EVALUATION OF TREATING AND COATING HVAC FIBROUS GLASS LINERS FOR CONTROLLING FUNGAL COLONIZATION AND AMPLIFICATION.

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ABSTRACT

Galvanized metal (steel coated with zinc) ductwork with an internal fibrous glass liner (FGL) is common in the heating, ventilating, and air-conditioning system (HVAC) in the United States. The purpose of using FGL is two folds: acoustics and thermo-insulation. The porous and rough texture nature, of the fibrous glass material, makes it a trap for fibers and dusts in the air stream. Fibers and dust, in the air-stream, are often organic and may serve as nutrients to fungal colonization in the air ducts. Fungal colonization in FGL, particularly within 3 meters downstream of the cooling coils, is common in HVAC air handling systems in the US. Several coatings, to be used on the internal surface of fibrous glass duct liner, which contain antifungal compounds, have been marketed by manufacturers in the US. No long-term data is available to support their antifungal claims.

Six air handling units (AHUs) in three Minnesota office buildings, which have histories of indoor air quality complaints, were determined to have fungal colonization and contamination in the FGL by scanning electron microscopy (SEM) and by bulk and wipe fungal analyses.

All six AHUs were cleaned. Six different procedures were used to change the surface of the FGLs. Three of the six changes involved using coatings with antifungal compounds. FGL's in these AHUs were sampled, using bulk and surface wipe sampling techniques, before initial cleaning and up to three cooling seasons after cleaning and changes. Results show that fungal populations recovered approximately 50% after one or two cooling seasons in FGL's not coated or sealed with antifungal coatings. Two of the three antifungal coatings yielded promising results after three years of testing. Further monitoring and testing are needed to evaluate the long-term effectiveness of these antifungal coatings.

INTRODUCTION

Fungal contamination in the HVAC system is often a combination of design and operation problems. Porous materials, such as internal FGL, in the HVAC system have been identified as a major source of fungal contamination (1,2).

From September 1990 to September 1995, the Minnesota Department of Administration investigated indoor air quality complaints in more than one hundred and fifty office buildings owned or leased by the State. All investigations used the National Institute for Occupational Safety and Health (NIOSH) protocol (3,4). The Minnesota studies identified microbial contamination (primarily fungal) as the primary indoor air quality problem in 29 percent of these surveys. In 92 percent of the cases, microbial contamination of FGL was identified. Minnesota's warm, humid, summer weather may have contributed to the high percentage of

fungal cases identified. Because of widespread fungal contamination of FGL materials inside the ductwork, priority was given to mitigation of this concern.

This article describes how the fungal contamination was identified and how the fungi recolonized and amplified after six different treatment procedures.

MATERIALS AND METHODS

A systematic approach was defined for sampling. Both pre- and post-treatment sampling followed the same approach, at approximately the same locations. Pre-treatment bulk samples of the FGL, six sq.cms. in size and one cm deep, were gently cut with a sharp razor blade and placed in a clean plastic bag. Wipe samples from areas measuring 1, 25 or 100 sq. cms were collected using a sterile cotton swab wetted with sterile water and placed in a clean sterile container. A sample blank consisting of a wetted unused swab was sent with each set of samples. All samples were shipped by an overnight delivery system to an environmental microbiology laboratory for analysis.

Both wipe and bulk samples were used in order that comparisons of surface fungal population could be made between coated FGL and bare galvanized metal. Bulk samples of uncoated FGL are believed to give more reliable fungal levels than wipe samples because of the rough texture of this material. For uncoated FGL, three 1 sq.cm areas were initially wiped and the results averaged for each location. Follow up wipe samples on coated FGL and galvanized metal were taken from 25 or 100 sq.cm areas.

Samples were processed in the laboratory upon arrival. Bulk samples were weighed, suspended in sterile distilled water, diluted serially, and inoculated onto 2% malt extract agar (MEA). Swab samples were directly suspended in sterile distilled water, diluted and inoculated as in bulk samples. All plates were incubated at 25°C and examined twice in seven days. Fungal colonies on MEA were enumerated and identified.

The cooling and heating coils and the ductwork in the supply side of the AHUs were cleaned. The cleaning methods included the following.

1. Sections of the ductwork were air-washed with an omni-directional air jet
2. Where accessible, surfaces were directly vacuumed, with a HEPA vacuum cleaner, to remove debris. As necessary, surfaces were cleaned with a pneumatic rotating brush.
3. All diffusers, grilles and registers in affected ductwork were removed, washed with a detergent solution and re-set.
4. All heating and cooling coils were power washed with a detergent solution and then rinse with clean water.

It was found that operational techniques were very important while cleaning the duct system to avoid damaging the fragile interior FGL. Some FGL, which was not firmly attached to the walls of the ductwork, was removed down to bare metal.

After cleaning, either the FGL was removed down to bare metal, sanitized with a stabilized chlorine dioxide, or coated with a common asbestos encapsulant, a coating containing solubilized copper 8-quinolinolate, a coating containing zinc oxide and borates, or a coating containing antimony trioxide and decabromodiphenyl oxide. These areas were monitored for two or three cooling seasons.

RESULTS AND DISCUSSION

Fungal contamination of FGL was recognized in six, 18 to 30 years old AHUs in three buildings. The most common fungi identified during initial and follow up sampling in both bulk and surface wipe samples were *Cladosporium(C), Penicillium(P), Rhodotorula(R), Aureobasidium(A),* and yeasts(Y).

Nineteen initial bulk samples of FGL, taken from six different AHUs had average fungal levels of 2.1 million, with a range of 400 to greater than 8 million colony forming units per gram (CFU/g) of FGL. Twelve initial surface wipe samples of FGL, taken from four different AHUs had average fungal levels of 57,000, with a range of nondetectable (less than 100) to 240,000 colony forming units per square centimeter of surface (CFU/sq.cm).

1. Removal of FGLs Down to Bare Galvanized Steel. - This occurred in all six AHUs. Four initial wipe samples taken from the interior surface of galvanized metal in two AHUs had an average fungal level of 9, with a range of non-detectable (<4) to 36 CFU/sq.cm. Eighteen follow up wipe samples taken after one, two or three cooling seasons in six AHUs had average fungal levels of 16, with a range of nondetectable (<4) to 109 CFU/sq.cm.

2. Cleaning and Sanitizing of Interior Fibrous Glass Ductliners - This occurred in three AHUs. Retesting within one month of cleaning and sanitizing indicated bulk fungal concentrations (one sample) of 600 CFU/g and surface concentrations (two samples) of non-detectable (<4) to 4 CFU/sq.cm. Follow up testing in three AHUs after one cooling seasons indicated fungal populations (three samples) of 1,500, 26,500 and 3.4 million CFU/g. SEM pictures showed fungal growth occurring on debris present in the FGL. A white visible fungal growth, (similar to initial conditions) covered almost the entire surface of the liner in one AHU, after 2 cooling seasons.

3. Cleaning and Treating with an Asbestos Encapsulant - This occurred in two AHUs. Retesting after one cooling season (one sample) showed low levels of contamination on the surface of 700 CFU/sq. cm. However, one bulk sample taken indicated relatively high levels of contamination - 175,000 CFU/g. Retesting after two cooling seasons showed fungal levels on the surface of 14,000 CFU/sq.cm. SEM pictures taken, after three cooling seasons, indicate fungal growth occurring directly on the surface of the coating. After two cooling seasons, visible microbial growth was present on the FGL treated with this coating in both AHUs.

4. Cleaning and Treating with a Coating Containing Solubilized Copper 8-quinolinolate - This occurred in one air handling unit. A bulk sample taken within a month of coating indicated fungal levels of 105,000 CFU/g. After one cooling season visible fungal regrowth was evident and one bulk sample showed fungal levels of 840,000 CFU/g in this liner. After three cooling seasons, a white visible fungal growth covered almost the entire surface of this coated liner.

5 Cleaning and Treating with a Coating Containing Zinc Oxide and Borates - This occurred in four AHUs. Six initial wipe samples had average fungal levels of 45,000, with a range of 9,300 to 119,000 CFU/sq.cm. Twenty-two samples taken after one, two and three cooling seasons indicates average surface fungal populations of 89, with a range of non-detectable (less than 4) to 1190 CFU/sq.cm. With the exception of one

sample at 1190, all samples were less than 30 CFU/sq.cm. Five initial bulk samples taken in three AHUs had average fungal levels of 607,000, with a range of 2,200 to 1.7 million CFU/g. This coating is specifically U.S. EPA registered as a pesticide for use on FGL.

Five initial wipe samples taken from the interior surface of galvanized metal in two of the AHUs where the FGL was coated had an average fungal level of 4, with a range of non-detectable (<4) to 6 CFU/sq.cm. Ten follow up wipe samples taken after one, two or three cooling seasons in four AHUs had average fungal levels of 20, with a range of nondetectable (<4) to 109 CFU/sq.cm.

6. Cleaning and Coating with a Coating Containing Antimony Trioxide and Decabromodiphenyl Oxide - This occurred in one AHUs. Five initial wipe samples had average fungal levels of 97,400, with a range of 3,000 to 240,000 CFU/sq.cm. Ten samples taken after one and two cooling seasons had average surface fungal populations of 4, with a range of non-detectable(<4) to 4 CFU/sq.cm. Five initial bulk samples had average fungal levels of 3.01 million, with a range of 19,000 to 9 million. Nine bulk samples taken after one and two cooling seasons had average fungal levels of 57,800, with a range of non-detectable (<1,000) to 268,000. With the exception of two samples, both taken in the same location, all sample results were less than 32,000. SEM pictures taken after two cooling seasons show no active fungal growth on the surface of the coating.

   Ten follow up wipe samples taken in the same general area as the above wipe samples but taken from the interior surface of galvanized metal in this AHU after one and two cooling seasons had average fungal levels of 9, with a range of nondetectable (<4) to 40 CFU/sq.cm.

The six AHUs investigated in these three large office buildings are common AHUs used in U.S. office buildings built in the past thirty years. These AHUs have centralized heating and cooling coils to condition the air. This conditioned air is then ducted to occupied spaces. Return air ducts exhaust air from the occupied spaces and return this air back to the central air handling unit. Each of these three buildings have between 14 and 46 centralized AHUs. Each air handling unit provides conditioned air for 10 to 100 building occupants.

FGL was used for noise control and thermo insulation purposes on the interior surfaces of the AHUs themselves and in the supply and return air ductwork. FGL was present immediately downstream of the cooling coils, on most surfaces (all AHUs had some bare galvanized metal present in these areas), and continued for at least three meters downstream in all AHUs. In parts of all three buildings the FGL extended downstream of the cooling coils for hundreds of meters in the supply ductwork and was also present for hundreds of meters in the return air ductwork. FGL on the interior surfaces of ductwork in these buildings covered thousands of square meters of interior ductwork surface area.

Conclusions

Attempts were make to control fungal populations on the interior surfaces of six AHUs in three buildings using six methods. Three of the six methods were successful at controlling the fungal populations for up to three years. Two of the successful methods employed the use of coatings containing antifungal compounds. The successful coatings contained either zinc oxide and borates or antimony trioxide and decabromodiphenyl oxide. Removing the FGL materials down to the bare galvanized steel surface (steel coated with zinc) was also successful.

The coating containing copper 8-quinolinolate was not successful in controlling the fungal populations. *Penicillium* was the dominate fungus found in the regrowth on the FGL treated with this coating. Copper is usually toxic to most molds, particulately at low pH. Some *Penicillum* species are known to neutralize high levels of copper by producing oxalic acid to form harmless and relatively insoluble copper oxalate (5).

Cleaning the FGL material and then sanitizing it with a sanitizer with chlorine dioxide containing compounds was initially successful. However, regrowth of fungal populations were observed after one cooling season.

Cleaning the FGL material and then coating it with a common asbestos encapsulant was also initially successful in limiting fungal growth on the surface of the coating. However, regrowth of fungi populations occurred within two to three years.

There are three factors which affect whether or not interior surfaces of an air handling unit will be contaminated with fungi:

1. The accumulation of dirt, on interior components, which become nutrients for the fungi. The quantity of dirt present is affected by the efficiency of the filtration system for the air handling unit,
2. interior surfaces which serve as a shelter and habitat for their growth, and
3. high relative humidity levels in AHUs, which occur when outdoor air dew points are above the cooling coil discharge air temperature (typically 16°C). Air discharged from the cooling coils under these conditions, usually has a relative humidity level of 90% or higher.

Common to areas of AHUs, which are heavily contaminated with fungi, is the presence of FGL (or potentially any interior surfaces which are likely to trap and collect dirt readily) and the potential for high relative humidity levels inside ductwork when the outdoor air dew points are above 16°C. If any one of these three factors is missing, heavy fungal growth is not likely to occur.

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FUNGAL COLONIZATION OF HVAC FIBER-GLASS AIR-DUCT LINER IN THE U.S.A.

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ABSTRACT

Nearly one thousand and two hundred bulk samples of fiber-glass air-duct liner (FGL) collected in 1994 & 1995 from the heating, ventilating, and air-conditioning (HVAC) system throughout the United States were analyzed for fungal contents. Occasionally, direct mounting and microscopic examination of FGL's were conducted. Because FGL is porous and often traps fiber and particles, including fungal spores, the recovery of fungi from FGL is not necessarily an indication of fungal colonization. The following criteria were used to determine if an FGL sample is colonized by fungi. They are: (1) fungal concentrations higher than 100,000 CFU/g, (2) no more than two dominant fungi detected, and (3) the presence of fungal hyphae and spores in FGL samples by direct microscopic examination.

Approximately 50% of the samples evaluated were considered to have fungal growth and colonization. Species of *Cladosporium* and *Penicillium* were the most frequently encountered colonizers. These two genera of fungi were often recovered from FGL samples taken from locations with high relative humidity, such as airducts downstream from the coils and the blower, or buildings in humid geographical areas (such as Florida and Texas). FGL samples taken from locations where liquid water is often present, such as at cooling coils or drain pans, were dominated by high water activity fungi, such as *Acremonium* spp., *Aureobasidium pullulans, Exophiala* spp., *Paecilomyces marquandii, Phoma* spp., *Rhodotorula* spp., and yeasts.

Because the samples were collected from buildings with known indoor air quality complaints, the percentage of fungal colonization in FGL's may be biased. However, it is important to note that fungal colonization of FGL in the HVAC system can not be ignored.

INTRODUCTION

Fungal contamination in buildings and its impact on indoor air quality (IAQ) are well documented (1, 2, 3, 4). A recent review from the U.S. Public Health Service, Division of Federal Occupational Health, indicated that 1/3 of indoor air quality problems may be microbe related (5). There is also data from the State of Minnesota suggesting that microbial contamination is the primary IAQ concern in approximately 29% of the more than 150 buildings studied (6).

Fiber-glass liners (FGL) are commonly used for acoustical and thermal insulation inside the air handler and its associated air ducts. It is a very useful material for the described purposes. However, Morey and Williams (7, 8) suggested that fungal growth and amplification were likely to occur in soft, porous insulation materials. Fibrous glass insulation liners were reported to be the primary source (92%) of microbial contamination in the Minnesota IAQ studies (6).

Since the mid-1980's, numerous FGL samples, taken in buildings throughout the U.S. and analyzed by the P&K Microbiology Services, Inc., were found to yield high fungal levels. They were often in pure growth, and were observed to have fungal growth and colonization. Soiled FGL's were the most common sources of fungal colonization. Statistics collected in 1994 & 1995 suggested that approximately 50% of FGL taken for IAQ studies and examined

by our laboratory were colonized by fungi. Direct microscopic examination was also used to reveal fungal hyphae colonizing glass fibers of FGL. Furthermore, insect parts, pollens, trichome (plant hairs), decayed leaves, and even dust mites have been seen in FGL samples. These organics are excellent nutrients for fungal growth. This article represents data collected in 1994 through 1995.

MATERIALS AND METHODS

Bulk FGL samples were collected by industrial hygienists conducting indoor air quality (IAQ) studies in the continental United States. A typical sample was 25 cm^2 (5 cm X 5 cm) approximately 1 cm deep section taken from interior FGL insulation of selected air handlers and air ducts. It was cut with a sharp razor blade or knife and placed in a clean plastic bag. Express shipping couriers were usually used to deliver the samples to the laboratory.

Upon receipt in the laboratory, a 0.10 to 0.25 gram sub-sample, taken from the air-stream side of the sample, was weighed, suspended in sterile distilled water, vortexed for 30 seconds, diluted serially, and inoculated onto 2% malt extract agar (DIFCO Laboratories, Detroit, MI) plates. All samples were incubated at 25°C and characterized in ten days. The characterization included enumeration of fungal colonies and identification of all fungi. Fungal colonies are identified to genus or to species using keys and descriptions in several reference books (9, 10, 11, 12). Fungal concentration in the sample was calculated and presented in colony forming units per gram (CFU/g).

Some samples were also examined directly under a stereo-microscope and a compound microscope. Glass fibers were removed directly with a pair of forceps or with sticky tape, mounted with biological dyes, and examined under a compound microscope at 100, 200, or 400X magnifications. The two biological dyes used were cotton blue in lactic acid and 0.1% phloxine in alcohol, glycerin, and distilled water (13, 14). In addition to fungal characterization, various particles and fibers (other than glass fibers) were identified and noted. Close attention was paid to fibers and dust particles of organics, which may become a nutrient source for fungal growth and colonization.

RESULTS

A total of 1,194 bulk FGL samples were analyzed for fungal contents. 578 of the 1,194 samples (48.4%) were determined to have fungal colonization. The determining criteria were: (1) fungal concentrations higher than 100,000 CFU/g, (2) no more than two dominant fungi detected, and (3) the presence of fungal hyphae and spores in FGL samples by direct microscopic examination. The majority of the samples with fungal colonization yielded concentrations greater than 1,000,000 CFU/g, some as high as 10,000,000 CFU/g. Fungal concentrations, however, may not directly reflect the extent of colonization. Higher fungal concentrations were likely to be related to the availability of moisture for active fungal growth during the cooling season.

Two distinct fungal populations were observed to colonize FGL. The primary group of fungi were the species of *Cladosporium*, primarily *C. cladosporioides*, *C. herbarum* and *C. sphaerospermum*, followed by *Penicillium* species. Various species of *Penicillium* are known to grow at a moderately high water activity between 0.90 and 0.85 (15, 16, 17). The second group of fungi included *Acremonium* spp. (slimy-spored), *Aureobasidium pullulans*, *Exophiala* spp., *Paecilomyces marquandii*, *Phoma* spp., *Rhodotorula* spp., *Sporobolomyces* spp., *and yeasts*. *Fusarium* spp. were occasionally detected. Because samples were taken by outside industrial hygienists, exact sample locations within the HVAC system were not known. It was not known whether the FGL samples were exposed to high relative humidity or to frequent wetting by condensate water. Samples with *Cladosporium* and *Penicillium* colonization were believed to be collected from areas of consistently high relative humidity. Many fungi in the second group are known to grow at high water activity (Aw > 0.90-0.95) or moist/wet conditions (17, 18, 19, 20). The samples were suspected to be taken from areas where

frequent wetting of FGL was likely to occur. These areas included drain pans and cooling coils.

Approximately 5% of the total samples were examined by direct optical microscopy. Fungal hyphae and spores were visible on glass fibers removed from samples that were considered to have fungal colonization. *Cladosporium*, as in the culture analysis, was the dominant fungus identified. *Penicillium* conidiophores and spores and yeast cells were also occasionally observed.

Dirt and dust in the FGL samples, upon microscopic examination, contained a variety of identifiable fibers and particles. In a few samples, taken from buildings in Florida and Texas, skeletons of dust mites mixed with fungal mycelia of *Cladosporium* were observed in the microscopic preparations. In addition to fungal spores, pollen particles, cellulose fibers, synthetic fibers, plant hairs (trichome), decayed leaves, insect parts, and organic matter were often detected. Cellulose fibers and synthetic fibers probably come from indoor sources. Pollen particles, trichome, decayed leaves, and insect parts most likely originate outdoors (14). Many of these were organics and could be nutrients for fungal growth and colonization. The presence of pollen particles, trichome, decayed leaves, and insect parts strongly suggests that the filtration system used in the HVAC was insufficient to remove them from the incoming airstream.

DISCUSSION

The fungi identified from these samples are known to be able to grow at relatively low temperature (17, 18). The operating temperature of cooling coils in the U.S. is usually designed for 11-18°C (or 52-65°F). Newer designs are often operated at a higher temperature for energy conservation. Fungal colonization of FGL was frequently observed near cooling coils and within 3 meters downstream of the cooling coils (6). Temperatures, within these areas, were expected to be near or slightly higher than the operating temperature. High relative humidity, just downstream of the cooling coils, helped promote fungal growth. Fungi that are able to grow at relatively low temperature are expected to grow well near the cooling coils.

Water and moisture play an important role in fungal growth and colonization. Fungi, including many commonly found indoors, are known to grow at a wide range of water activity (15, 16, 17). *Exophiala* species, *Rhodotorula, Fusarium*, and yeasts are indicator fungi of a high water activity (Aw > 0.90 - 0.95) (17). In addition, *Acremonium* spp., *Aureobasidium pullulans*, *Paecilomyces marquandii*, and *Phoma* sp., were reported to be contaminants in water from humidifiers (19). This agrees with our assessment that FGL's in areas of the HVAC system, subjected to frequent wetting, support growth and colonization of fungi of high water activity. *Cladosporium* and *Penicillium* appeared to grow better in areas where there was high relative humidity but not wetting.

A substantial portion (48.4%) of the samples examined strongly indicated the occurrence of fungal colonization, particularly those that were soiled and used in high relative humidity and wet conditions. It is recommended that FGL should be used in such a way that dusts and dirt are not trapped in the porous material so that fungal colonization cannot occur. FGL should also not be used in areas of the HVAC system where frequent wetting may occur. Exterior insulation is one possible solution. Ductwork can be quiet and energy efficient without relying on interior fibrous glass liners. Some U.S. manufacturers of air handling equipment have sealed interior fibrous glass liners with smooth plastic or galvanized sheet metal. This is likely to protect the insulation material from becoming soiled and colonized by fungi. Flex-duct, which is insulated with fibrous glass, has a smooth interior plastic liner. Flex-duct has been used for many years without significant concerns of fungal contamination.

The evaluated FGL samples were taken for IAQ evaluations and from buildings with known IAQ complaints. Therefore, the percentage of fungal colonization in FGL's may be biased. It

is nevertheless important to note that the relationship between IAQ and fungal colonization of FGL's in the HVAC system can not be ignored or overlooked (7, 8).

FGL is a very useful material for acoustical and thermal insulation and has been widely used in the U.S. for interior insulation of the HVAC system. A number of organic fibers and dust particles were identified from deposits found on FGL. The presence of these fiber and dust deposits is indicative of a poor filtration system which allows for fungi to grow and thrive. Upgrading of filtration efficiency is likely to reduce accumulation of organic fibers and dusts, and hence reduce the possibility of heavy fungal colonization.

Although no live dust mites were observed, the finding of dust mite skeletons suggests the possibility that, with high relative humidity, dust mites may grow in fungal colonized FGL. Dust mites are known to feed on fungi. An HVAC system with fungal colonization may also become a reservoir for dust mites.

A new industry of air duct cleaners has been firmly established over the last few years in the U.S.A. Biocides (chlorine-releasing chemicals) and sealants containing antifungal chemicals (such as zinc oxide and borates, and antimony trioxide and decabromodiphenyl oxide) designed to combat fungal colonization in the HVAC system have been registered with the U.S. Environmental Protection Agency for use in treating and coating FGL. FGL coated with anti-fungal compounds has also been marketed in the U.S.A. It is, however, prudent for the manufacturers and users of FGL to re-engineer the material to be suitable for use in the HVAC system.

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