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ENVIRONMENTAL STUDIES IN MOLDY OFFICE BUILDINGS

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ABSTRACT

The National Institute for Occupational Safety and Health (NIOSH) has carried out health hazard evaluations in five large office buildings where hypersensitivity pneumonitis (HP) and other respiratory diseases have been alleged or reported. Environmental studies made both in the occupied space and in the heating, ventilating, and air-conditioning (HVAC) system of each building are described. Several buildings were characterized by a history of repeated flooding, and all contained mechanical systems with pools of stagnant water and microbial slimes. Preventive measures that may be effective in reducing building-associated microbial contamination and building-associated HP illnesses include the following: (A) Prevent moisture incursion into occupied space and HVAC system components; (B) Remove stagnant water and slimes from building mechanical systems; (C) Use steam as a moisture source in humidifiers; (D) Eliminate the use of water sprays as components of office building HVAC systems; (E) Keep relative humidity in occupied space below 70%; (F) Use filters with a 50% rated efficiency; (G) Discard microbially damaged office furnishings; (H) Initiate a fastidious maintenance program for HVAC system air handling units and fan coil units.

INTRODUCTION

Hypersensitivity pneumonitis (HP) and other respiratory diseases in office workers have been repeatedly described since 1970 (Table 1). (1-8) Symptoms have included pulmonary manifestations such as chest tightness, coughing, and wheezing together with constitutional symptoms such as muscle aches, chills, fever, headache, and fatigue. Attack rates have varied from approximately 1% (4) to over 50%. (5) Disease has been attributed to thermophilic actinomycetes, (1-3) non-pathogenic amoebae, (7) fungi, (8) and Flavobacterium spp. or their endotoxins. (6) Despite extensive investigation the agents responsible for several large outbreaks were not determined. (4,5) In all outbreaks listed in Table 1, the source of microbial contaminants responsible for the disease outbreak was thought to be a component of the building heating, ventilating, and air-conditioning (HVAC) system. HVAC system ductwork, (1,3) humidifiers, (5-7) air

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washers [components of air handling units (AHUs) emitting a water spray], (2,4) and fan coil units (FCUs) (8) have been documented as sources of disease agents. Remedial and preventive measures used during HP outbreaks are poorly described but have ranged from the cleaning of a HVAC system component (3,8) to total replacement both of the HVAC system (4) and all furnishing in the occupied space of the building (Table 1).

Over the past five years, the Division of Respiratory Disease Studies of the National Institute for Occupational Safety and Health (NIOSH) through its Health Hazard Evaluation Program has been requested by other governmental agencies to evaluate apparent outbreaks of HP in office buildings. Since microbial agents are involved in the etiology of most HP-illnesses, environmental investigations in these buildings were primarily concerned with the identification of possible sources of biological agents. The suggestion of appropriate abatement procedures is an important component of each health hazard evaluation. Since October 1981, NIOSH has carried out environmental studies in five large, multistory office buildings wherein HP-like illnesses or other respiratory diseases were reported or alleged to occur. This paper describes environmental studies made both in the occupied space and in the HVAC system of each building. The possible sources of microbial agents in each building are described, and remedial and preventive measures, which may be effective in controlling environmental contamination that has been associated with building-related HP, are reported.

METHODS

Collection of airborne microorganisms was carried out using viable cascade impactors (9) including a modified sampler in which only the lowest sieve plate (stage 6) is utilized. (10) Total colony forming units (CFU)/m^3 were reported after correction of plate counts by the positive hole procedure. (9) Plates utilized in samplers for collection of fungi, bacteria, and amoebae contained rose bengal streptomycin agar (RBS) (100 μg streptomycin per ml), tryptic soy agar (TSA) (50 μg cycloheximide per ml), and nonnutrient agar coated with a suspension of *Escherichia coli*, respectively. Additional airborne microorganisms were collected in a two-piece cassette containing a sterilized cellulose ester filter (0.8 μm pore size) and backup pad as described elsewhere. (8) Viable impactor and filter cassette samplers were operated for a variable length of time at flow rates of 1.0 and 0.07 CFM, respectively [28.3 and 2.0 liters per minute (LPM)]. Bulk dust and water samples collected at building sites were analyzed for fungal and bacterial levels by standard serial dilution techniques using RBS and TSA media, respectively.

Respirable dusts were collected utilizing either a 0.5 in (1.27 cm) cyclone sampler [polyvinyl chloride 1.46 in (37 mm) filter with nominal 0.8 μm pore size] operating at 0.32 CFM (9 LPM), or a 1.0 in (2.54 cm) cyclone sampler [polyvinyl chloride 1.85 in (47 mm) filter, 0.8 μm nominal pore size] operating at a flow rate of 2.33 CFM (66 LPM). (11) Total suspended particulate was collected in occupied space utilizing a 8 x 10 in (20 x 25 cm), high volume sampler (glass fiber filter) operating at a flow rate of 70.6 CFM (2 m^3/minute).

The volume of outside air entering the mixing plenum of HVAC system AHUs in some buildings was estimated by multiplying the total area of louvered intake openings by the average air velocity through the free area of these openings. A rotating vane anemometer and/or a velometer was utilized to determine air velocity through open outside air intake louvers. The total volume of air flowing through each AHU was estimated at a position approximately 3 in (8 cm) downstream from the filter bank and was the product of the cross-sectional filter area and the average air velocity. The amount of conditioned air entering occupied space through ceiling diffusers was determined as the product of average air velocity (hot wire air velocity meter) and the area of diffuser openings.

Short-term colorimetric indicator tubes including those for CO_2, CCl_4, O_3, NH_3, NO_2, CO, Cl_2, hydrocarbons, perchloroethylene, and methanol-ethanol were utilized to test for the presence of possible contaminant gases in occupied spaces. Other possible air contaminants were collected in a large charcoal tube, desorbed with ethanol, and screened by gas chromatography. Environmental sampling for airborne fibrous glass was carried out by the fiber count method. (12)

RESULTS - Environmental studies in office buildings

Building A. At least one-third of the 350 employees in a building located in a southern city experienced recurring outbreaks of a febrile illness that led to a permanent evacuation of the facility. This building was constructed in the 1930's. Its HVAC system was installed in 1941 and contained two open water systems with nozzles for spraying water over a finless direct expansion evaporator coil for summer cooling. A mixture of return and outdoor air (up to 15%) passed through a filter bank and then through a water spray system in either of the two units. The spray water in each system was collected in a 3000 gal (12.7 m^3) tank, chilled, and then reaerosolized. Conditioned air from each spray water-direct expansion system passed through baffle plates, into fans, and then was transported via ducts to occupied space throughout the building.

The HVAC system was turned off on September 18, 1981, as cool weather was expected the following week. Because the temperature in the building had reached 30°C (85 F) by 0800 hr on September 21, the HVAC system was turned back on. During that day and evening an illness occurred in approximately one-third of the employees and consisted of headaches, muscle aches, fever, chills, nausea, wheezing, and chest tightness. In most affected individuals the symptoms had resolved by the next morning. Since there was a temporal relation between illness and turning the HVAC system on, the HVAC system was shut down and water spray systems were cleaned with steam and a quaternary ammonium compound. The HVAC system was then operated without effect upon building occupants until October 10 when it was shut down to repair one water spray system. The HVAC system, including water sprays, was turned on again on October 12 (Columbus Day, a holiday) and on October 13, a second mass illness occurred. The HVAC system was turned off, and remained off until October 15. On that day the HVAC fan system was turned on, a third mass illness occurred, and building occupants were moved into other office facilities.

Review of building operations showed that outbreaks of mass illness could not be related to climatological conditions or to process variables such as new construction, renovation, or cleaning activities. Each instance of mass illness was however temporally related to the activation of the HVAC system.

The baffle plates of both air washers were coated with a slime growth. Similarly slimes were found on the surfaces of water spray sumps, on both pipe insulation and masonary wall surfaces located between water spray systems and fans, and on the floor in the vicinity of the fans. The microorganisms listed in Table 2 were isolated from these slimes. Slimes also contained unidentified flagellates, free-living nematodes (e.g., *Rhabditis* spp.), and mites. Water spray sump waters were dominated by *Flavobacterium* spp., amoebae (e.g., *Acanthamoeba* spp.), and ciliates (e.g., *Vorticella* spp.).

Levels of airborne microorganisms in the occupied space of Building A were measured 10 days after the third outbreak of mass illness, at a time when the HVAC system had been turned off and water spray systems had been drained. Airborne fungal levels were approximately 800 CFU/m^3. At the same time respirable dust levels [0.5 in (1.27 cm) cyclone] in occupied space were 46 $\mu g/m^3$, and the relative humidity was found to be 52%. However, eight hours after turning on the HVAC system including one water spray system, the relative humidity in occupied space rose to 78%.

The microbial contamination found in the HVAC system of Building A was considered to be responsible for the recurring outbreaks of febrile illness. A number of isolates from Building A including *Bacillus* spp., (13) *Flavobacterium* spp., (6) thermophilic actionmycetes, (1-3) *Cephalosporium* spp., (14) *Aspergillus* spp., (15) *Penicillium* spp., (8,16) and *Acanthamoeba* spp. (7) have been implicated as agents in other outbreaks of HP and humidifier fever. If the source of the agent responsible for this disease outbreak was the aerosolization of microorganisms in or near the water sprays, the high relative humidity associated with this type of HVAC system operation would be conducive to the survival of viable particles at locations throughout the ductwork and in occupied space of this building. Consequently, it was recommended that all non-disposable building contents, including books, desks, carpets, drapes, HVAC system ductwork, and water spray-direct expansion system surfaces be thoroughly cleaned with a vacuum incorporating a high efficiency particulate air (HEPA) filter. It was further recommended that building contents that could not be adequately cleaned be discarded and replaced.

Building B. In this building, which is located in an eastern city, 12 of 41 office workers in a central zone on the seventh floor experienced HP-like symptoms consisting primarily of fever, chills, muscle aches, and chest tightness. Building B is an eight-story structure constructed in 1975 that is currently occupied by over 1300 employees. Most floors have eight office zones. One centrally located zone on the seventh floor has been the site of a series of floods, one of which occurred on January 27, 1982. Over the following months, several persons in this zone experienced a subacute febrile illness. Ill persons were more likely than non-ill persons to occupy desks within 16.4 ft (5 m) of water leaks. (17) The cafeteria kitchen on the eighth floor is directly above this zone and its water-drainage system runs through the common return air plenum above the suspended ceiling over offices occupied by personnel experiencing illnesses. The plumbing for the cafeteria dishwasher had no grease traps. Consequently, grease periodically clogged drain pipes, causing water to back up and eventually flood the underlying office zone.

Eighteen main AHUs and over 900 FCUs condition supply air in Building B. Main AHUs condition a mixture of outdoor and return air whereas FCUs condition only recirculated air. Conditioned air from each main AHU is transported to offices through ducts that terminate in slots around the periphery of ceiling light fixtures and in long slot type supply outlets at some building perimeter locations. Each AHU in Building B provides supply air to vertically superimposed zones on a number of different floors. Return air from occupied space passes into centrally located slots in ceiling lighting fixtures and enters the return air plenum. Return air from zones on each floor moves through this common plenum and then through shafts or risers and is transported (by return fans) to main AHUs or is expelled from the building during economizer operation. Air interchange between AHUs occurs because of mixing both in common return plenums and in building risers. Thus, once an air contaminant enters a common return plenum it could be easily distributed into other AHUs and then throughout the building.

Microorganisms were isolated from damaged ceiling tiles and carpets obtained from the seventh floor zone where illness had occurred. In addition, similar analyses were carried out from debris obtained from the outside surface of pipes in the common return air plenum above this zone plus a sample of water collected during a flood that occurred on April 1, 1982. All specimens examined for protozoa contained Acanthamoeba polyphaga. Other predominant microorganisms isolated were Monosporium apiospermum, Rhodotorula spp., Aureobasidium spp., Colpoda spp., and Mastigamoeba spp. Sampling for airborne fungi was carried out in this office on March 16 and again on May 7, 1982. On both occasions levels of fungi were low, being less than 100 CFU/m^3. Dust samples collected from main AHUs and FCUs throughout the bulding contained Thermoactinomyces spp. as predominant isolates. Attempts using serologic techniques to determine if Acanthamoeba, Aureobasidium, Thermoactinomyces, and other microorganisms isolated for Building B were disease agents proved inconclusive. (17) Additional microbiological studies revealed that up to 1×10^8 bacteria/ml were present in flood waters reaching the office zone where illness occurred. Stagnant water containing microbial slimes was present in the drain pans of some AHUs.

The average concentration of respirable dust collected in this office zone with the 1.0 in (2.54 cm) cyclone was 25 $\mu g/m^3$. Total dust and CO_2 levels never exceeded 40 $\mu g/m^3$ [American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) recommended limit is 260 $\mu g/m^3$ over a 24 hr period] (18) and 400 ppm (Japanese and World Health organization recommended limits are 1000 ppm) (19), respectively. All tests for contaminant gases by colorimetric indicator tubes were negative. Air samples collected by charcoal tubes contained toluene, xylene, and a series of mostly branched alkanes in the C_{10}-C_{12} region, but only in trace amounts, and were log orders below applicable occupational threshold limits.

Because disease was related to working within 16.4 ft (5 m) of water leaks (17) and because the affected office was contaminated with a variety of microorganisms, some of which are known to cause HP-lung disease, (17,20) it was postulated that the affected persons experienced respiratory exposure to an unidentified microbial agent associated with flooding from the overhead cafeteria.

Only minimal levels of airborne fungi were recovered by sampling on March 16 and May 7, 1982. However, in both instances, aerobiological sampling was carried out at least one month after the office zone had been flooded, at a time when airborne levels of viable spores may have been dissipated or affected by such variables as temperature, humidity, clean-up activities in occupied spaces, and filtration by the HVAC system. In another office building where HP was shown to be caused by spores emanating from contaminated FCUs, (8) the time at which aerobiological sampling was carried out was shown to be critical in attempts to relate disease prevalence to airborne levels of microorganisms. Sampling conducted on the day that FCUs were operated in their heating mode showed that airborne fungal spore density was 50 to 80 fold above background levels; on the previous day when FCUs were quiescent, spores in occupied space were present only at background levels. (8) By analogy, aerobiological sampling in Building B might have been a more useful indicator of disease prevalence if it had been carried out during or within a few days after the floods of January 27 and April 1, 1982.

Clean-up measures recommended for the affected office zone in Building B included the following: (A) Structural changes in cafeteria plumbing should be made so that flooding in offices is prevented. (B) Discard damaged carpeting and ceiling tiles; clean the outside surfaces of pipes from which floods originated; clean all upholstered furniture, wall partitions, and office materials that need to be reused with a vacuum incorporating a HEPA filter. (C) Disinfect the floor with bleach and then refurnish and reoccupy the office.

After our investigation and during the clean-up of the affected office in the third week of May 1982, large amounts of dust were liberated when office partitions were handled. Illness reoccurred in previously ill individuals. Even though our analyses were unsuccessful in identifying the etiologic agent, it was probably present in office partitions in May. There are many potential reasons for the difficulty in identifying the specific disease agent, and these include: (A) The agent may be an organism other than the predominant ones that were isolated from the environmental samples. (B) The agent may not be viable and therefore was not cultured from bulk samples and was absent from the panel of antigens used in serologic studies. Disease may also have been caused by microbial toxins such as endotoxin. (C) The exact etiology of this disease may be demonstrable only by provocative challenge, which was not attempted in this study.

Building C. Respiratory illnesses were studied among office workers in a nine-story building located in a southern city. One employee on the seventh floor of the building had symptoms suggestive of HP. In August 1982 an industrial hygiene survey was carried out in this building to determine if there was an environmetal basis for these complaints.

Conditioned air is supplied to office areas by a HVAC system that contains five main AHUs. Each AHU supplies air to an adjacent pair of floors. The unit supplying the seventh floor also provides air to the floor below. FCUs located next to outside walls on all floors provide supplemental heating and cooling in occupied spaces. Air from occupied space enters the common return plenum on each floor through slots in light fixtures, moves through a large riser along with return air from three or more floors, and is subsequently transported to AHUs by return fans. Therefore, in Building C, it is possible that a contaminant from one AHU might enter additional AHUs because of the mixing of return air streams.

The back of each AHU is located next to an outside building wall. A variable amount of outside air enters AHUs directly through louvered intakes and dampers in these walls. Outside air is combined with return air in a mixing plenum, the mixed air stream passes through a roll filter (no ASHRAE atmospheric dust spot efficiency rating), (21) and then successively through cooling coils and an air supply fan. Cooled and dehumidified air (summer mode of operation) is transported through a system of ducts and into occupied space through slots found in the sides of some fluorescent light fixtures.

The cooling deck of the AHU serving the seventh floor lacked an adequate drain pan necessary for the collection and removal of condensed water. As a result, condensed water pooled to a depth of 2 in (5 cm) and stagnated on the deck of the plenum housing the cooling coils and the air supply fan. Several liters of microbial slime were found on the wetted surfaces of this AHU. Drain pans in FCUs found in the office occupied by the complainant were also coated with a thick layer of slime.

Water and slime samples from the AHU and FCU were analyzed for viable fungal and bacterial contents. For comparison purposes, similar analyses were carried out on water collected from an external source of microorganisms, namely a cooling tower on the roof of Building C. Condensate water from the AHU and from the reservoir of the cooling tower contained equivalent numbers of microorganisms (Table 3). However, slime from the AHU contained concentrations of bacteria and fungi several orders of magnitude greater than that characteristic of cooling tower water. Sludge from the drain pan of the FCU was also more heavily contaminated with microorganisms. Cooling towers are well known microbial incubators. (22) Since contamination within AHUs and FCUs is equal to or greater than that found within cooling towers, and because air flow within the HVAC system directly impacts upon microbially contaminated surfaces, it is likely that microorganisms are aerosolized directly into the conditioned air supplied to occupied space.

The number of people working on the sixth and seventh floor of Building C was 219. The total volume of conditioned air moving through the AHU serving these floors was 23200 CFU (11600 L/s). Of the total airflow, 6150 CFM (3075 L/s) was outside air. Assuming equivalent distribution of conditioned air to all sixth and seventh floor offices and perfect mixing in each room, each occupant on average was supplied with 28 CFM (14 L/s) of outdoor air, which exceeded the ASHRAE recommended value of 20 CFM (10 L/s) per occupant for buildings where cigarette smoking is permitted. (18) Additional air measurements were made in an office occupied by the complainant on the seventh floor. The office housed six employees (one case, five noncases) and was being provided with a total of 560 CFM (280 L/s) of conditioned air through slots around ceiling lighting fixtures. Assuming that 26% of the conditioned air being provided to the seventh floor is derived outdoors [23200 CFM (11600 L/s) total flow through AHU; 6150 CFM (3075 L/s) outdoor air; assume perfect mixing in AHU and in room], this office received 148 CFM (74 L/s) of outdoor air or approximately 24 CFM(12 L/s) outdoor air per occupant, again slightly above ASHRAE minimal recommendations. The health related complaint on the seventh floor was thus likely due to causes other than inadequate ventilation.

Tests for other air contaminants were negative. Levels of respirable dust collected [1.0 in (2.54 cm) cyclone] in the return air stream were always less than or equal to 50 $\mu g/m^3$. Contaminant gases were not detected by short-term indicator tubes. A thick layer of eroded and porous fibrous glass was found lining the inside structural surface of AHUs and the main air supply duct downstream from the fan. Microbial analysis of a dry sample of fibrous glass obtained from supply air ductwork indicated that approximately 200 viable fungi and bacteria were present in each g of insulation. Although airborne fibrous glass particles in occupied space were present in trace levels (<0.05 fibers/cc) far below the NIOSH recommended threshold of 3 fibers/cc, (12) it does appear likely that this deteriorating insulation harbors a large population of microorganisms that can be potentially aerosolized into occupied space.

The following were among the remedial recommendations made with regard to Building C. (A) Provide adequate drainage for condensed water under cooling coils. For drains originating in the vicinity of cooling coils, install deep sealed-water filled traps. (23) Trap depth should exceed the maximum suction pressure head created by the fan. (B) Clean and disinfect cooling coils and drain pans of AHUs and FCUs.

Building D. Following an outbreak of HP in the middle 1970s (4) this office building located in a southwestern city was vacated, and both its HVAC system and all furnishings in occupied spaces were replaced. In 1981, the building was reoccupied. NIOSH conducted follow-up environmental and epidemiological studies in this building.

Building D has 19 stories. The first 10 floors are occupied by offices. The open water spray system that was associated with the outbreak of HP in the middle 1970s was removed during building renovation. The new HVAC system contains 31 AHUs. Eleven of these units, one each on the basement through the 10th floor, provide conditioned air containing a variable amount of outside air mostly to central zones on each floor. The remaining 20 AHUs recirculate air in occupied spaces along exterior building walls.

Each central AHU contains a plenum wherein outdoor and return air are mixed, a roll filter without any rated atmospheric dust spot efficiency, a fan, and a bank of cooling and heating coils. Conditioned air leaving the central AHU is transported through ducts and delivered to occupied space on the same floor through ceiling diffusers. Air from occupied space enters the common plenum on each floor through grilles in the suspended ceiling. Return air moves either to peripheral AHUs for conditioning and recirculation to occupied space along peripheral floor zones or to the central AHU where return air is mixed with outdoor air prior to conditioning and transport back to central floor zones.

Stagnant water was found in drain pans located under cooling coils of both central and peripheral AHUs in Building D. A growth of microbial slime several mm thick was found on wetted surfaces of drain pans and cooling coils. The access door to the cooling deck of each AHU was so tiny (1/2 ft^2 or 460 cm^2) that preventive maintenance was impossible for both the cooling deck and drain pan.

Airflow measurements made in the third floor central AHU operating under summer cooling conditions (minimum outdoor air dampers open) showed that only 525 CFM (262 L/s) of outdoor air was being taken into this unit. The number of employees on this floor was 93, indicating that an average of about 6 CFM (3 L/s) outdoor air (30% of ASHRAE minimal recommended level for occupied space where cigarette smoking is permitted) (18) was being provided per occupant. Employees working in zones served by peripheral AHUs are likely provided with amounts of outdoor air below this average value. Additional environmental measurements showed that occupied space was free of contaminant gases and that total suspended particulate in indoor air was below 50 $\mu g/m^3$.

Since the newly installed AHUs in Building D are contaminated with microbial slimes, the potential exists for a renewed outbreak of HP. Possible problems with microbial contamination are increased because of inadequate dilution by outside air. We recommended the installation of adequately sized access doors to the cooling deck portion of AHUs to assure and facilitate a preventive maintenance program to remove slime and stagnant water. We suggested that the HVAC system be operated according to ASHRAE guidelines. (18) The amount of outdoor air taken in by central AHUs might have to exceed the ASHRAE minimum of 20 CFM (10 L/s) per occupant so as to compensate for inadequate outdoor air in zones served by peripheral AHUs.

Building E. NIOSH conducted a health hazard evaluation in an office complex (located in an eastern city) housing more than 2000 employees. Some employees of an agency that occupied the lower floors of this building reported symptoms ranging from eye, nose, and throat irritation to persistent cough, shortness of breath, and fatigue. The building, constructed in 1969, has had a history of persistent indoor environmental problems including floods from roof leaks and a relative humidity that often exceeds 70% during the summer air-conditioning season.

The central HVAC system of Building E contains seven main AHUs that supply 100% outdoor air to occupied space. Conditioned air moves through common supply plenums formed by the suspended ceiling and the slab of the floor above. Supply air enters occupied space through diffusers located in the suspended ceiling. Air within Building E is further conditioned and recirculated by over 350 small AHUs and more than 1000 peripheral FCUs. Each small AHU is located in an interior zone, and it provides recirculated and conditioned air (cooling only) to occupants in several rooms through a system of ducts. Peripheral FCUs are found in rooms along outside walls. These units condition (heat or cool) and recirculate air within occupied space. A more detailed description of the HVAC system of Building E is found elsewhere. (24) During several visits to this building it was observed that main AHUs were turned off for several hours during the working day.

Inspection of lower floors of Building E in January and September, 1983 revealed evidence of moisture incursion into occupied space such as wet ceiling tiles and wet masonry. Tiles in some offices were partially covered by colonies of sporulating fungi. During the air conditioning season (September, 1983) it was additionally observed that stagnant water and microbial slimes were present under cooling coils in some main AHUs and in some FCUs. Bacteria were present at a concentration of 1 x 10^7/ml in stagnant water found in one AHU. It could not be ascertained if microbial slime was present in drain pans of small AHUs because the cooling coil section of each unit was totally inaccessible (sealed in room walls) for maintenance purposes.

Filters present in most AHUs and FCUs were heavily laden with dust and debris. Dust from a filter in a small AHU (January 1983) contained approximately 3 x 10^7 viable fungi/g. More than 90% of the isolates were Penicillium spp. All small AHUs and FCUs in Building E were lined along some interior surfaces with a porous fibrous glass that was heavily encrusted with dust and debris. In some units fungal mycelia were found on insulation surfaces.

Sequential sampling for airborne fungi was carried out in an interior room where most of the conditioned air was provided by a small AHU. Air samples were collected on a table in the center of the room during various operating conditions including when the fan was turned on, when the ductwork was pounded, and when the filter was replaced (Table 4). A seven-fold increase in levels of airborne fungi was associated with simply turning on the unit's fan. Pounding of ductwork during fan operation additionally doubled the level of airborne fungi. Fungal levels in the conference room increased more than an order of magnitude when the unit's dirty filter was replaced and the ductwork was subsequently pounded.

Fungal levels present in the air of office rooms served primarily by FCUs were highly variable (Table 5). In one room with an inactive FCU the concentration of airborne fungi was only 165 CFU/m^3; a nearby room with a characteristic "barnyardlike" odor contained over 7000 fungal CFU/m^3. The drain pan of the FCU in the latter room contained stagnant water and a thick microbial slime. When the fan of this FCU was turned on and its outside metallic surface was agitated (similar to backing a chair into the unit) the level of airborne fungi became so high as to exceed the measuring capacity of the viable sampler (>94000 CFU/m^3).

The generic composition of airborne fungi isolated from selected rooms in Building E is given in Table 6. In the room with the contaminated FCU airborne Penicillium spp. accounted for more than 90% of isolates both with the unit off and on. In the conference room served by the small AHU Cladosporium spp. accounted for more than 80% of the isolates. In contrast, the outdoor air contained a more varied composition of flora. Although Cladosporium spp. accounted for almost half of the outdoor fungi, all air samples contained moderate numbers of Penicillium spp., Alternaria spp., and unidentified isolates.

It may be concluded that peripheral FCUs and small AHUs act as reservoirs for viable fungi in Building E. Because maintenance of mechanical systems in Building E is poor, events such as activating a FCU or AHU fan, changing filters, or even backing a chair into a peripheral FCU, may result in an elevated fungal level of up to 100X the outdoor concentrations. The problem of high levels of airborne fungi in the occupied space of this building is additionally exacerbated by inadequate outdoor air ventilation which makes dilution of viable aerosols less effective.

Recommendations for remedial action included the following: (A) Prevent moisture incursion into occupied space such as from drain pan overflows. (B) Replace filters from FCUs and AHUs routinely and frequently. Seal dirty filters in bags immediately after removal so as to prevent dissemination of spore clouds into occupied space. Replace dirty interior sound lining in these units. (C) Operate main AHUs during all times that the building is occupied.

DISCUSSION

A common feature of office buildings wherein outbreaks of HP or of similar illnesses have occurred may be moisture incursion into occupied space or into the HVAC system. Thus Buildings A, B, and E were characterized by a history of repeated floods. In addition, all HVAC systems contained AHUs with pools of stagnant water and deposits of microbial slimes. That moisture incursion can lead to elevated microbial levels that are associated with respiratory disease is evident in a residential case study of an individual with rhinitis. (25) Airborne sampling conducted subsequent to a roof leak revealed levels of viable fungi exceeding 5000 CFU/m^3. A level of only 260 CFU/m^3 was present before the flooding. (25) Since air is a ready source of microorganisms, and since substrate that supports microbial growth, such as paper, plasterboard, ceiling tiles, carpet, and organic dusts are commonly found in office buildings, prevention of moisture incursion into occupied space and within HVAC systems is probably the best means of preventing microbially induced respiratory disease.

There is no environmental criteria for deciding if a measured airborne level of fungi or bacteria is a risk factor with regard to HP or other respiratory disease. Any quantitative criteria must take into account the qualitative nature of the viable and nonviable etiologic agents thought to be responsible for these illnesses. Problems associated with quantitative microbial standards have been previously discussed. (26) For example, is air containing a total of 500 fungi/m^3 of which 20% are Penicillium spp. inherently safer than that with 1000 fungi/m^3 but with only 10% Penicillium spp.? Establishment of a quantitative standard is further complicated because nonviable spores (25) and microbial products (6) may cause illness and large doses of organic dust may be needed to produce sensitization whereas a subsequent response may be evoked by a small quantity of material. (20)

Nevertheless, several suggestions have been made concerning acceptable levels of airborne viable particulate. In 1948 a level of approximately 1775 bacteria-containing particles/m^3 was described as the threshold for clerical offices in need of investigation and improvement. (27) Levels of about 700 bacteria/m^3 were considered reasonable. In 1969 it was stated that total levels of microorganisms exceeding 1700/m^3 were seldom found in rooms. (28) During an outbreak of humidifier fever, levels of Flavobacterium spp. approximating 3000/m^3 were associated with the operation of a contaminated humidifier; this bacterium was absent from the air when the unit was turned off. (6) The threshold levels of Cladosporium spp. and Alternaria spp. spores for evoking allergic symptoms have been reported to be 3000 and 100 CFU/m^3, respectively. (29) Levels of fungi approximating 5000 to 10000 CFU/m^3 were associated with an outbreak of HP in a small office. (8) These literature citations collectively suggest that a level of viable microorganisms in excess of about 1×10^3 CFU/m^3 indicates that the indoor environment may be in need of investigation and improvement. However, this is not to say that the air is unsafe or hazardous. Illness in the workplace can only be determined by medical or epidemiological studies.

Numerous and sometimes unpredictable variables affect results of aerobiological sampling carried out in office buildings. Among these are the following:

1. Sampling must occur in close temporal relationship to the event that triggers illness. In Building A, illness was associated with the activation of a HVAC system containing stagnant water, but unfortunately sampling occurred 10 days after this event. In Building B, sampling occurred at least a month after the floods that were related to illness.

2. Respiratory diseases such as HP are caused by a wide variety of microorganisms or microbial products that may require special sampling instrumentation (25,30) and special collection media. (7)

3. Sampling may be affected by the variable contamination and variable operational parameters of HVAC system components including AHUs, FCUs (Tables 4 and 5), humidifiers(6), and water sprays.

4. Viable sampling indoors will be affected by the sedimentation rate of airborne particles, (31) the effect of HVAC filtration units, (31) and the infiltration of seasonally varying loads and types of microorganisms in the outdoor air. (32)

While the above discussion indicates that microbial sampling is complex and affected by numerous variables, it has been shown to be of significant value in establishing disease etiology when closely integrated with medical and epidemiological investigations. (6-8,25)

It was earlier suggested that airborne microbial levels greater than 1×10^3/m^3 may be indicative of an indoor environment in need of improvement. Our studies have shown that two additional quantitative parameters, namely, counts of microorganisms both in stagnant water and in dusts found in HVAC systems, may be helpful in deciding if the indoor environment of a building is in need of improvement. Slime and stagnant water found in AHUs and FCUs in Buildings C and E contained microbial loads ranging from 1×10^5 to 1×10^7/ml. By contrast the reservoir of well-maintained cooling towers is reported to contain only about 1×10^3 to 1×10^4 bacteria/ml. (33,34) While the microbial aerosols associated with cooling towers are generally found outside the building envelope, those aerosols that may arise from stagnant water and slimes within a HVAC system will likely be delivered directly to building occupants by the supply air stream. An additional parameter that may be useful in determining if the indoor environment is in need of improvement is the level of microorganisms present in dusts found in HVAC system components. Dust from filters of the type described in Table 4 contains about 3 x 10^7 fungi/g. By contrast, house dust contains about 2 x 10^5 fungi/g. (35,36) Although much further study is necessary, our preliminary conclusion is that a level of bacteria or fungi in excess of 1 x 10^5/ml in stagnant water or slime and levels of fungi in excess of 1 x 10^6/g in dust suggest that microbial contamination of HVAC system components is excessive.

According to ASHRAE Standard 62-1981, (18) "indoor air should not contain contaminants that exceed concentrations known to impair health and cause discomfort to occupants." Microorganisms are among the contaminants listed by ASHRAE as possible indoor air pollutants. Unfortunately there are no studies of dose/response relationships that describe the concentration of microorganisms that may impair health or cause occupant discomfort. ASHRAE Standard 62-1981 does address the problems of certain occupant generated contaminants such as cigarette smoke and CO_2 by recommending that conditioned air contain a minimum of 20 and 5 CFM (10 and 2.5 L/s) of outdoor air/occupant for smoking and non-smoking environments, respectively. It is well known that humans shed microorganisms and that the number of bacteria in indoor air can be related to the number or density of room occupants. (37,38) Furthermore, airborne bacterial levels have been inversely related to room ventilation rates. (39) Dilution ventilation of the type recommended by ASHRAE appears to be adequate to lower airborne levels of microorganisms generated by occupants, at least when sources are moderate. In a study in a San Francisco office building, the level of airborne bacteria was lowered from 179 to 105 CFU/m^3 when the supply of outdoor air per occupant was increased from 4-6 CFM (2-3 L/s) to 20-23 CFM (10-11.5 L/s). (40)

Not specifically addressed in ASHRAE 62-1981 is building-associated microbial contamination of the type described in our studies. This includes microorganisms found in HVAC system components such as water spray systems, humidifiers, AHU drain pans, and FCUs. Local exhaust ventilation as a remedial measure is impractical and the effects of increased dilution with outdoor air have not been studied.

CONCLUSION

Very little information is available on preventive and remedial measures that are effective in reducing building-associated microbial contamination. Future studies in this area are urgently needed. Listed below are some preventive measures which may be effective in reducing building-associated microbial contamination and building-associated HP illnesses. As such, it would be prudent for building engineers and managers to incorporate at least some of the following into their preventive maintenance programs.

1. Repair all external and internal leaks promptly and permanently.

2. Stagnant water should not be allowed to accumulate under cooling coils in any type of AHU. Proper inclination and continuous drainage of drain pans is required. Cooling coils should be run at a low enough temperature so that adequate dehumidification can result to keep space relative humidities at proper levels and so that spores and substrate impacted on coils may be washed away in condensate water. AHUs components should be inspected for the presence of slime and stagnant water. AHUs must be constructed or modified so that maintenance personnel have easy and direct access to the heat exchange components as well as to drain pans. If contamination with microbial slime is found, it must be removed. Mechanical or detergent cleaning may be necessary to remove slime before using microbiocidal chemicals. Steam lancing can be used to remove slime providing that the treatment does not damage heat exchange surfaces. (41) Chlorine generating slimicides and proprietary biocides may be used for disinfection provided that these chemicals are removed before AHUs are reactivated. (41) Aerosolization of microbiocidal chemicals into occupied space must never occur.

3. Humidifiers in HVAC systems should preferentially use steam as a moisture source. Raw steam from the plant boiler system generally contains corrosion inhibitors that are meant to carry over into condensate return lines. For humidifiers, avoid steam sources that contain volatile amines. It may be more desirable to use a small separate steam generator for humidification purposes. Also in many instances large boilers are not operable year around. Humidifiers utilizing recirculated water are not recommended, as these almost always become rapidly contaminated with organic dusts and microorganisms. (42) The addition of biocides to this type of humidifier has been ineffective in controlling microbial contamination. (5,43) If cold water type humidifiers are used, water should originate from a potable source and water should be run to a drain (7) instead of being recirculated. Cold water humidifiers should also be subject to a fastidious preventive maintenance program (42,44) involving regular inspection, cleaning, and disinfection as outlined in part two. The use of portable cold mist vaporizers is discouraged, since these devices are known to readily contaminate air with microorganisms. (45)

4. The use of water sprays as components of office building HVAC systems should be eliminated as these units have been associated with several outbreaks of HP (Table 1). (2,4) If water sprays are to be utilized, a very rigorous preventive maintenance program of the type described elsewhere (30,46) must be employed to control microbial contamination. Water spray systems that are utilized in AHUs to enhance heat exchange capacity of coils must be subject to a preventive maintenance program as described in part 2. Migration of water/microbial aerosols from water spray systems into ductwork and occupied space must be prevented.

5. Relative humidity in occupied spaces should not exceed 70%. As relative humidity rises above this level, the increased moisture content of organic substances encourages fungal spore germination and proliferation. (35,47) This recommendation is contrary to generally accepted energy management techniques wherein occupied space relative humidities can exceed 70% during the cooling months. Relative humidity can be lowered either by reducing the moisture content or raising the temperature of the air. Cooling coils of AHUs must be run at a low enough temperature to dehumidify conditioned air. In buildings using economizer systems, where relative humidity is sometimes excessive, outdoor air may require dehumidification. The sensible heat (dry-bulb temperature) of the outdoor air may be suitable, but the total enthalpy may be unacceptable. Reheat coils may have to be utilized to raise the temperature of dehumidifed supply air, as the dry-bulb temperature of this air may be too low due to the prior necessary dehumidification process.

6. Filters used in AHUs should have a moderate (50% to 70%) efficiency as measured by the ASHRAE atmospheric dust spot test (21,48) and in general should be the extended surface type. To prolong the life of these filters and to improve cost effectiveness, prefilters (such as roll type) should be used to clean the air prior to passage over the higher efficiency filters. Filters of this efficiency will remove spores as well as organic dusts that support microbial growth. Electronic air cleaners have also been reported to be effective in removing microorganisms from the airstream, (49,50) but first cost and maintenance may prohibit their use. Care also must be exercised to insure that these air cleaners do not liberate ozone into the airstream. The location of filters in the HVAC system is important. In most AHUs, filters are located upstream of the heat exchange components so as to protect the heat exchange capacity of these surfaces. Building occupants will not be entirely protected by these conventionall located filters if microbial contamination occurs downstream (e.g., slime in cooling coil drain pan). Therefore, it is sometimes necessary to provide filtration downstream from heat exchange components to achieve suitable protection. Because dirty filters in AHUs are sources of microorganisms (Table 4) (8) a preventive maintenance program must exist by which filters are inspected and replaced at regular intervals.

7. Microbial aerosols from cooling tower drift, sanitary, and other exhaust vents may enter improperly located outdoor air intakes. Remedial action may include

relocation of the vents or increasing their heights appropriately, relocation of outdoor air intakes, or upgrading AHU filter efficiency. A preventive maintenance program to inhibit slime build-up in cooling towers is essential. (42,51,52) Outdoor microbial aerosols may also enter buildings through idle exhaust ducts and miscellaneous stacks and vents. (53) For this reason, the building should be operated so that inside pressure is slightly positive (0.02 to 0.03 in or 5 to 8 mm water gauge) (54) with respect to the outdoors.

8. In buildings or zones of buildings where carpet, upholstery, ceiling tiles, and other porous furnishings are contaminated with microbial material, it is better to discard these items rather than to attempt disinfection (Building B). (25) However, if the extent of microbial contamination is unknown or uncertain, disinfection may be attempted using a vacuum cleaner with a HEPA filter. Since it is almost impossible to clean contaminated suspended ceiling-return air plenums, (38) these may have to be bypassed by installation of return air ductwork. A special maintenance program may be needed to clean FCUs. This should include the removal of debris from beneath and within units (55) and replacement of dirty insulation along inside surfaces. During building clean-up, microbially laden materials (e.g., carpets, sound lining, filters, etc.) should be carefully removed so as to minimize aerosolization of inhalable particulate. Personnel assigned to clean-up operations should, at a minimum, wear respirators with high efficiency particulate filter media. Structural and other building surfaces should be vacuumed with an instrument incorporating a HEPA filter and then disinfected with bleach or proprietary biocide.

9. At a minimum, outdoor air should be provided in conditioned air at a rate of 20 and 5 CFM (10 and 2.5 L/s) per occupant for smoking and non-smoking environments, respectively. (18) Higher levels of outdoor air intake may be required to effectively dilute microbial aerosols associated with contaminated buildings.

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TABLE 1
Sources of Microbial Contamination, Disease Agents, and Remedial Actions Associated with Past Outbreaks of HP or Allergenic Respiratory Disease

Author	No. Persons Ill/ Total Exposed	Source of Building Contamination	Etiologic Agent	Remedial Action
Weiss a Soleymani (1)	case report	dust in HVAC system duct-work; water spray unit	thermophilic actinomycetes	Tried unsuccess-fully to clean occupied space; removed water spray unit
Banaszak et al. (2)	4/27	HVAC system water spray	thermophilic actinomycetes	Removed water sprays; steam clean HVAC system
Scully et al. (3)	1/40	Water in HVAC system ductwork	thermophilic actinomycetes	Clean ductwork
Arnow et al. (4)	48/4023	HVAC system water spray	unknown	HVAC system replaced; All furnishings in occupied space replaced.
Ganier et al. (5)	26/50	Stagnant water in humidifier	unknown	Tried unsucces-fully to decon-taminate humidifier with fungicide; Removed humidifier from HVAC system.
Rylander et al. (6)	3/7	Aerosol from humidifier reservoir	*Flavobacterium* spp. or their endotoxins	Unknown
Edwards (7)	20/50	Microbial slime in humidifier	nonpathogenic amoebae	Filter air entering humidi-fier; Water in humidifier run to waste; Replaced furnishings in occupied spaces.
Bernstein et al. (8)	2/14	Contami-nated fan coil units	*Penicillium*	Clean fan coil units; Replace filters.

TABLE 2

Microorganisms Found in Slimes in HVAC System of Building A

Bacteria:	*Bacillus* spp.[a] (including 55°C thermophiles)
	Flavobacterium spp.[a]
	Pseudomonas spp.
	55°C *Actinomycetes*[a]
Fungi:	*Penicillium* spp.[a]
	Cladosporium spp.
	Cephalosporium spp.[a]
	Aspergillus spp.[a]
	Trichoderma spp.
	Mucor spp.
	Ostracoderma spp.
	Rhodotorula spp.
	Cryptococcus spp.
	Fusarium spp.
	Harposporium spp.
Protozoa:	*Acanthamoeba* spp.[a]
	Vorticella spp.
Nematodes:	*Rhabditis* spp.

[a]Organisms that have been implicated as etiologic agents in previous outbreaks of HP or humidifier fever.

TABLE 3

Fungi and Bacteria in Samples from the HVAC System and the Cooling Tower of Building C

Sample Description	Fungi/ml	Fungi/g	Bacteria/ml	Bacteria/g
Slime from AHU	2.0×10^5	-	7.4×10^7	-
Condensate Water From AHU	1.3×10^2	-	1.2×10^5	-
Water From Cooling Tower	3.5×10^2	-	1.3×10^5	-
Moist Sludge From Drain Pan of Fan Coil Unit	-	1.1×10^6	-	6.1×10^6

TABLE 4

Sequential Levels of Airborne Fungi in Conference Room in Building E Where Conditioned Air is Provided by a Small AHU

Temporal Sequence of Measurement	Operation of AHU[a]	CFU/m^3 [b]
1	Unit off	240
2	Fan on during sampling	1650
3	Pound ductwork before sampling; fan on during sampling	1810
4	Ductwork pounded and fan on during sampling	3450
5	Filter replaced before sampling[c]; Ductwork pounded and fan on during sampling	62000
6	Pound filter during sampling; fan on	70000

[a]Unit turned off between sequential sampling.
[b]Level of fungi in outdoor air = 800 CFU/m^3.
[c]Filter removed from unit two hours before sampling sequence initiated. Filter was heavily laden with dust and debris.

TABLE 5

Levels of Airborne Fungi in Office in Building E in Which Conditioned Air is Provided by a Perimeter Fan Coil Unit

Room and Description of Fan Coil Unit	CFU/m^3 [a]
Room #1; had been occupied by complainant; unit off; stagnant water in drain pan	7360
Room #1; had been occupied by complainant; unit on and agitated; stagnant water in drain pan	>94000
Room #2; individual previously housed in room α1 now occupies this office without apparent complaint; unit off; no stagnant water in drain pan	165

[a]Level of fungi in outdoor air = 800 CFU/m^3.

TABLE 6

Generic Composition of Fungi in Building E and Outdoors[a,b]

Location	Penicillium	Cladosporium	Alternaria	Aspergillus	Other
Conference room; sequence 5 and 6 of Table 4	13.6	80.6	0	0.4	5.4
Room #1 Table 5; unit off	>99	<0.1	0	<0.5	<0.1
Room #1 Table 5; unit on	97.7	2.0	0	0	0.3
Outdoor air	12.5	48.6	12.5	0.7	25.7

[a]% of Total airborne isolates in each location.
[b]Sampling and identification were carried out in September 1983.

Discussion

R. HERMANS, University of Minnesota, Minneapolis, MN: Are there any studies of low-level microbial contamination immuno-suppressed patients?

MOREY: The studies which I have described all took place in large commercial office buildings. We have not studied airborne microbial contamination in rooms housing immuno-suppressed patients in hospitals. Because of the susceptible nature of the latter population I suspect that airborne microbial contamination levels in these hospital zones would be much lower than that characteristic of offices.

C. HILLER, EPRI, Palo Alto, CA: Is there evidence that a drying out of the "slime" areas is sufficient to kill off the variou microorganisms, or would they just go dormant, laying in wait for more humid conditions to return?

MOREY: Some bacterial and fungal spores are very resistant to desiccation and would germinate when wet or more humid conditions return. It should also be recognized that dead microorganisms (spores) or components of microorganisms (bacterial endotoxins) can cause allergic reactions among susceptible individuals. If dead spores or endotoxins are aerosolized within ventilation systems when conditions are dry, there could thus be problems for susceptible individuals.

D. J. MOSCHANDREAS, IIT Research Institute, Chicago, IL: How frequently should HVAC be maintained, checked for maintenance?

MOREY: Filters should be changed at intervals recommended by manufacturers. Drain pans should probably be checked for stagnant water and slime at least once per month. The problem with the five buildings described in this paper is that there is little or zero attention given to preventive maintenance.

G.H. GREEN, University of Saskatchewan, Saskatchewan, Canada: Your investigations all covered buildings located in southern or eastern high-humidity areas. Do you know of any problem buildings in the northern or dry regions?

MOREY: I myself have conducted no studies in northern or dry regions. There are reports in the literature describing outbreaks of hypersensitivity pneumonitis in buildings in the southwestern United States where air-conditioning was carried out by evaporative or "swamp" coolers. While high humidity in the southeastern United States probably does encourage fungal growth indoors, the extent and nature of the moisture in the ventilation system is likely of greater importance.

GREEN: Your investigations were done in six buildings. How many had carpets?

MOREY: All buildings were for the most part carpeted.

L. HARRIMAN, Cargocaire Engineering, Amesbury, MA: Since R/H downstream of coils is always 90% or more, that is apparently not a problem until the actual space is above 70%.

MOREY: Fungal spores can germinate when the equilibrium moisture content of dusts and debris reaches about 12% and this occurs when the relative humidity in a room exceeds 70%. The dirt and debris embedded in porous insulation lining the inner surfaces of fan coil units and air handling units offers an excellent niche for microbial proliferation when the humidity is 90% or better.

W. F. SPIEGEL, Walter F. Spiegel, Inc., Jenkintown, PA: Would a GP physician be able to provide a pertinent medical opinion on whether an illness is related to a moldy air-conditioning system? If not, what specialty should the physician have?

MOREY: My opinion is that most GP physicians would not recognize the problem. One would have to consult with a physician specializing in occupational medicine or internal medicine. Preferably the specialist would have some background in epidemiology and indoor air quality issues.

SPIEGEL: Are you aware of any phenomenon of local surrounding vegetation that would cause mold or slime in air-conditioning systems?

MOREY: I am aware of one study carried out at the University of California in Los Angeles which showed that pollen from an olive species entered the ventilation system of a building and caused allergic reactions among occupants. Other studies have shown that the presence of dead vegetation (e.g., leaves) at or near the outdoor air intake of a building can lead to contamination of a building by fungal spores.