CASE STUDY INDUSTRIAL HYGIENE

Successful Mold Growth Remediation in HVAC Systems

by Paul Buckmaster

The summer of 2003 was one of the wettest in Maryland history. Later that fall, an indoor environmental quality (IEQ) investigation in a leased facility revealed mold growth in the air handing units (AHUs) and main supply duct of all 12 of the building's HVAC systems. During the next two months, we worked with occupants, our leasing agent, the building owner, and his contractor to successfully remediate the mold growth. We decided to assess mechanical hygiene in 15 other buildings.

This article focuses on one building and describes the strategies and lessons learned by a team of facility, engineering, and industrial hygiene staff during the remediation project completed in May 2004.

HVAC System Description

The building is a four-story concrete slab and column structure built in the mid-1950s with a total area of 1.5 million square feet. Each floor is served by eight HVAC systems. Renovation has been ongoing since 1997, and 17 of the 32 systems have been replaced. The original design consisted of constant-volume AHUs with electric steam generators to provide space humidification. These were abandoned in the 1980s because of maintenance problems. Fiberglass insulation (FGI) was used extensively inside AHU cabinets and on air stream surfaces in both supply and return ductwork.

During the renovation, existing systems are replaced with variable air volume AHUs. Duct static pressure is monitored and controls a variable frequency drive on the supply fan. Humidification is provided by a steam-to-steam heat exchanger located between the cooling coil and fan inlet. Controls include a humidistat located in the return air duct and a high limit sensor in the supply discharge. New systems were designed with several features to improve mechanical hygiene. Condensate pans were constructed of stainless steel and sloped to improve drainage. Particulate filters with a Minimum Efficiency Reporting Value (MERV) of 12 were installed to keep coils and ductwork cleaner and improve energy efficiency. AHU cabinets have double-wall construction to eliminate exposed FGI; however, engineers required FGI to be installed in the initial 30 feet of supply and return ductwork and downstream of fan-powered VAV boxes to reduce noise.

Methodology

Mold spores are ubiquitous, and one should expect to find them in the indoor air and on surfaces inside the building envelope. In well-maintained buildings with effective particulate filtration, we typically find that:

- indoor levels are less than 5 percent of outdoor levels,
- rank order of outdoor and indoor taxa are similar, and
- concentrations of indicator species are absent or very low.

Air sampling has resulted in false negatives in several building investigations when there was extensive mold growth in the HVAC system. Because of this, we did not use air sampling as part of the methodology. We adopted a standard of care that stipulated mold growth was not acceptable and used visual inspection and surface sampling to determine conformance.

Historically, we used vacuum pumps and MCEFs to collect surface samples and used a contract laboratory to culture samples to determine total fungal counts and taxa. This worked well during the investigation, but the cycle time was too long for post-remediation verification. After the first project, we began to look for other methods to characterize mold growth. We learned about the Mycometer®-Test from the conference proceedings[1] and contacted the distributor for a demonstration. After reviewing the literature and talking to other users, we purchased the instrument.

The Mycometer®-Test is a patented method that allows the quantification of surface mold in less than one hour at a cost of about $25 per sample. The test uses the enzyme activity found in the spores and mycelium of all mold. Activity is measured using an enzyme substrate that releases a fluorescent compound when excited by UV light. Fluorescence is measured by a portable fluorometer that displays a unitless mycometer value (MV), which is proportionate to the amount of biomass on the surface. Later research[2] showed a correlation between this enzyme and ergosterol, the gold standard for characterizing fungal biomass on surfaces.

Establishing categories that defined fungal biomass on a surface was an important part of method development. To do this, 102 samples were collected from clean surfaces in well-maintained buildings. These were found to have an $MV \leq 25$. This was defined as Category A and represents normal fungal ecology. Next, 127 samples were collected from visibly dusty surfaces with moderate to heavy spore deposition. About 96 percent of these samples had an $MV < 450$. Category B was defined as an $MV > 25$ but < 450. Samples collected from surfaces with active mold growth had $MVs > 450$ and were defined as Category C. Categories and interpretive guidelines are found in Table 1.

Sample Results

Industrial hygienists and facility technicians visually inspected all 32 HVAC systems. IHs collected swab samples from cooling coils, condensate pans, and supply ductwork. There was no visible growth in any location, and samples from coils and pans were found to be Category A. However, samples from ductwork revealed problems. Results and descriptive statistics for these are presented in Table 2.

In existing systems, MVs ranged from 9 to 138 with a mean of 32. Fifty-nine percent of the samples were Category A, and 41 percent were Category B. In contrast, MVs from new systems (less than six years old) ranged from 3 to 12,000 with a mean of 1,228. Sixty percent of the systems were Category A, 13 percent were Category B, and 27 percent were Category C. Active growth was found in ductwork in four systems, where MVs ranged from 491 to 12,000 with a mean of 4,467. In each, growth was found on FGI within 20 feet of the fan discharge.

TABLE 1. MYCOMETER-TEST CATEGORIES

Category	Mycometer Value	Description
A	≤ 25	The level of mold is not above normal background levels.
B	25 < MV ≤ 450	The level of mold is above normal background levels. This may be due to high concentrations of spores in dust deposits or may in some cases indicate the presence of old mold growth.
C	> 450	The level of mold is high above normal background level due to active mold growth.

TABLE 2. MYCOMETER RESULTS FOR SUPPLY DUCTWORK

System Type	Range (Mean)	SD	GM	GSD	Cat A	Cat B	Cat C
Old (17)	9-130 (32)	30	24	2.032	10 (59%)	7 (41%)	0
New (15)	3-12,000 (1228)	3120	61	14.66	9 (60%)	2 (13%)	4 (27%)

Risk Communication

Risk communication is a critical part of any mold remediation project. We crafted a good strategy for the first project and carried that forward in this project. Initial notification began with an e-mail to affected supervisors stating we'd found mold growth in the HVAC system serving their space and would:

- clean that system and return it to a normal fungal ecology,
- clean the office space to remove mold spores and other particulate,
- provide an occupational medicine consultation to any occupant with symptoms from mold exposure, and
- present a series of town meetings to inform occupants about mold, its health effects, and our plans to clean the systems and affected rooms.

After 24 hours, a similar notification was e-mailed to affected employees. Town meetings began within a week, with 14 held over the next five days. We also developed a Web site with streaming video about mold and its health effects, PowerPoint presentations from the town meetings, copies of supervisor and occupant notices, and the proposed cleaning schedule for the HVAC systems and associated rooms. The strategy helped to control outrage and rumors so well that more facility and health professionals than occupants attended the last two town meetings.

Scope of Work

Facilities and contacting specialists teamed with the industrial hygienist to develop a scope of work (SOW) for the project. The National Air Duct Cleaners Association (NADCA) published two documents dealing with the cleaning and restoration of HVAC systems[3,4] that were used as the basis for an SOW that would cover multiple projects in multiple buildings over a three-year period. We were concerned about the knowledge and skills of firms bidding on the contract proposal, so in addition to the usual requirements for bonding, insurance, and previous work experience, we required a "competent person" on the job site at all times work was being performed. This person needed at least one of the following credentials from NADCA or the American Indoor Air Quality Council (AmIAQC):

- Certified Air Systems Cleaning Specialist (NADCA)
- Certified Ventilation System Mold Remediator (NADCA)
- Certified Microbial Remediation Supervisor (AmIAQC)
- Certified Microbial Remediator (AmIAQC)

Five companies responded to a Request for Proposal, and the three judged to be most qualified were selected to work on our campus. Bidders' past safety performance was considered in the selection.

Pre-Operational Meeting

Prior to start-up, we met the contractor to discuss its safety plan and the project scope, which included:

1. Remediating mold growth on FGI in the initial 20 feet of supply duct in four HVAC systems.
2. Cleaning the coils, condensate pan, and interior surfaces of four AHU cabinets.
3. Cleaning 200,000 square feet of office space, including HEPA-vacuuming carpet and chairs and damp wiping nonporous surfaces.

We discussed security issues, cleaning methods, containment strategies, differential pressure requirements, post-remediation verification, the role of the competent person, and how the government would monitor contractor performance. Work was scheduled after hours and weekends during April and May 2004.

Remediation Project

Facilities Services managed the project, and a Certified Industrial Hygienist served as the safety and health consultant. Containment was designed to isolate the AHU and affected supply duct from the rest of the HVAC system and occupied space. To do this, the contractor installed a HEPA-filtered negative air machine at one of the AHU's access doors. The return air damper was closed and the outdoor air damper was opened to provide make-up air. A 24-inch by 24-inch access panel was installed in the supply duct downstream of the mold growth, and foam pillows were used to zone off. A floor-to-ceiling plastic enclosure was erected and used to enter the supply duct for cleaning. A second access door was used to enter and clean the AHU and components.

The negative air machine was operated to maintain a differential pressure of at least -0.02 inches water gauge. The contractor continuously monitored this requirement. The industrial hygienist inspected the containment each day and issued a notice to proceed. A particle counter was used to determine the effectiveness of the HEPA-filtered negative air unit and to monitor background levels of particulate.

There was some concern that fiberglass insulation could not be adequately cleaned. One study[5] showed it was possible to remove approximately 90 percent of the mold using mechanical methods. Another[6] showed cleaned liners sealed with an EPA registered antifungal protective coating (AFPC) remained free of mold growth after 10 years. Using this data, we developed the following decision logic:

- Eroded FGI would be removed, and the metal duct would be cleaned and treated with an AFPC to lock down residual FGI.
- FGI with an MV > 1000 would be removed, and the metal duct would be cleaned and treated with an AFPC to lock down residual FGI.
- FGI with an MV $\leq$ 1000 would be cleaned and coated with an AFPC.
- Metal duct would be cleaned only.

HEPA-filtered vacuums were used to remove particulate from surfaces inside the AHU and supply ductwork. Heat exchange coils and condensate pans were cleaned using detergent and high-pressure water because there was no exposed FGI. After cleaning, the industrial hygienist completed a visual inspection and collected samples to determine the residual fungal biomass. Surfaces with an MV $\leq$ 25 met the post-remediation verification criteria and were judged to be clean.

Causal Factor Analysis

No remediation is successful until the moisture source is identified and corrected. Despite manufacturers' claims, many studies have shown that FGI supports mold growth.[7] The material is hygroscopic and retains water. Over time, enough mold spores and nutrients are deposited on the surface that growth will occur when adequate moisture is present.

The problem is that moisture exists in any HVAC system. During the cooling season, chilled water coils produce condensation and high-humidity air, and face velocities greater than 400 feet per minute can cause water stripping. The new AHUs had an additional moisture source. Steam humidification was condensing at the fan inlet and wetting the FGI surface.

The engineer's investigation revealed several other moisture problems. AHUs were installed directly on the floor slab, and there was not enough clearance to install a trap with the proper stem height. As a result, condensate pans did not drain properly and were filled with 30 to 40 gallons of water during the cooling season. This water aerosolized and deposited downstream of the fan onto the ductwork.

Installation of AHUs also was problematic. Cabinets were designed in three sections that were supposed to be assembled using a come-along. This was never done, and sections leaked excessively. Mechanical rooms were not air-conditioned, so warm, humid air leaked into the cabinet and condensed on metal surfaces.

Corrective Actions

The project team initiated the following actions to address causal factors and improve mechanical hygiene:

1. Design standards were modified to prohibit FGI from air stream surfaces in the first 20 feet of supply and return ductwork. Insulation is permitted downstream of fan-powered VAV boxes because Mycometer sampling has shown these surfaces remained free of mold growth after four years in service.

2. Humidifiers were taken out of service immediately. Our health care providers developed a fact sheet that discussed steps to take during the winter months to deal with low humidity at work and home.

3. Condensate traps were redesigned. Contractors penetrated the floor slab to allow additional clearance to increase stem height. Later AHUs were installed on a 14-inch-high housekeeping pad to provide adequate clearance.

4. AHU construction was tightened up. Contractors installed additional gasket material between sections and torqued corner bolts to manufacturers' specifications. Supply terminals were installed in the main duct to introduce conditioned air into the mechanical room.

5. Construction IAQ management plans are now required for all major renovation projects. Contractors are required to protect ductwork and building materials from moisture and dirt.

6. Construction standards were revised to include provisions for duct access openings to permit inspection and cleaning.

7. Mechanical hygiene assessments are conducted on all new HVAC systems. Surfaces with MVs > 25 units are required to be cleaned by the contractor prior to occupancy.

8. Operation and maintenance standards were modified to conform with ASHRAE Standard 62.1. We are currently looking adopting ASHRAE Standard 180P, *Standard Practice for the Inspection and Maintenance of Commercial Building HVAC Systems*, as the standard of care.

9. Particulate filtration has been upgraded to MERV 13 to conform to the Leadership in Energy and Environmental Design (LEED) criteria.

Follow-Up Assessments

We continue using the Mycometer to characterize fungal biomass in new HVAC systems. Ninety percent of the surfaces remain free of mold growth (i.e., MVs < 100) after three years. ■

Paul Buckmaster, M.S., CIH, CIEC, is a Technical Leader with a defense agency located at Fort Meade, Md. He can be reached at 443-479-0625.

References

1. Reeslev, M. and Miller, M.: The Mycometer Test: A New Rapid Method for Detection and Quantification of Mould in Buildings, Healthy Buildings 2000 Proceedings.
2. Reeslev, M., Miller, M., and Nielson, K.F.: Quantifying Mold Biomass on Gypsum Board: Comparison of Ergosterol and Beta-N-Acetylhexosaminidase as Mold Biomass Parameters, *Applied and Environmental Microbiology*, July 2003, pp. 3996-3998.
3. General Specification for the Cleaning of Commercial HVAC Systems, National Air Duct Cleaners Association, 2001.
4. Assessment, Cleaning and Restoration of HVAC Systems, National Air Duct Cleaners Association, 2003.

Additional references are in this article's online version, www.ohsonline.com.