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Case Studies

Evaluation of Microbiological Contamination in a Museum

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Our everyday encounters with typical background levels of microorganisms generally do not pose a significant occupational health risk to healthy adults. However, certain contaminated environments present unique exposure concerns due to the nature of the microorganisms encountered, the concentrations of the microorganisms, and the susceptibility of the exposed population. Such was the case when the National Institute for Occupational Safety and Health (NIOSH) received a request to conduct a health hazard evaluation of a capitol annex building located in the southern United States. There were approximately 50 employees working there, responsible for archiving, restoring, and displaying historical items and disseminating the state's historical information to the public. Some of these employees reported upper respiratory irritation, allergies, and hypersensitivity pneumonitis (HP), which they associated with mold contamination in their work environment.

An initial investigation, which established the presence of two primary indoor microbiological contamination sources, was conducted in July 1996. A second, more extensive investigation was conducted in December of the same year to better characterize the nature and extent of the microbiological contamination. This case study presents the findings from these investigations.

Background

The Annex Building

The annex is a four-story, five-floor building of approximately 30,000 square feet built in 1869. It houses a museum, library, and state historical society offices, as well as space for archival storage and historical artifact restoration. The museum is located on the first floor and the library is on the third floor. The basement has additional historical displays as well as an historical archive restoration room, maintenance workshop, security and archive offices, a paintings storage room, and a small lunchroom. The second floor includes offices and storage rooms for maps and photographs. In addition to the library, the third floor includes a room which houses a rare books collection and several offices. On the fourth floor is a small enclosed room used for manuscript storage.

The heating, ventilating, and air conditioning (HVAC) system was installed in 1973 and consists of two constant volume air handling units (AHUs), pneumatically controlled, which run 24 hours per day for archive stability. Each room in the annex building has its own terminal reheat box. The supply ducts are all lined internally with fibrous glass sound liner downstream from the terminal reheat boxes. A steam humidification system, operated from a dedicated boiler, has been used in past winters. Filtration consists of approximately 30 percent efficient roll filter media, which is advanced when the static pressure increases to 0.5 inches water gauge. The boilers and chiller are located in the basement, and a separate area on the fourth floor houses the two AHUs. The roof, which was replaced in 1991, is where the cooling tower is located.

During the July investigation, it was brought to our attention that failing hot water valves located over the museum and over several second- and third-floor offices had leaked and caused some damage to suspended ceiling panels and carpets throughout the building. These water-damaged items had not been cleaned or replaced at the time of our visit. We also observed that the interior of the windows was covered with condensed moisture.

Microbiological Contamination

In recent years, bioaerosols (the term given to airborne microorganisms and their products) have become an important occupational health issue in the areas of agriculture, biotechnology, and non-industrial indoor environments. Much of the concern regarding exposure to bioaerosols has focused on the ability of certain microorganisms to elicit inappropriate immunological responses in susceptible individuals. Adverse health effects to microorganisms are ultimately determined by the immunological state of the exposed individual, the affecting agent (e.g., fungi, bacteria, viruses, cell wall constituents, protozoans, and metabolic products such as mycotoxins), the airborne concentration, and the associated disease outcome (infection versus a sensitization reaction). A comprehensive understanding of these determinants and their interactions is necessary to help resolve occupant exposure risk.

Microorganisms (including fungi and bacteria) are normal inhabitants of the environment. The saprophytic varieties (those utilizing non-living organic matter as a food source) inhabit soil, vegetation, water, or any reservoir that can provide an ample supply of nutrients. Under the appropriate conditions (optimum temperature and pH, sufficient moisture, and available nutrients) saprophytic microorganism populations can be amplified. Through various mechanisms, these microorganisms can then

be disseminated as individual cells or in association with soil, dust, or water particles. In the outdoor environment, the level of bioaerosols will vary according to the geographic location, climatic conditions, and surrounding activity. In a well-maintained indoor environment, where there is no unusual source of microorganisms, their level may vary somewhat as a function of HVAC system filtration, the overall cleanliness of the HVAC system, and the number and activity level of occupants. Typically, the indoor levels of bioaerosols are expected to be below the outdoor levels with a consistently similar ranking among the individual microorganisms.[1,2]

Acceptable levels of bioaerosols have not been established. This is primarily because allergic reactions can occur even with relatively low airborne concentrations of allergens, individuals differ with respect to immunogenic susceptibilities, and the diversity of the microorganisms to which we may be exposed is great. It is unlikely that evaluation criteria for bioaerosols will be established in the near future given the lack of scientifically valid epidemiological and toxicological data to establish dose-response relationships. Hence, the current strategy for the evaluation of environmental microbiological contamination involves an inspection to identify sources (reservoirs) of microbial growth and potential routes of dissemination (pathways). In those locations where contamination is either visible or suspected, bulk and surface samples may be collected to identify the predominant microorganism (fungi, bacteria, and thermoactinomycetes). In limited situations, air samples may be collected to document the presence of a suspected microbiological contaminant and the dissemination pathway(s).[3]

Fungal growth, as well as being a potential health hazard, can also be a serious problem for paper collections and archives. Fungi will grow on anything offering suitable nutrients, including the paper, adhesives, and leather of books. Some types of fungi prefer the easily digested starches, gums, and gelatin found in book bindings and paper size, while others attack and digest the cellulose in paper, causing irreversible weakening and staining. The presence of visible fungal contamination indicates the potential for exposure and is sufficient reason to initiate remediation activities.[4]

Health Effects

Exposure to bioaerosols in indoor environments can cause a range of health effects including infectious, toxic, and allergic/inflammatory responses; however, why some persons develop disease while others remain healthy is, at present, poorly understood. Because fungi were the predominant organisms identified in the annex building, this discussion is limited to fungi and their known health effects related to indoor environments.

Only a few fungi (e.g., *Histoplasma, Blastomyces*, and *Cryptococcus*) are considered primary, systemic, human pathogens that can infect healthy persons.[5] A large number of fungal species are known to cause infection in immunocompromised persons, such as those with AIDS or those receiving chemotherapy. These infections are known as opportunistic infections and frequently involve fungi from the genera *Aspergillus* and *Fusarium*. Exposure to *Aspergillus* in this population may lead to respiratory or systemic forms of aspergillosis. *Fusarium* infections are rare and normally cause local skin infections, although lethal invasive cases have been documented.[6]

Allergic respiratory diseases resulting from exposure to fungi have been documented in agricultural and industrial biotechnology settings, offices, and home environments,[7-14] and include allergic rhinitis (nasal allergy), allergic asthma, allergic bronchopulmonary aspergillosis, and HP.[15] Allergic rhinitis is characterized by sneezing, itching of the mucous membranes, nasal congestion, and rhinorrhea (runny nose) with postnasal drainage. Allergic asthma is characterized by cough, shortness of breath, and wheezing as a result of the narrowing of bronchial passages (airways). Allergic bronchopulmonary aspergillosis, which can occur in people with asthma, is characterized by cough, fatigue, low-grade fever, and wheezing.[16,17] Heavy exposures to airborne fungi can cause an acute form of HP, which is characterized by chills, fever, malaise, cough, and shortness of breath appearing four to eight hours after exposure. In the chronic form, thought to be induced by continuous low-level exposure, onset occurs without chills, fever, or malaise and is characterized by progressive shortness of breath with weight loss.[18] Some of the fungal species associated with HP include *Penicillium*, *Aspergillus*, and *Cladosporium*. However, most cases of HP are found in agricultural settings and occupations, and are associated with a filamentous bacterium known as thermoactinomycetes.[19] Thermoactinomycetes are most numerous in molding hay, cereal grains, and compost heaps that have heated spontaneously to over 60°F.[20]

Methods

July Environmental Evaluation[21]

The initial evaluation was conducted to determine if microbiological contamination existed in the offices that could cause or contribute to the reported symptoms and to determine if a follow-up bioaerosol evaluation would be of value. Twelve sticky-tape surface samples were collected by pressing cellophane tape to the visibly contaminated HVAC system sound liner, supply diffusers, and historical artifacts, including books and paintings. The samples were microscopically analyzed to identify fungi, to species if possible. Nine bulk samples were collected from visibly contaminated AHU sound liners, terminal reheat box sound liners, suspended ceiling panels, and carpeting. The samples were submitted for analyses of total colony count and identification, to species if possible, for fungi, bacteria, and thermoactinomycetes. Relative humidity (RH) and temperature measurements were collected on each floor of the building and in offices where sticky-tape and bulk samples had been collected.

July Medical Evaluation

Private medical interviews were conducted with six symptomatic employees who wished to speak with NIOSH investigators, including one employee with a reported diagnosis of HP. During the interviews, employees were asked if they had experienced any health symptoms while at work, the frequency of the symptoms, the temporal relationship of symptoms to work, and any observations which they had about the office environment. Medical records of the employee with HP were obtained from the treating physician, who was also interviewed.

December Environmental Evaluation[21]

The second evaluation was conducted to better characterize the nature and extent of the microbiological contamination during the winter season, when the majority of adverse health effects were reported to occur. Surface, bulk, and air samples were collected at the annex building over three consecutive days and were analyzed using both culturable and microscopic methods. Sample locations were chosen based on employee complaints, use of the work area, and suspected or obvious contamination of historical artifacts and the HVAC system. The annex building's HVAC system performance was also assessed during this evaluation.

Surface Samples

Sticky-tape surface samples (11 total) were collected by pressing cellophane tape over visibly contaminated historical artifacts, including books, paintings, and maps. These items were fragile and required a technique which would not damage the surface of the artifact. An additional five surface samples were collected by pressing a replicate organism detection and counting (RODAC) plate filled with malt extract agar (MEA) against less fragile surfaces, including bookshelves and filing cabinets, where microbiological contaminants may have settled. The tape samples were analyzed by optical microscopy, and the RODAC samples were incubated at room temperature and then observed for fungal genera (type) and number of colonies. Micro-vacuum sampling, which involves using an air pump to "vacuum" suspected surface contaminants onto a mixed cellulose ester (MCE) filter, was also conducted. Fourteen micro-vacuum samples were collected from book covers, maps, carpets, and the backs of canvas paintings. For each sample, analysis consisted of two methods—microscopy, and then dilution of the filter contents which were placed onto several different nutrient media, including MEA and dichloran glycerol (DG 18) agar, to determine fungal genera and concentration.

Bulk Samples

As in the July evaluation, two bulk samples were collected by cutting approximately one square inch of material from the sound liner downstream of the cooling coils inside both AHUs. An additional three bulk samples were collected the same way from the interior sound liners of the terminal reheat boxes in the security office, the lunchroom, and in a second floor office. A bulk sample of the vacuum cleaner water, taken from the catch basin of the vacuum after it was used to "steam-clean" clothing, was collected in a glass vial. All of the bulk samples were diluted and cultured on MEA, for fungal cultures, and tryptic soy agar (TSA), for bacterial cultures, and then analyzed microscopically for fungal and bacterial genera and concentrations.

Air Samples

Air samples were collected using an Andersen single-stage sampler, where a known volume of air passes into the sampler and airborne fungal spores are impacted onto an MEA-filled plate. The samples were incubated at room temperature and analyzed for fungal genera and concentration. From 6 to 12 Andersen single-stage samples were collected in each of 11 locations over 3 days throughout the 5 floors of the annex building and outdoors, for a total of 108 samples.

Annex Building HVAC System Performance

To further evaluate the HVAC system performance, the as-built drawings for the system were reviewed, a visual inspection of the system was performed, and temperature, RH, and carbon dioxide (CO_2) measurements were made at ten locations indoors and one location outdoors, corresponding to the locations of the air samples.

Results

July Environmental Evaluation Results

The environmental results from the July evaluation established the presence of two primary sources of indoor microbiological contamination: the annex building's HVAC system and the historical artifacts collection. Sticky-tape surface and bulk samples indicated the presence of relatively large concentrations of *Penicillium*, *Cladosporium*, and *Tritirachium* species growing on the fibrous glass sound liners downstream of the cooling coils of the annex building's two AHUs and on many of the historical artifacts, including books, clothing, and paintings. These samples also indicated the presence of other fungal genera, including *Aspergillus*, found growing on the supply air diffusers in several annex building offices. The sticky-tape surface and bulk sample results from the July evaluation are compiled in Tables I and II, respectively.

The RH measured throughout the annex building during the July evaluation ranged from 52 percent to greater than 66 percent, with most of the measurements being greater than 60 percent.

December Environmental Evaluation Results

During the December evaluation, 8 of the 11 sticky-tape surface samples contained *Aspergillus glaucus* section, and the remaining 3 had no apparent fungal structures. Conidia, hyphae, and condiophores of *A. glaucus* section were found on book covers and a ledger in the manuscript storage room, on book covers in the rare book room, and on backs

TABLE I
Sticky-tape surface sample results—July evaluation

Sample location	Fungal identification
Air handling unit A, sound liner, downstream of cooling coils	*Penicillium*
Air handling unit B, sound liner, downstream of cooling coils	*Cladosporium* and *Penicillium*
Air handling unit B, sound liner, downstream of cooling coils	Mycelia and spores of *Cladosporium*, *Penicillium*, and *Tritirachium*
Library supply diffuser 1	Unidentified fungal spores
Library supply diffuser 2	Mycelia and spores of *Cladosporium* and *Aspergillus*
Library supply diffuser 3	Mycelia and spores of *Cladosporium*
Library supply diffuser 4	Mycelia and spores of *Cladosporium*
Library supply diffuser 5	Mycelia and spores of *Cladosporium*
Second floor office terminal reheat box sound liner	Mycelia, probably *Cladosporium*
Second floor office supply diffuser	Unidentified fungal spores
Second floor office ceiling panel	Unidentified fungal spores
Basement office ceiling panel	Unidentified fungal spores

of paintings in the painting storage and archival storage rooms. Results of the RODAC plate surface samples, which are compiled in Table III, indicated that spores of numerous fungal genera were found on bookshelves in the manuscript storage and rare book rooms, and on a metal file cabinet in the map room.

Seven of the 14 micro-vacuum surface samples analyzed by optical microscopy, like the sticky-tape surface samples, indicated *A. glaucus* section contamination of books, ledgers, and maps in the manuscript storage and rare book rooms. Nine of the 14 samples collected in the manuscript storage and rare book rooms, and also from the museum, paintings storage room, and the map room, contained *Aspergillus*-*Penicillium*-, and *Cladosporium*-like spores. Results from the cultured micro-vacuum samples are compiled in Table IV. Although most of the samples (9 of 14) showed no growth, the remaining 5 had low concentrations of *Penicillium*, *Cladosporium*, and other fungal genera.

TABLE II
Bulk sample results—July evaluation

Sample location	Fungal Identification	Total fungal concentration (CFU/g)[A]
Air handling unit A, sound liner, opposite cooling coils	*Penicillium*	15,520,000
Air handling unit B, sound liner, opposite cooling coils	*Penicillium*	6,744,000
Second floor office, reheat coil sound linear, upstream	*Penicillium*	1724
Second floor office, sound liner, below cooling coils	*Penicillium*	725
Second floor office, ceiling panel, next to diffuser	None detected	N/A
Second floor office, carpet under bookcase	None detected	N/A
Second floor office, carpet under leaky hot water valve	None detected	N/A
First floor museum room, ceiling panel	None detected	N/A
First floor storage room, carpet	*Penicillium*	10

[A]CFU/g = colony forming units per gram of sample.

Results from the analysis of the six bulk samples are compiled in Table V. AHUs A and B were both contaminated with *Penicillium*, and AHU B was also contaminated with *Cladosporium*. *Penicillium* concentrations ranged from more than 13 million colony forming units per gram (CFU/g) in AHU A to more than 22 million CFU/g in AHU B. These samples also contained low concentrations of *Thermoactinomyces candidus (TA candidus)* (4724 CFU/g in AHU A and 847 CFU/g in AHU B), which is usually only found in agricultural environments. The samples collected from the interior sound liners of the terminal reheat boxes in the security office, the lunchroom, and the second floor office contained low concentrations of *Penicillium* and *Cladosporium* (*Penicillium* concentrations ranged from 1587 CFU/g [second floor office] to 73,134 CFU/g [lunchroom]). The reheat boxes in the security office and the second floor office also contained low concentrations of *TA candidus* and thermophilic bacteria, and the reheat box in the lunchroom contained more than 15 million CFU/g of unspecified gram-negative bacteria. The bulk sample collected from the wastewater catch basin of the steam vacuum cleaner contained low concentrations of several fungal species, thermophilic bacteria, and gram-negative bacteria.

A graphical summary of the Andersen single-stage air sample results shown Figure 1. The left vertical axis refers to the bars in the graph and indicates the average (arithmetic mean) of the total

concentration of all fungal genera identified in each location. The right vertical axis refers to the two types of fungi listed, *Tritirachium* and *Aspergillus versicolor*, and the percentage each contributed to the samples taken at each location. For example, in the manuscript storage room on the days we sampled, we found an average fungal concentration of 205 colony forming units per cubic meter (CFU/m^3) of air. Of that total concentration, the fungal genera *Tritirachium* composed 18 percent and the genera and species *A. versicolors*, 7.5 percent. Overall, *Tritirachium*, which was not found outdoors, ranged from 18 percent to 57 percent indoors and was present in 84 percent (82/98) of all the air samples collected indoors. The *Aspergillus* genera, which made up 16 percent of the outdoor samples, ranged from 3 percent to 19 percent indoors, and the species *A. versicolor*, which made up 1.2 percent of the outdoor samples, ranged from not detected to 7.5 percent indoors. *Penicillium* comprised 10 percent of the outdoor samples and from 1 to 14 percent of the indoor samples.

During the visual inspection of the HVAC system, it was found that AHU B had a one-inch gap between the roll filter and the filter frame, allowing unfiltered air into the supply airstream. Interior CO_2 concentrations ranged from 425 to 650 parts per million (ppm), interior temperatures ranged from 62°F to 80°F, and interior RH ranged from 14 percent to 36 percent. (The humidifier was not operating at this time.) By comparison, RH measurements taken during the July visit ranged from 52 percent to 66 percent, which shows wide RH fluctuations between the heating and cooling seasons.

TABLE III
RODAC plate surface sample results—December evaluation

Sample location	Fungal identification	Colony counts
Manuscript storage room (Row 1 book shelf)	*Penicillium*	14
	Basidiomycetes	2
	Chaetomium	2
	Cladosporium	2
	Aspergillus fumigatus	1
Manuscript storage room (Row 2 book shelf)	*Penicillium*	9
	Cladosporium	5
	Basidiomycetes	2
	Aspergillus versicolor	1
	Tritirachium	1
Rare book room (shelf under supply diffuser in back of room)	*Cladosporium*	15
	Basidiomycetes	6
	Penicillium	6
	Aspergillus versicolor	3
	Aspergillus fumigatus	1
	Tritirachium	1
Rare book room (book shelf in last row)	*Basidiomycetes*	20
	Cladosporium	8
	Epicoccum nigrum	3
	Phoma	3
	yeasts	3
	Penicillium	1
	Rhodotorula	1
Map room (top of metal file cabinet)	*Penicillium*	11
	Basidiomycetes	6
	Cladosporium	6
	Epicoccum nigrum	3
	Pithomyces	3
	Chaetomium	2
	Nigrospora	2
	Phoma	1

July Medical Evaluation Results

Of the six employees interviewed during the initial July visit, four worked on the second floor, one in the basement, and one on the third floor of the annex building; most reported working in other areas of the building throughout the day to accomplish their job duties. Although the majority of the interviewed employees' work involved administrative and clerical duties, at times they were required to work directly with the exhibits and to handle historic clothing, photographs, books, furniture, and other artifacts. One employee's job required extensive work with the photographic archives in the archive storage room.

All six employees interviewed were non-smokers. All noted increased symptoms while in the annex building; headaches, sinus congestion, and sinus pressure were the most commonly reported symptoms and the symptoms most relieved when employees left the building. Three of the employees interviewed felt that their symptoms were worse in winter. One reported an episode of "hives" on the trunk and extremities that lasted for several months during the winter.

Three workers reported physician-diagnosed allergies to molds and dust, and one of the three also reported allergies to grasses and trees. Two of these employees worked on the second floor and one on the third floor. All three were receiving allergy shots regularly and taking medications such as antihistamines as needed. One employee with extensive

contact with photographic artifacts developed upper respiratory symptoms, episodes of low-grade fever, chills, and muscle aches, which persisted through the winter and led to several courses of antibiotic therapy for "bronchitis." Subsequent medical testing revealed serum antibodies to *Aspergillus niger* and *TA candidus*. The treating allergist made a provisional diagnosis of HP based on work history, medical symptoms, and results of the HP panel. The allergist had not seen the worker during the period of acute illness, when physical exam and a diagnostic work-up may have helped to establish the diagnosis. This clinical picture prompted the physician to recommend investigation of the HVAC systems in the employee's work and home environments for evidence of fungal contamination.

Discussion

Overall, the sampling results indicated that, although the annex building envelope (exterior walls) showed no visible evidence of contamination or water damage, components of the HVAC system and building interior show contamination (visible mold growth) with high concentrations of many fungal and some bacterial genera. Because patterns of growth and contamination change with every season, the results obtained during these surveys are only indicative of conditions at those times.

In all, 45 fungal genera and species were identified from the samples that were collected during the December evaluation, 36 inside and 23 outside the annex building. Most of the genera identified indoors were also found outdoors, with one exception being the fungus *Tritirachium*. In other studies, *Tritirachium* has been isolated from building HVAC systems and can be found outdoors only during certain seasons.[22] *Tritirachium*,

TABLE IV
Cultured micro-vacuum surface sample results—December evaluation

Sample location	Total samples	Total fungal concentration (CFU/g)[A]	Fungal taxonomic rank[B,C]
Manuscript storage room (book cover dust)	1	38,461	*Pen> > Acre> Clad/Chae*
Manuscript storage room (book cover dust, maps, ledgers, and journals)	5	No growth	*N/A*
Rare book room (rare book covers)	2	No growth	*N/A*
Rare book room (shelf under supply diffuser in back of room)	1	5300	*Clad> > > Pen> Asp/Trit/Acre*
Map room (top of metal file)	1	700	*Pen> Clad/Pith*
Museum room (original museum rug, antebellum gallery)	1	5800	*Clad> > Phoma/Pen> E. nig/Pith/yeasts*
Museum room (original museum rug by dresser [less foot traffic])	1	1800	*Clad> > yeasts/Pen/Phoma/Alt*
Painting storage room (backs of canvas paintings)	2	No growth	*N/A*

Key:
[A] CFU/g = colony forming units per gram.
[B] *Pen* = *Penicillium*
Acre = *Acremonium*
Clad = *Cladosporium*
Chae = *Chaetomium*
Asp = *Aspergillus*
Trit = *Tritirachium*
Pith = *Pithomyces*
E. nig = *Epiccocum nigrum*
Alt = *Alternaria.*
[C] ">" indicates approximately one order of magnitude higher concentration
">>" indicates approximately two orders of magnitude higher concentration
">>>" indicates approximately three orders of magnitude higher concentration
"/" indicates approximately equal concentrations of organisms.

although collected from the sound liner of AHU B in July, was not found in any of the outdoor air samples we collected, or even actively growing within any of the HVAC components we sampled in December; *Tritirachium*, however, was found in 84 percent of the Andersen air samples collected inside the annex building. This indicates the presence of an indoor environmental reservoir and subsequent dissemination throughout the annex building. Although this organism has not been associated with any particular health effects, all fungal spores are potentially allergenic.

Although no clear indoor sources of *Tritirachium* were identified in December, *Penicillium*, *Cladosporium*, and *Aspergillus* were identified on surfaces and in the two AHUs servicing the annex building. These are among the 10 most frequently detected microorganisms in humid buildings and are widely distributed in soil, dust, and other organic debris. Each of these has been associated with case reports of HP, although predominantly in agricultural environments with heavy airborne exposure.[19] *Penicillium* was found actively growing in the two AHUs, most likely because of increased moisture and debris on the sound liner downstream of the cooling coils (although the sound liner of both AHUs was noticeably wetter during the July visit than during the December visit). In both the July and December evaluations, AHUs A and B had visible growth of *Penicillium* and *Cladosporium* and are thus a potential source for dissemination and contamination throughout the rest of the HVAC system.

A total of 12 *Aspergillus* species were identified in the air samples collected in the annex building. *A. fumigatus*, *A. flavus*, *A. niger*, and *A. terreus* were found in small concentrations on surfaces and in the air inside the annex building. *A. glaucus* section was identified in larger quantities on artifacts and other surfaces throughout the annex building. All have been associated with infections in immunocompromised persons, although *A. fumigatus* is responsible for most of these types of infections.[1] *A. versicolor* was found at airborne concentrations that were higher indoors than outdoors, which indicates

TABLE V
Bulk sample results—December evaluation

Sample location	Total fungal concentration (CFU/g)[A]	*TA candidus*[B] concentration (CFU/g)	Fungal taxonomic rank[C,D]
Air handling unit A (sound liner)	13,300,790	4724	*Penicillium only*
Air handling unit B (sound liner)	24,738,980	847	*Pen> > > Clad*
Basement room A (terminal reheat box sound liner)	5556	No growth	*Pen> Clad*
Basement room B (terminal reheat box sound liner)	76,119[E]	746	*Pen> > > Clad> Phoma*
Second floor room A (terminal reheat box sound liner)	11,111	794	*Rhod> > Pen> Clad*
Waste vacuum cleaner water	6050[F]	No growth	*yeasts> > Rhod> Phoma/Clad*

Key:
[A] CFU/g is colony forming units per gram.
[B] *TA candidus* is *Thermoactinomyces candidus.*
[C] *Pen* is *Penicillium*
Clad is *Cladosporium*
Phoma is *Phoma*
Rhod is *Rhodotorula*
[D] ">" indicates approximately one order of magnitude higher concentration
">>" indicates approximately two orders of magnitude higher concentration
">>>" indicates approximately three orders of magnitude higher concentration
"/" indicates approximately equal concentrations of organisms.
[E] This sample also contained a concentration of 15,543,280 CFU/g gram-negative bacteria.
[F] This sample also contained a concentration of 5,288,360 CFU/m^3 gram-negative bacteria. (No gram-negative bacteria were found in any other bulk samples.)

potential indoor growth and dissemination of this organism. Although not detected in any of the samples collected from the HVAC system components, the presence of this organism, which requires a relatively high-moisture environment, may indicate contamination of the system.

TA candidus was found in low concentrations in several HVAC system components. The advent of the heating season may provide an environment suitable for the proliferation of this organism due to the warming of the ventilation system. However, the concentrations we found are inconclusive as to the presence of an indoor reservoir. *TA candidus* has been associated with HP, usually in agricultural environments.[19] The suspicion of HP in the worker with antibodies to *TA candidus*, recurrent respiratory symptoms, and a possible history of occupational exposure is appropriate, although the diagnosis of HP could not be firmly established from the history and medical records available to the NIOSH investigators. A high degree of clinical suspicion is required to confirm a diagnosis of HP.[23] The presence of antibodies to *TA candidus* and *Aspergillus niger* in blood samples indicates that at some point this individual was exposed to these fungal species; however, it is difficult to say with certainty what role workplace exposure may have played and whether development of disease was related to these exposures. Follow-up of recurrent symptoms in someone with the symptoms of HP is important because a decline in lung function with continued antigen exposure has been demonstrated for most forms of HP, and avoidance of continued antigen exposure is the mainstay of treatment.

Many fungal genera were also found growing on the historical artifacts, and their growth should be stopped as soon as possible to reduce potential employee exposures and further damage to the artifacts. The growth of *A. glaucus* section, a xerophile, is indicative of a chronically humid, but not saturated, environment (i.e., a building or materials which remain in the range of approximately 50–70 percent RH) and can result in the destruction of the artifacts it contaminates by decomposing the cellulose.[24]

The measured interior CO_2 concentrations indicated that sufficient outdoor air was being provided by the HVAC system. However, the temperature and RH were poorly controlled throughout the annex building (the humidification system was not operational during the December evaluation). Greater than 60 percent RH in a building is considered too high and will contribute to the growth of fungi such as those we identified.[25] Furthermore, the variability of the RH measurements suggests relatively poor humidity control, and the condensate that was visible on the inside of the windows during the July evaluation indicates the potential for chronic water damage to the building structure.

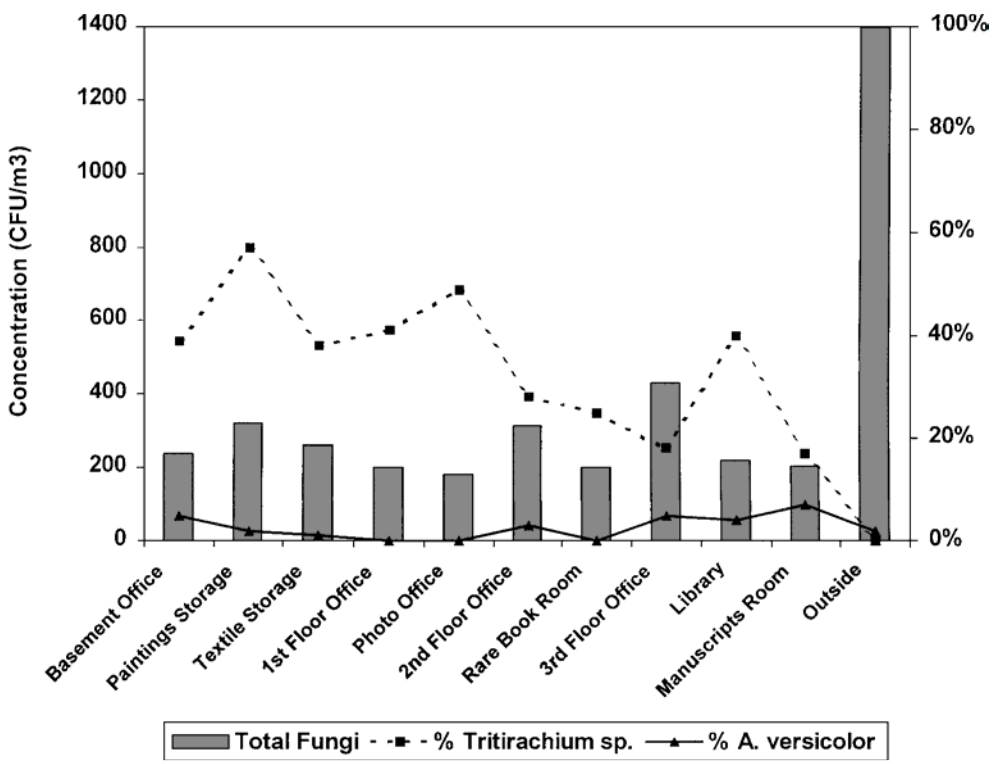

FIGURE 1
Andersen single-stage air sampling results/fungal concentrations by location
December evaluation.

The increased symptoms reported by employees with allergies to molds when in the annex building are consistent with allergic responses. Syndromes such as sinusitis and chronic bronchitis may also be occurring, and the role of indoor allergens in these conditions is possible or suspected, but largely undefined.[26] Three of the employees who reported allergies to molds work in offices or work areas where there was visible mold growth or where molds were identified in the AHUs which supply their offices. One of the most symptomatic employees works in an office where there was visible mold growth on the supply air diffuser and where multiple deficiencies in the AHU (unit B) were identified. The symptoms which these employees reported are likely to be associated with the work environment given their reported allergies to molds and the documented presence of molds in their immediate work area. When workers have known allergies to microorganisms like those identified in the annex building, ideally, the workers, their treating physicians, and the employer must collaborate to create a safe work environment by eliminating or reducing exposures to the allergens and managing symptoms. If allergic reactions are severe enough and total amelioration of the allergen is not possible, the worker should be reasonably accommodated in another location or may need to leave the work area or job entirely.

Recommendations

Recommendations were made to address employees' health concerns, to reduce the contamination of the HVAC system and historical artifacts, and to help control dissemination of the microorganisms into the work environment:

- Employees should know about the presence of mold in their work environment so that they can recognize symptoms of undiagnosed allergies, and so that those with known allergies can, in consultation with their physicians, work to minimize symptoms. In addition, all employees who develop symptoms potentially related to workplace exposures should be evaluated by an occupational physician.
- Employees should minimize the potential for exposure by isolating moldy artifacts from general work areas. Either as a concerted effort, or as they are used by employees or patrons, all visibly contaminated historical artifacts should be cleaned and disinfected by vacuuming with a cleaner fitted with a high efficiency particulate air (HEPA) filter and/or by using a disinfectant that will not cause irritation to employees or damage the artifacts. The vacuuming and cleaning should be done in a contained area, such as under a laboratory hood or in a sealed room so that microorganisms are not spread throughout the rest of the annex building by the HVAC system.
- Because of the potential for fungal spores to become aerosolized during handling, use of a respirator should be considered when employees work with visibly moldy artifacts. At a minimum, NIOSH-approved N-95 respirators should be used. These are the type recommended for protection against the *Mycobacterium tuberculosis* organism, which is similar in size to the smallest fungal spores. (Whenever respirators are offered to employees, a respirator program must be in place that meets the minimum requirements outlined in the OSHA respiratory protection standard [29 Code of Federal Regulations 1910.134 (1992)].[27] Additional information on respiratory protection is available in the *NIOSH Guide to Industrial Respiratory Protection*.[28]) Also, when working with visibly moldy artifacts, gloves made of nonlatex or low-protein, powderless latex should be worn, hands should be washed after handling historical artifacts, and disposable gowns should be used.
- For the annex building, it was recommended that the RH be maintained below 60 percent at all times of the year and, to maximize employee comfort and reduce microbiological contamination, improve the RH control system so that a tighter optimal range of RH can be maintained. Computerized electronic controls for the HVAC system should be installed. This should result in better temperature and relative humidity control, with increased employee comfort, and should decrease energy use.
- The remaining recommendations involved the HVAC system included removing and discarding the contaminated sound liner in AHUs A and B and in all the supply air ducts and disinfecting the AHUs and ducts with a 10 percent bleach solution (14.2 ounces of household chlorine bleach, typically a 5.2 percent solution, per gallon of water), preferably during unoccupied hours, to minimize employee exposure to chlorine odors. (If insulation is required to maintain proper operation, apply it only to the outside of each AHU or duct.) It was also recommended that they upgrade the filtration for AHUs A and B to the highest efficiency filters practical, given existing fan static pressure. Until the filtration can be upgraded, they should repair the gap between the roll filter and the filter frame

in AHU B. All visibly contaminated supply air diffusers should also be cleaned and disinfected. The HVAC system should be brought into full working order. This includes (at least) repairing or replacing HVAC components as necessary, calibration of all HVAC controls, test and balance of the HVAC system, installation of a humidity controller for each humidifier, and cleaning the HVAC ducts (as determined by a duct inspection). A preventive maintenance program for the HVAC system should be developed and instituted. At a minimum, this should include routine inspection and maintenance of HVAC components, routine calibration of HVAC system controls, and routine test and balance of the HVAC system.

Afterword

Fungal growth, as well as being a potential health hazard, can also be a serious problem for paper collections and archives. Although typical background levels of microorganisms generally do not pose a significant health risk to healthy adults or cause harm to historical artifacts, conditions must be maintained that will prevent the growth of fungal spores. Library and archival collections can and should be protected by maintaining RH conditions below 55 percent, or, better, below 45 percent, and by preventing water accidents, like roof leaks. These should be among the highest priorities for any such institution.[29]

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