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Effectiveness of Vacuum Cleaning on Fungally Contaminated Duct Materials

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ABSTRACT

Ventilation system materials are of particular significance as potential microbial contamination sources because of their potential to rapidly spread contamination throughout a building. Portions of ventilation systems near cooling coils and drain pans are known to be exposed to high moisture levels for extended periods, and fibrous duct insulation materials are known to have become sources of microbial contamination in some buildings.

Cleaning has been suggested as a possible strategy for the prevention of microbial contamination, as well as for the remediation of already contaminated materials. However, the efficacy of cleaning has not been determined. Recommendations that materials appearing to be wet or moldy should be discarded are not always followed.

The objectives of this research program were to: determine, under constant temperature, relative humidity, and air flow test conditions, whether fungal spores levels on HVAC (heating, ventilating, and air-conditioning) duct material surfaces could be substantially reduced by thorough vacuum cleaning, and evaluate whether subsequent fungal growth would be limited or contained by a single mechanical cleaning treatment.

Three fiberglass duct materials were tested. All were artificially soiled. The results showed that notable amounts of surface dust were removed, and surface spore levels could be reduced in the short term on all materials by vacuuming. However, regrowth occurred within 6 - 12 weeks.

INTRODUCTION

Because of their location and consequent potential to rapidly spread contamination throughout a building, ventilation system materials are of particular significance as potential microbial contamination sources. Portions of ventilation systems near cooling coils and drain pans are known to be exposed to high moisture levels for extended periods, and fibrous duct insulation materials are known to have become sources of microbial contamination in some buildings[1]. The cause is invariably the presence of adequate moisture and nutrients in those materials for extended periods of time.

Microbial growth can be limited by controlling the amount of moisture and nutrients in or on building materials[2,3,4,5]. And in general, the availability of nutrients may be influenced by: good cleaning and maintenance practices, building pressurization and outdoor air filtration, and selecting materials that provide limited encouragement to microbial growth. Many of these practices are currently a routine part of good construction practices and good operation and maintenance (O&M). Unfortunately, either through failure to follow what are generally considered good practices or some other combination of

circumstances, building materials do at times become contaminated and serve as sources of microbial contamination in buildings. When this situation arises, it can severely impact the building's IAQ (indoor air quality). Exposure to microbial spores can cause severe allergic and/or toxic responses among the occupants.

To help address this issue in duct materials, both the National Air Duct Cleaners Association (NADCA) and the North American Insulation Manufacturers Association (NAIMA) have published guidelines: "Understanding Microbial Contamination in HVAC Systems"[6]; and "Cleaning Fibrous Glass Insulated Air Duct Systems"[7]. In them the authors address a number of important issues associated with the cleaning of fibrous duct liner, including a discussion of when and if insulated ducts should be cleaned. The NAIMA document states that fibrous glass insulation that appears to be wet or moldy should be discarded. Unfortunately, that advice is not always followed. Instead, cleaning is being used in the field as a method for the prevention of microbial growth, as well as for the remediation of fibrous glass duct liner that is already contaminated with microbial growth. However, the efficacy of cleaning as either a prevention or remediation strategy for microbial contamination has not been determined.

As summarized in NAIMA's recommended practice, three types of cleaning techniques are most commonly used for air duct cleaning: contact vacuuming, air washing, and power brushing. Of the three cleaning methods, contact vacuuming has the most potential for cleaning fungally contaminated fibrous liner, because fungal growth is not confined to the surface of the fiberglass materials. Air washing and power brushing are largely surface techniques. Contact vacuuming is hand-operated to ensure direct contact between the brush on the vacuum nozzle and the interior surfaces of the ducts to dislodge and remove dirt and debris. Operating parameters such as contact time, number of passes, and vacuum level can also be controlled in the laboratory. Therefore, contact vacuum was selected as the cleaning method to be evaluated during this research to provide the most rigorous test of duct cleaning's potential effectiveness.

The objectives of this research program were to: determine, under dynamic test conditions, whether fungal spores levels on HVAC duct material surfaces could be substantially reduced by thorough vacuum cleaning; and evaluate whether subsequent fungal growth was limited or contained by that cleaning. The constant high relative humidity (RH) environmental condition to which the test materials were exposed during this study was chosen because it can be achieved downstream of a continuously operating air-conditioning coil, albeit at a lower temperature. (We have previously shown that lower temperatures slow but do not stop growth[3].) There was no liquid water carryover in the high RH air, however, as might occur in an operating HVAC system. Operated this way, the miniducts were intended to provide a serious but realistic challenge for duct materials.

METHODS AND MATERIALS

Duct Materials Tested

Three new duct materials were tested: two brands of fiberglass duct liner and one brand of fiberglass ductboard. The materials were purchased from local commercial vendors. The compositions of the new fiberglass materials compiled from the Material Safety Data Sheets are summarized in Table 1.

FDL-B contained a permanent (bound) antimicrobial in the coating of the airstream surface. Both FDL-A and FDL-B were nominally 2.5 cm thick, and were classed as 24.0 kg/m^3 (1.5 lb/ft^3) in density. In appearance, these duct liners were very similar, with an uncoated surface intended to be attached to a rigid duct material and a polymer coated surface intended to be in contact with the moving air in the duct. The fiberglass ductboard material was classed as a 72.0 kg/m^3 (4.5 lb/ft^3) material, with a reinforced foil outer coating and a dense but uncoated duct interior surface.

Table 1. Composition of Fiberglass Duct Material Tested

Material	Composition
Fiberglass duct liners A (FDL-A)	> 44 - 98% fiberglass, 1-18% urea polymer of phenol and formaldehyde or urea-extended phenol-melamine- formaldehyde resin, < 0.1% formaldehyde
Fiberglass duct liner B (FDL-B)	82 - 98% fiberglass, 2 - 18% urea-extended phenol-formaldehyde resin (cured) or urea-extended phenol-melamine-formaldehyde resin (cured), < 1% non-woven, Foil-Skrim-Kraft or vinyl facings or vinyl or latex coatings
Fiberglass ductboard (FGD)	85 - 96% fiberglass wool, 4 - 15% cured binder, < 1% formaldehyde

Artificially Soiling of Duct Materials

All the materials included in the test were artificially soiled. This was accomplished in an aerosol deposition chamber. Sieved (250μm) duct dust obtained from a local duct cleaner was used to soil the samples. Duct material samples were placed around the periphery of the deposition chamber floor, duct dust was injected using an air injector, mixed in the chamber, and allowed to settle on the test material samples.

Prior to the study, the uniformity of duct deposition in the chamber was evaluated by comparing the mass deposited on small test samples placed at different locations on the chamber floor. Acceptable deposition uniformity was achieved except at the center of the deposition chamber, which was not used for the studies.

Table 2 presents the precleaning dust loadings for the artificially soiled test materials. The top row lists the targeted amount of dust for deposition in milligrams per 100 cm^2. The amount used was considered moderately soiled (approximately 100 mg dust / 100 cm^2). This level was selected with reference to the 1.0 mg dust / 100 cm^2 definition of cleanliness given in NADCA Standard 92-01[8]. NADCA 92-01 states that a surface may be verified as clean only if the surface is visibly clean and if the weight of the debris collected by the NADCA vacuum test does not exceed 1.0 mg dust / 100 cm^2. This standard is intended only for non-porous surfaces, but its definition of the amount of soil that may remain in a "cleaned" duct provides the only quantitative benchmark available. (In this study the NADCA vacuum test was not used to determine dust loading.) Therefore, moderately soiled, as targeted in this research, was about 100-fold higher than the standard.

The bottom row shows the actual amount of HVAC dust deposited on the surface of the artificially soiled materials. Glass microscope slides were used as coupons during the artificial soiling process. The slides were weighed, placed in the chamber, artificially soiled simultaneously with the test materials, and weighed. The actual dust loading correlated well with the targeted amounts.

Table 2. Amounts of HVAC Dust Deposited on the Test Materials in mg dust / 100 cm^2

	MS-FDL-A	MS-FDL-B	MS-FGD
Target amount	100	100	100
Actual amount, mean ± SD	95 ± 10	95 ± 10	115 ± 10

Note: MS- Moderately Soiled
SD- Standard Deviation

All of the artificially soiled material pieces were autoclaved after soiling (but before inoculation with *P. chrysogenum)* on a short cycle for better adhesion of the HVAC dust. Because the short autoclave cycle was not sufficient for sterilization, the artificially soiled materials were considered naturally inoculated as well as inoculated with the test organism.

Selection of Test Organisms and Inoculation

Penicillium chrysogenum was selected as the inoculated test organism for these studies. It has been reported as one of the most frequently isolated molds from the air, dust, and surfaces of indoor environments[9]. It has been proposed as a causative agent of allergic alveolitis[10]. In addition, this organism has also been isolated from a number of air-conditioning systems in environments where patients were suffering from allergic disease. Skin challenge testing against *P. chrysogenum* isolated from these systems yielded more positives than any of the other organisms isolated[11].

The particular *P. chrysogenum* strain selected for these studies was isolated from a contaminated building material by RTI and cultivated for use in the laboratory. The culture is being maintained in the University of Texas Medical Branch Fungus Culture Collection as UTMB3491.

The *P. chrysogenum* was prepared for inoculation onto the test materials as previously described[3,4]. The suspension was nebulized into the aerosol deposition chamber utilizing a six-jet BGI-Collison nebulizer at 138 kPa (20 psi) for 2 hours and allowed to settle on the duct material pieces.

Surface Sample Collection

To quantify the growth as a function of exposure time, each material was periodically sampled. A closed-faced filter cassette sampler with a pipette nozzle was used to sample the airstream surface of the duct material. The sample was obtained from a 10 cm^2 surface area as determined by a template. Dust mass was determined for each sample gravimetrically. Each of the filters was weighed before sampling and again after sampling and the weight change computed. After the second weighing, the membrane filters were analyzed using routine plating/counting techniques to determine the colony forming units (CFUs) per 10 cm^2.

Experimental Apparatus and Procedure for Dynamic Growth Experiments

The growth experiments were conducted in the Dynamic Microbial Test Chamber (DMTC)[12]. The DMTC is a room-sized test facility designed and constructed to conduct studies on the conditions and factors that influence biocontaminant emissions and dissemination. The chamber, a cube with inside dimensions of 2.44 m, was constructed with stainless steel walls and floor and an acrylic drop-in ceiling. Temperature (18 - 32°C) and relative humidity control (55 - 95% RH) are provided through an air handler, conventional ductwork, and ceiling diffusers with an air circulation rate between 1.4 and 4.8 m^3/min.

Of the conditions that must be reproduced in a duct-like test, temperature, humidity, dust (nutrient) loading, and air velocity over the duct material, temperature has been shown to be of secondary importance. Lowering the temperature slowed the beginning of a fungal growth response but did not change the eventual amount of measured growth[3]. The bulk of the previous tests were conducted at ambient temperature, as were the dynamic tests. Humidity and dust loading are both known to be important, while air flow rate has not been investigated.

To provide these conditions in the DMTC, the chamber was adapted to contain eight miniducts. An artist's rendition of the DMTC containing the miniduct apparatus is shown in Figure 1. The blower forces the conditioned DMTC air into a High Efficiency Particulate Air (HEPA) filter, from which the air for the eight miniducts is obtained. The miniduct channel design was chosen to limit the total amount of air required for a single test, allowing multiple tests to be run simultaneously.

Figure 2 shows an expanded view of the miniduct apparatus. The upper part of the figure shows the blower, the duct leading to the HEPA filter unit, and an individual duct delivering conditioned air to a miniduct. The bottom part of the figure shows an expanded view of one of the miniducts.

Recommended air velocities in ventilation system ducts are in the range of 2.5 - 4.6 m/s (500 - 900 ft/min)[13]. A velocity of 2.5 m/s (500 ft/min) was chosen for the present study as a reasonable velocity that could be provided to the eight miniducts by a small fan. Higher velocities might also lead to unrealistically high surface velocities and turbulence in the narrow channels. Achieving 2.5 m/s in a miniduct, whose flow channel is 2.5 cm high and 40 cm wide, required a volumetric flow rate of 0.025 m^3/s (53 ft^3/min). The dampers shown in Figure 2 were used to obtain the desired flow rate to each miniduct. To reduce flow development and edge effects within the area of the duct material samples, the material samples were placed in a recess in the middle of the miniduct flow area with the upper surface of the material 2.5 cm below the channel top. A 10 cm flow development buffer space was provided upstream, and 5 cm buffers were provided on the sides and downstream.

Miniduct flow rates were routinely measured downstream of the samples at the channel center point. Flow distribution at the upstream end of the channel was enhanced with screens to achieve a horizontally uniform velocity profile. The inoculated duct material samples were placed in the miniducts with the upper surface flush with the bottom of the flow channel, allowing the filtered and conditioned air to flow across the material just as it would when in a duct.

After artificial soiling and inoculation, the 30.5 x 91.4 cm (1 x 3 ft) pieces of test material were placed in the miniducts. For all experiments the temperature and relative humidity throughout the miniducts were at 23.5°C and 94% RH. The air velocity through the miniducts was 2.5 m/s (500 ft/min).

Duplicate surface samples were collected on each of the test days. For the FDL-A and FDL-B experiments, duplicate surface samples were collected the first, second, third, fourth, sixth, and eighth weeks prior to cleaning. The materials were then contact vacuumed and postcleaning surface samples were collected the first through fourth and sixth weeks. In the FGD experiment that schedule was amended slightly. Duplicate surface samples were collected the first through fourth weeks prior to cleaning. The materials were then contact vacuumed and postcleaning surface samples were collected the first through sixth weeks, and again the twelfth and thirteenth weeks.

Duct Material Cleaning

Once mature growth was reached and quantitatively evaluated, the duct material was cleaned in place using a Minuteman Model C82906-03 HEPA vacuum cleaner operating at 2.7 m^3/min (95 ft^3/min). Prior to cleaning, the bag was weighed. The combination floor tool was used. The tool measures 14 x 4 cm and one side houses a single-edge brush. A thorough cleaning procedure was developed and followed rigorously for all pieces. The cleaning pattern consisted of four passes over each surface crosswise and four passes lengthwise. The first pass was across the width of a piece from left to right. The second pass was back across the same width from right to left. This was repeated for passes three and four. The brush was then moved down the piece by a brush-width, and this pattern was repeated down the length of the whole piece of the test material. Once the entire piece had been cleaned crosswise, the procedure was repeated for the length of the material. During cleaning, the material was inspected and any light spots cleaned. Relative to field duct cleaning observed by the authors, this constitutes extremely thorough cleaning. Care was taken not to abrade the surface of the materials. The combination floor tool was decontaminated with 70% ethanol between vacuuming the different materials.

RESULTS

Precleaning

Table 3 presents the levels of growth attained on the three materials before the contact vacuuming protocol was performed. The data are expressed as the log increase between the initial levels measured on week 1 and the levels measured on weeks 4 and 8.

As discussed previously, although the materials were autoclaved before inoculation with *P. chrysogenum*, only short-exposure autoclaving was performed to promote HVAC dust adhesion to the artificially soiled samples. Killing spores by autoclaving (sterilization) requires longer exposure times and higher temperatures; therefore, a certain natural inoculation from the spores dormant on the surface was anticipated. The dominant organism that grew from this natural contamination was *A. versicolor*, whose growth on fiberglass materials is well documented[14]. No other organism resulted from the natural contamination in detectable levels. *A. versicolor* is of particular concern because it is a toxigenic fungus, and its growth was documented as part of the experiment. The data for the two test organisms, *P. chrysogenum* and *A. versicolor*, are reported separately.

Table 3. Log Difference in Levels of CFUs for *P. chrysogenum* and *A. versicolor* between Week 4 or Week 8 and Week 1

Material	**Week 4**		**Week 8**	
	P. chrysogenum	*A. versicolor*	*P. chrysogenum*	*A. versicolor*
MS-FDL-A	2.3 ± 0.1	1.2 ± 0.1	2.9 ± 0.2	1.9 ± 0.3
MS-FDL-B	2.4 ± 0.2	3.5 ± 0.2	2.8 ± 0.1	4.5 ± 0.2
MS-FGD	3.1 ± 0.2	2.8 ± 0.7	ND	ND

ND = Not Done

As can be seen from Table 3, after 4 weeks the two artificially soiled fiberglass duct liners (MS-FDL-A and MS-FDL-B) had sustained at least a 1 log increase for both organisms. The levels of *P. chrysogenum* were similar for both duct liners, but the levels of *A. versicolor* were considerably higher on the MS-FDL-B than the MS-FDL-A. Levels of both test organisms increased approximately 3 logs on the fiberglass duct (FGD).

As discussed previously, cleaning by contact vacuuming was performed on MS-FDL-A and MS-FDL-B on the eighth week of the study. The levels of both of the organisms continued to increase from the fourth to the eight week; although, with the exception of *A. versicolor* on FDL-B, the increases were small. Previous experiments using static chambers have demonstrated similar or slightly lower increases for similar time spans and conditions[3,15]. That is, the addition of air flow in the dynamic experiments may have yielded slightly higher levels of growth than were found in static experiments. Because growth between weeks 4 and 8 was small, the FGD experiment did not go beyond week 4 before cleaning.

Impact of Contact Vacuuming on Dust Mass

The total weight of the dust removed by contact vacuuming from each of the materials is shown in Table 4. The weights were obtained by determining the dust mass in the vacuum cleaner bag after cleaning.

Table 4. Dust Mass From Dust Removed by Contact Vacuuming in mg dust /100 cm^2

	MS-FDL-A	**MS-FDL-B**	**MS-FGD**
Amount removed by contact vacuuming	75	89	127

For the moderately soiled FDL-A and -B, the total mass removed was 75 and 89 mg dust / 100 cm^2, respectively. Based on the 100 mg / 100 cm^2 targeted amount, this was 75 and 89% of the amount

initially deposited. However, the moderately soiled FGD yielded 127 mg dust / 100 cm^2; that is, approximately 25% more was removed than was added initially.

Table 5 shows a comparison of the amount of dust measured on the test materials both before and after contact vacuuming. These values are the means and standard deviations of the replicate dust mass measurements collected by surface sampling. Of particular interest is that the difference between the precleaning and postcleaning numbers is not equal to the total mass removed by contact vacuuming as shown in Table 4. Visual examination of the surface samples showed that a notable proportion of the sample content was fibers removed from the surface during the surface sample collection process. Examination of the contact vacuuming dust in the vacuum cleaner bag also showed similar fiber content. The results demonstrate that: 1) evaluating total dust on a duct surface is a difficult measurement, and 2) there appears to be continued fiber loss from the surface of the fiberglass materials with repeated vacuuming.

Table 5. Dust Levels Determined by Surface Sampling in mg dust / 100 cm^2

	MS-FDL-A (n=8)	MS-FDL-B (n=8)	MS-FGD (n=4)
Before contact vacuuming	73 ± 31	100 ± 28	196 ± 17
After contact vacuuming	42 ± 16	62 ± 35	133 ± 34

Impact of Contact Vacuuming on Microbial Load

Tables 6 and 7 show the results of cleaning by contact vacuuming as the percent reduction on the fungal load for the three different test materials. The tables show the comparison of the precleaning and immediate postcleaning levels for both of the test organisms. Table 6 presents the results for *P. chrysogenum*, which was inoculated onto the surface of the materials at the beginning of the experiments; and Table 7 shows the results for *A. versicolor*, the natural inoculum.

As can be seen in the tables, there were large decreases in both *P. chrysogenum* and *A. versicolor* levels immediately postcleaning. This was probably due to a high percentage of the fungal growth being in or on the dust that was removed by contact vacuuming. MS-FDL-A, MS-FDL-B, and MS-FGD all decreased by at least 95%, except less of a decrease was seen for the *P. chrysogenum* on MS-FGD.

Table 6. Percent Reduction of *P. chrysogenum* on the Surface of the Test Material Immediately after Contact Vacuuming

	MS-FDL-A	MS-FDL-B	MS-FGD
Before contact vacuuming,CFU/cm^2	46,000	61,000	410,000
After contact vacuuming,CFU/cm^2	680	200	48,000
% Reduction	98.5	99.7	88.3

Table 7. Percent Reduction of *A. versicolor* on the Surface of the Test Material Immediately after Contact Vacuuming

	MS-FDL-A	MS-FDL-B	MS-FGD
Before contact vacuuming,CFU/cm^2	25,000	1,800,000	58,000
After contact vacuuming,CFU/cm^2	< 25	1,300	<2,500
% Reduction	99.9	99.9	95.7

Impact of Cleaning on Fungal Growth

Figures 3 and 4 show the levels of *P. chrysogenum* and *A. versicolor*, respectively, immediately postcleaning, 6 weeks postcleaning, and 12 weeks postcleaning. All have been normalized to the initial precleaning (first week) levels for that particular test material. The black bars represent the immediately postcleaning levels. The gray bars show levels at the 6 weeks postcleaning, and the white the 12 week levels. The figures show that on all materials regrowth occurred for both organisms.

The levels of organisms isolated from the immediately postcleaning samples varied greatly between materials and organisms. *P. chrysogenum* was isolated from all the samples, but on FDL-A *A. versi-color* levels were below the detection limit. As seen in Figure 3, by the 6 weeks postcleaning measurement, the level of *P. chrysogenum* had rebounded from the immediate postcleaning levels for all samples. FDL-A and FDL-B showed increases of at least 2 logs. FGD showed a smaller increase probably because the levels on that material had not been reduced as much by cleaning. The 12 weeks postcleaning levels showed continued increases in CFUs on most materials. As discussed earlier, the experiments with FDL-A and -B were discontinued at 6 weeks so no data are available at the twelfth week.

Figure 4 shows the comparison of the immediate and 6 and 12 weeks (where available) postcleaning levels of *A. versicolor* normalized to the initial preclean (first week) levels for each of the test materials. As discussed earlier, *A. versicolor* was not inoculated onto the test materials but was considered a natural inoculum. Generally, the overall results were similar to those seen and discussed above for *P. chrysogenum*.

DISCUSSION AND CONCLUSIONS

Surface cleaning by contact vacuuming was able to remove notable amounts of dust from the surface of the artificially soiled duct materials. Large amounts of fibers were removed from the fiberglass materials. Fiber shedding was evident with the new as well as the used duct liners. Although the amount of shedding was not quantified in this study, visual inspection suggested that a fair percentage of a surface sample was composed of fibers or fragments of fibers.

Cleaning artificially soiled materials caused noticeable reductions for both of the organisms in the immediate postcleaning period. The surface dirt was readily removed from the artificially soiled materials along with the organisms colonizing the dirt.

In the longer term, the levels of both *A. versicolor* and *P. chrysogenum* recovered to precleaning levels within 6 weeks and, where studied, growth continued for both organisms over the entire 3 months. Therefore, mechanical cleaning by contact vacuuming, at best, was able to only temporarily reduce the surface fungal load. The current guideline to discard contaminated or potentially contaminated materials should be followed. This may have been because cleaning is a surface treatment, and the organisms were growing both on the surface dirt and deep in the material.

These data showed that, at least for the conditions used in this study, a bound antimicrobial had no effect on fungal growth on soiled and cleaned contaminated fiberglass duct liner. There was no difference between regrowth on the fiberglass duct liner with or without the bound antimicrobial. This finding supports the results of our previous static chamber studies[3]. Additional work is needed to determine the benefit of using a biocide or antimicrobial as part of the duct cleaning process for prevention and remediation of fungal growth on the various duct materials.

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REFERENCES

1. Morey, P. R. and C. M. Williams. 1991. Is Porous Insulation Inside an HVAC System Compatible with a Healthy Building? *Healthy Buildings: Proceedings of IAQ '91*. ASHRAE, Atlanta, GA, pp. 128-135.
2. Chang, J.C.S., K.K. Foarde, and D.W. VanOsdell. 1996. Assessment of Fungal *(Penicillium chrysogenum)* Growth on Three HVAC Duct Materials. *Envir. Inter.*, 22 (4):425-431.
3. Chang, J.C.S., K.K. Foarde, and D.W. VanOsdell. 1995. Growth Evaluation of Fungi (*Penicillium* and *Aspergillus spp.*) On Ceiling Tiles. *Atmospheric Environment*. 29:2331-2337.
4. Foarde, K.K., D.W.VanOsdell, and J.C.S. Chang. 1996. Evaluation of Fungal Growth on Fiberglass Duct Materials for Various Moisture, Soil, Use, and Temperature Conditions. *Indoor Air*. 6:83-92.
5. Foarde, K., D. VanOsdell, and J. Chang. 1996. Static Chamber Method for Evaluating the Ability of Indoor Materials to Support Microbial Growth. ASTM STP 1286 *Methods for Characterizing Indoor Sources and Sinks*. pp. 87-97.
6. NADCA. 1996. *Understanding Microbial Contamination in HVAC Systems*. National Air Duct Cleaners Association, Washington, DC.
7. NAIMA. 1993. *Cleaning Fibrous Glass Insulated Air Duct Systems, Recommended Practice*. North American Insulation Manufacturers Association, Alexandria, VA.
8. NADCA 1992-01. 1992. *Mechanical Cleaning of Non-porous Air Conveyance System Components*. National Air Duct Cleaners Association, Washington, DC, p. 11.
9. Hunter, C.A. and R.G. Lea. 1995. The airborne fungal population of representative British homes. *Health Implications of Fungi in Indoor Environments*, R.A. Samson et al., eds. Air Quality Monographs, 2:141-153.
10. Fergusson, R.J., L.R.J. Milne, and G.K. Crompton. 1984. *Penicillium* allergic alveolitis: faulty installation of central heating. *Thorax*. 39:294-298.
11. Schata, M., W. Jorde, J.H. Elixman, and H.F. Linskens. 1989. Allergies to molds caused by fungal spores in air conditioning equipment. *Environment International*, 15:177-179.
12. VanOsdell, D., K. Foarde, and J. Chang. 1996. Design and Operation of a Dynamic Test Chamber for Measurement of Biocontaminant Pollutant Emission and Control. ASTM STP 1286 *Methods for Characterizing Indoor Sources and Sinks*. pp. 44-57.
13. ASHRAE. 1992. *Air Distribution Design for Small Heating and Cooling Systems*. HVAC Systems and Equipment, ASHRAE, Atlanta, GA, pp. 9.4 - 9.5.
14. Ezeonu, I.M., J.A. Noble, R.B. Simmons, D.L. Price, S.A. Crow, and D.G. Ahearn. 1994. Effect of relative humidity on fungal colonization of fiberglass insulation, *Applied and Environmental Microbiology*. 60(6):2149-2151.
15. Foarde, K. K., D. W. VanOsdell, and J. C. S. Chang. 1995. *Susceptibility of Fiberglass Duct Liner to Fungal (Penicillium chrysogenum) Growth*. Proceedings of Engineering Solutions to Indoor Air Quality Problems, EPA and Air and Waste Management Association, Research Triangle Park, NC, July.

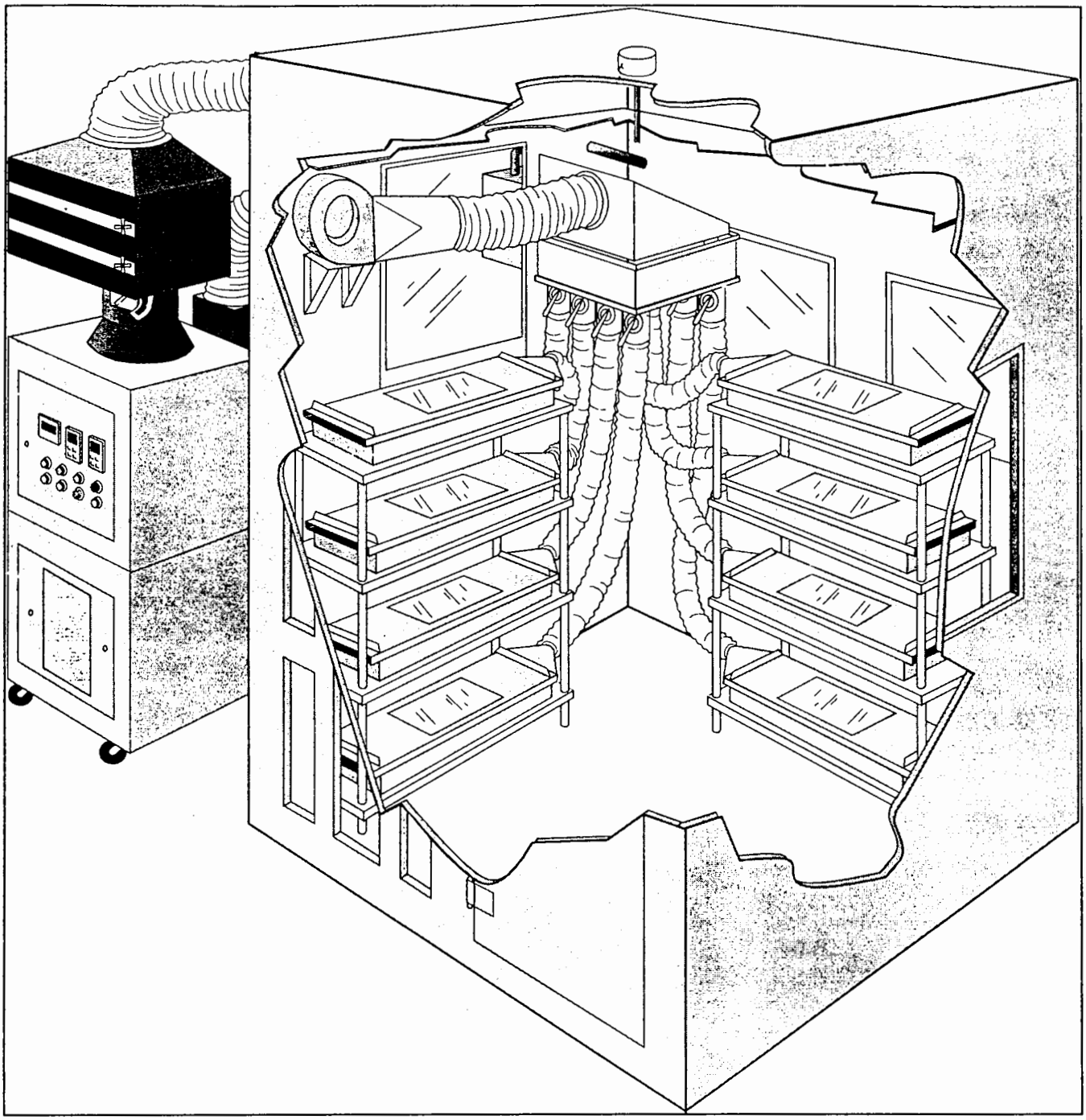

Figure 1. Drawing of Dynamic Chamber with "Miniduct" Apparatus.

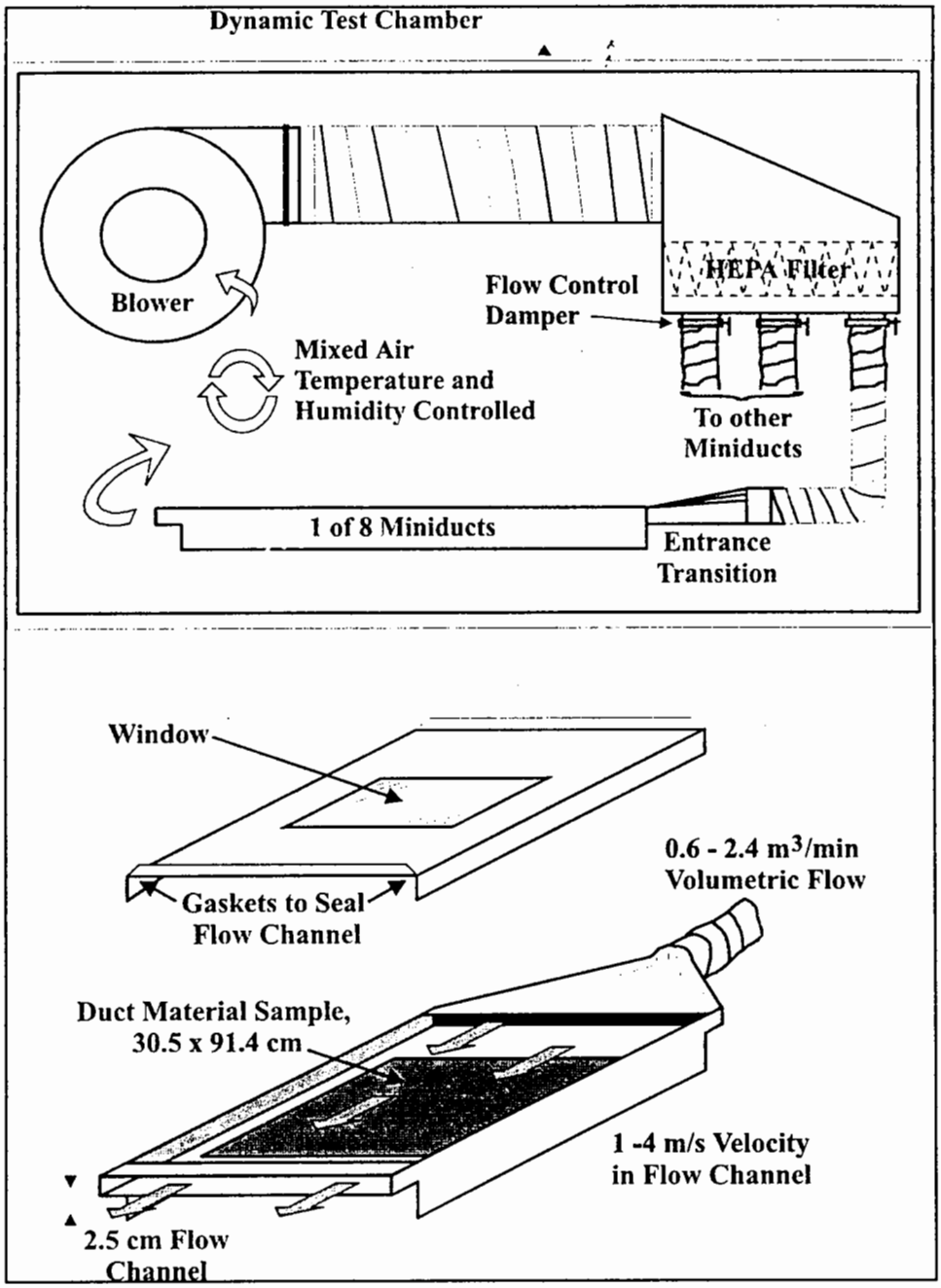

Figure 2. Diagram of Miniduct Apparatus.

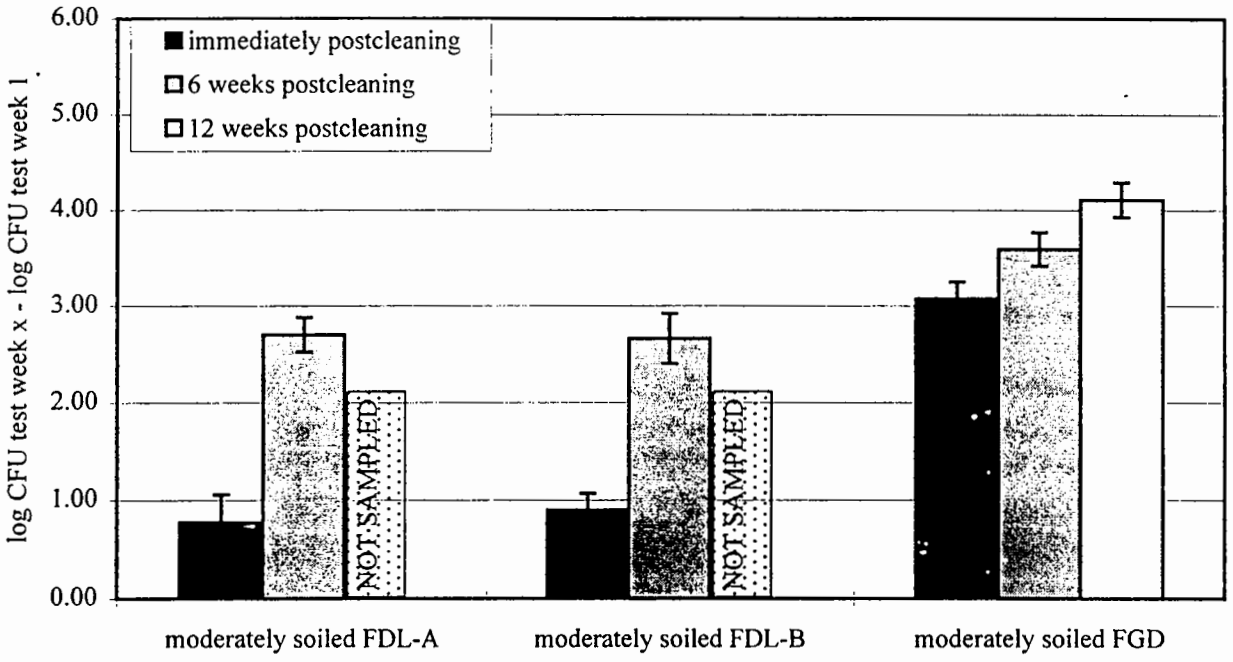

Figure 3. Immediately postcleaning, 6 weeks postcleaning, and 12 weeks postcleaning levels of *P. chrysogenum*.

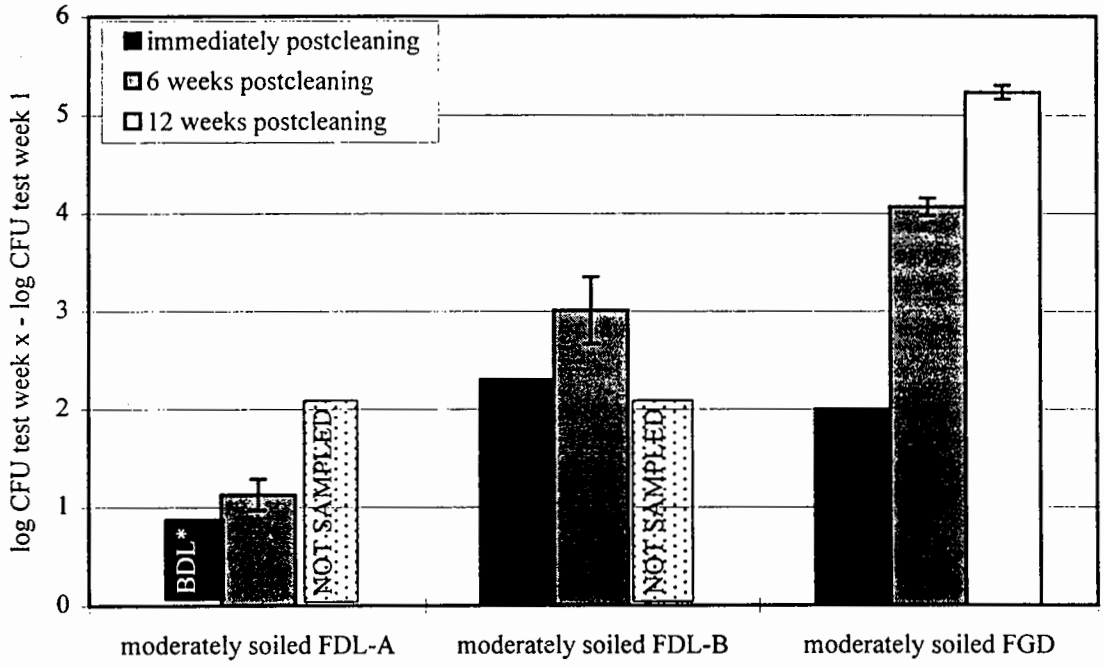

Figure 4. Immediately postcleaning, 6 weeks postcleaning, and 12 weeks postcleaning levels of *A. versicolor*.

* Below Detection Limit

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TECHNICAL REPORT DATA
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16. ABSTRACT The paper gives results of research to: determine, under constant temperature, relative humidity, and air flow test conditions, whether fungal spore levels on heating, ventilating, and air-conditioning (HVAC) duct material surfaces could be reduced substantially by thorough vacuum cleaning; and evaluate whether subsequent fungal growth would be limited or contained by a single mechanical cleaning treatment. Three fiberglass duct materials were tested. All were soiled artificially. The results showed that notable amounts of surface dust were removed, and surface spore levels could be reduced in the short term on all materials by vacuuming. However, regrowth occurred within 6-12 weeks. Ventilation system materials are of particular significance as potential microbial contamination sources because of their potential to rapidly spread contamination throughout a building. Portions of ventilation systems near cooling coils and drain pans are known to be exposed to high moisture levels for extended periods, and fibrous duct insulation materials are known to have become sources of microbial contamination in some buildings. Cleaning has been suggested as a possible strategy for preventing microbial contamination, as well as for remediating already contaminated materials. However, the efficacy of cleaning has not been determined.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution	Ducts	Pollution Control	13B 13K
Vacuum Cleaners	Heating Equipment	Stationary Sources	13G 13A
Cleaning	Ventilation		13H
Fungi	Air Conditioning		06C
Spores	Dust		11G
Fiberglass Reinforced Plastics			11D, 11F

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