungal populations found in the fibrous glass were 17,600 CFU/g and 60,300 CFU/cm^2 and, for the closed cell foam insulation were 640 CFU/g and 142 CFU/cm^2. For galvanized metal, the average populations were 78 CFU/cm^2.

On August 31, 2000, the cooling coils were cleaned with detergent and water. On September 5, 2000, all of the tests were repeated. The repeat tests were taken within 25 cm of the August 3, 2000, locations but were not taken at the same locations. Average fungal populations found in the fibrous glass were 1.5 million CFU/g and 553 CFU/cm^2 and for the closed cell foam were less than 900 CFU/g and 1 CFU/cm^2. For the galvanized metal, the average population was 3 CFU/cm^2.

CONCLUSIONS

These studies show that fungal levels in fibrous glass insulation in contact with the airstream surface in an air conveyance system are hundreds of times higher than the fungal levels found in closed cell foam or on galvanized metal surfaces. Cleaning air conveyance cooling coils with detergent mixed with water and then rinsing increased the fungal levels in the fibrous glass insulation but not in the closed cell foam insulation or the galvanized metal located within three meters downstream of the cooling coils. The fungal levels in the fibrous glass liner increased greatly and indicated the active growth of fungi in this material. Active growth of fungi in fibrous glass liners in low moisture areas is less likely to occur because adequate moisture for growth is less likely to exist in these areas. Fibrous glass liners located in low moisture areas can collect fungal organisms from the airstream and release these organisms to the occupant space. Because of these factors, our conclusions are as follows.

Porous Liners in High Moisture Areas

Porous fibrous glass liners in high moisture areas (with relative humidifies during the cooling season routinely exceeding 70%) are very likely to promote active growth of fungal organisms. Fibrous glass liners, if installed at these locations, should be removed and replaced with materials like galvanized metal or closed cell foam insulation, which are less likely to encourage fungal growth.

Porous Liners in Low Moisture Areas

Porous fibrous glass liners located in low moisture areas (routine relative humidity levels less than 70%) readily collect debris, including airborne fungal organisms. Porous fibrous glass liners contaminated with fungal spores can release these organisms to the occupied space and degrade the air quality. Previous testing has shown that removal of these imbedded fungal spores by cleaning is virtually impossible (Johanning and Yang 1995; Yang and Ellringer 1996). Two choices exist in repairing air conveyance systems with fungal contaminated porous fibrous glass liners. The best option is total replacement of the contaminated liners. This option is very expensive and difficult to accomplish in an occupied building. The second best choice is to coat the porous insulation, which provides two benefits: (1) a smoother surface that is less likely to collect future debris from the airstream and (2) the coatings encapsulate fungal organisms present inside the porous liners and help prevent the release of these fungal organisms into the airstream.

Our studies have shown that encapsulated fungal organisms will, with time, decrease in number and are much less likely to be a concern for the building occupants. Coatings used on porous fibrous glass liners must be picked with extreme care to avoid creating additional problems for the building occupants (Johanning and Yang 1995; Yang and Ellringer 1996). Some coating may serve as food for fungal organisms, which can create additional fungal problems. Other coatings may give off toxic gasses or obnoxious odors that may be harmful or perceived as harmful to the occupants. Successful coatings typically employed the use of antifungal compounds such as zinc oxide, borates, antimony trioxide, or decabromodiphenyl oxide.

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DISCUSSION

Wayne Thomann, Director, Occ. & Env. Safety, Duke University Medical Center, Durham, NC: In the second building, the FGL had been in place since 1982 and was "pre-conditioned" with accumulation of debris from 14 years of operation. (1) Is it appropriate to compare the much older FGL, which has pre-existing mold growth, with a new clean closed-cell product? (2) How do the findings from old, contaminated FGL product relate to the performance of new FGL products with newer surface finishes?

Paul Ellringer: (1) The FGL and galvanized metal were both installed and "pre-conditioned" for the same length of time, which was 14 years at the start of the most recent testing. Comparing these two surfaces is very appropriate. The closed cell foam was added later and it is not as appropriate to compare this material to the FGL. What is most interesting is that the fungal levels on the newer material, the closed cell foam, and the galvanized metal are essentially the same over a five-year period. The FGL is the only material that is quite different in fungal populations by several orders of magnitude.

(2) This study does not look at this. We believe that the newer materials will not be much different from the older materials. The most important characteristic of an interior ductwork surface is whether the surface readily collects debris. Porous fibrous glass surfaces readily collect debris from the airstream. This is true of older fibrous glass products and newer fibrous glass products. We believe the fungi are feeding on the collected debris. Ductwork surfaces need to be nonporous and free of fibrous materials.

Larry Schoen, Schoen Engineering, Columbia, Md.: I am very interested in the increased growth that occurred after coil cleaning; I hadn't though of this as a possible negative result of this maintenance activity. Coil cleaning, it seems to me, is a very variable activity; for instance, you can forward or back wash, protect or not protect the ductwork, use chemicals and low-pressure water or use a high-pressure washer. Did you make an attempt to standardize the coil cleaning activity? Could such variation explain the differing results between the first and second coil cleanings?

Ellringer: We did standardize the coil cleaning. We used a low-pressure washer to apply a detergent solution to both sides of the coil. This was allowed to soak for 30 minutes and was then rinsed off with a low-pressure washer. The adjacent ductwork surfaces were also rinsed off with water. In these units the drainage pan is the low point of the system. Fungal levels following the cleaning are essentially the same during both cleaning activities. Levels of 2.6 and 1.5 million CFU/g are similar numbers with this type of testing. We expect that the fungal levels rise and fall, especially in the fibrous glass insulation, in relationship to the amount of food present (collected debris from the airstream or soap residue from cleaning) and the amount of moisture present. A porous material like fibrous glass insulation will readily collect debris from the airstream and will also readily collect and retain cleaning solution residues.