HETA 97-0068-2690
Point Pleasant High School
Point Pleasant, West Virginia

Daniel J. Hewett, CIH

PREFACE

The Respiratory Disease Hazard Evaluations and Technical Assistance Program (RDHETAP) of the National Institute for Occupational Safety and Health (NIOSH) conducts field investigations of possible health hazards in the workplace. These investigations are conducted under the authority of Section 20(a)(6) of the Occupational Safety and Health Act of 1970, 29 U.S.C. 669(a)(6) which authorizes the Secretary of Health and Human Services, following a written request from any employer or authorized representative of employees, to determine whether any substance normally found in the place of employment has potentially toxic effects in such concentrations as used or found.

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ACKNOWLEDGMENTS AND AVAILABILITY OF REPORT

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Health Hazard Evaluation Report 97-0068-2690
Point Pleasant High School
Point Pleasant, West Virginia
May 1998

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SUMMARY

In April 1997, the National Institute for Occupational Safety and Health (NIOSH) received a request from employees of Point Pleasant High School (PPHS) for a health hazard evaluation at PPHS. The requestors asked NIOSH to evaluate the indoor environment, specifically employees' exposures to gases produced during the operation of gas-fired furnaces. PPHS employees reported headache, sinus problems, upper respiratory problems, dizziness, tiredness, and burning, itchy eyes which they associated with exposures to the PPHS indoor environment.

From May 28 to 30, 1997, NIOSH investigators performed a walk-through inspection of the school, which included a physical inspection of the building and the heating, ventilating, and air conditioning (HVAC) systems in the gymnasium, in certain classrooms, and in the basement and crawl space below the ground floor. A symptom survey was made available to employees to determine symptoms experienced while at PPHS.

No visible evidence of significant microbial contamination was observed. Outdoor air filters fit poorly, and supply and return airways had accumulated a significant amount of dust and other debris from poor filtration over a period of several years. The gymnasium air handler and ventilation ducts were heavily contaminated with dust; this HVAC system had not been fitted with filters since its commissioning. All HVAC systems had been operating for an undetermined period with outdoor air dampers nearly 100% closed. Many perimeter air handlers were very noisy during operation; these units were often turned off by employees who have trouble communicating with students while the units are in operation.

Thirty-five of approximately 49 employees returned the symptom surveys to NIOSH investigators. Employee interviews and surveys mentioned dissatisfaction with excessive surface dust, temperature variations, odors and noise associated with the HVAC systems, and with inoperation of perimeter air handler fans. Employees reported headache, unusual fatigue, ear/nose/throat irritation or burning, chest tightness, wheezing, chest colds and illnesses, body ache, shortness of breath, chills and/or fever, chronic phlegm, chronic cough, feeling faint, lightheaded, sleepiness, sneezing, nosebleeds, and eye irritation associated with their occupancy of PPHS.

From July 21 to 25, 1997, NIOSH investigators returned to PPHS to obtain area air samples of volatile organic compounds (VOCs) produced by furnace operation. Area air samples and HVAC duct bulk dust samples were collected to quantify microbial contaminants.

During the two week period following July 28, 1997, a contractor cleaned the central air handler components; supply and return ducts, grills, registers, plenums, fans, and fan rooms. Cleaning included removal of dirt by vacuuming and brushing. Main supply fans were painted.

On December 17, 1997, a NIOSH investigator returned to the school to measure carbon dioxide (CO_2), carbon monoxide (CO), temperature, and percent relative humidity (%RH) while the main building and two small detached classroom buildings housed approximately 500 students and employees. Air flow measurements were performed to approximate the volume of outdoor air entering the building through perimeter air handlers. In the main building, mean CO_2 concentrations ranged from 700 to 2200 parts per million (ppm), compared to outdoor measurements of 300 to 400 ppm. Indoor temperatures ranged from 70 to 81 degrees Fahrenheit (°F); the outdoor range was 44 to 64°F. Relative humidity ranged from 16 to 33%; the outdoor range was 18 to 38%. In the detached classrooms, CO_2 concentrations ranged from 600 to 3800 ppm, temperatures ranged from 60 to 67°F, and relative humidity ranged from 25 to 55%. No CO was detected in any area.

On the basis of the data obtained during this investigation, it is unlikely that the concentrations of chemical compounds emitted by the furnaces are a significant health threat to building occupants. Odors detected during furnace firing are likely to be related to increased ambient air concentrations of acetone, propane, propene, and isopropanol and lesser concentrations of ethanol, methanol, and isobutane. It is likely that the odor of these chemicals has triggered symptoms in certain individuals. NIOSH investigators did not find clear evidence that employee symptoms were caused by microbial contaminants. There were no environmental conditions measured in the complaint area that indicated that a unique and hazardous environment exists in that area when compared to the non-complaint area. No humidity control, poor temperature control, and an inadequate volume and/or distribution of outdoor air were measured during December 17, 1997.

Recommendations are made to correct temperature, humidity, and outdoor air control problems which should result in reduced employee complaints.

Keywords: SIC 8211 (Elementary and secondary schools), indoor environmental quality, IEQ, thermal comfort, carbon dioxide, microbial contamination, fungi, bacteria, thermoactinomycetes, ventilation.

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INTRODUCTION

In April 1997, the National Institute for Occupational Safety and Health (NIOSH) received a request from employees of Point Pleasant High School (PPHS) at Point Pleasant, West Virginia. PPHS provides secondary education, continuing education during evening hours, and hosts athletic events.

The request was initiated by reports of headache, sinus problems, upper respiratory problems, dizziness, tiredness, and burning, itchy eyes among employees. The employees associated symptoms with the indoor environment; specifically employees' exposures to gases produced during the operation of gas-fired furnaces. The indoor environment at PPHS was associated with symptoms because employees reported that their symptoms lessen or resolve when they leave the building. Employees were also concerned with perimeter air handlers which are very noisy during operation; these units were often turned off by employees who have trouble communicating with students while the units are in operation. In addition, employees reported discomfort due to high temperatures and low relative humidity.

In response to this request, NIOSH investigators performed an inspection of the school from May 28 to 30, 1997. The building heating, ventilating, and air conditioning (HVAC) systems in the gymnasium, in certain classrooms, and in the basement and crawl space below the ground floor were inspected. In addition, products in use at the school were reviewed, and symptom surveys were made available to employees.

From July 21 to 25, 1997, NIOSH investigators returned to PPHS to perform area air sampling for volatile organic compounds (VOCs) produced by furnace operation. Area air and duct bulk dust samples were collected to quantify microbial contaminants.

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BACKGROUND

Constructed in 1963, Point Pleasant High School (PPHS) is a single-story, steel, masonry and wood frame building located in a residential area. According to school staff, approximately 1100 individuals may occupy the building throughout the day. The school is occupied by approximately 500 individuals from 7:30 a.m. to 3:30 p.m. Forty-nine of this number are adult employees. Up to 600 additional individuals may occupy the building for continuing education classes or athletic activities until approximately 10:00 p.m. The building is divided into four ground floor "wings" (Figure 1, not to scale) and a basement area which houses an air handler, four natural gas furnaces, and a utility room. Classroom, kitchen, gymnasium, administrative, and library areas are located on the ground floor. Two detached wood frame buildings (51 and 52, see Figure 1) serve as classrooms.

HVAC System Overview

The school contains two main air handlers; a basement air handler with heating and cooling capacity that services Sections A, B, and D, and a gymnasium air handler with heating capacity that services the gym in Section C (see Figure 1). A total of 32 fan-driven perimeter air handlers are installed in the outside walls of classrooms. A few induction units are installed in hallways and in some offices. Two rooftop package-type (heating and cooling) units ventilate the band rooms (Rooms 49 and 50) in Section C of the building. No humidifiers or dehumdifiers are installed in any of the air handlers. No commissioning blueprints exist for any of the HVAC systems. There are no maintenance logs, and no records of fan capacities and design air flows.

The basement air handler is a single fan, constant volume unit operated at full heating or full cooling. Four gas-fired furnaces heat supply air as the air travels over furnace manifolds. In December 1996, repairs to the furnaces were conducted to ensure that the furnaces were operating properly. During the cooling season, a damper blocks the manifolds from the supply air path and redirects airflow over two sets of cooling coils. These cooling coils and a four unit chiller were installed during the 1994 to 1995 school year.

Outdoor air enters the basement air handler at grade level. The intake is positioned above an outdoor stairwell which leads to the basement. Outdoor air flows past a bird/insect screen, through a set of dampers, and through a bank of filters before entering the fan room. The basement air handler was fitted with filters in 1995 after operating for several years without filters. Outdoor air is mixed with return air in the fan room before it enters the fan as supply air. Supply air is heated or cooled before it travels through unlined ducts to perimeter air handlers and induction units. Cooling coils and return air filters were added from 1994 to 1995. Three main supply ducts lead to Sections A, B, D, and the offices. The ducts are positioned inside concrete-lined crawl spaces that run underneath the school floor.

Smaller supply ducts branch off the three main supply ducts. These smaller ducts run under the floor of the school in concrete block-lined tunnels which branch from the crawl spaces. Supply ducts inside the tunnels are attached to the base of classroom perimeter air handlers and induction units. Supply air entering the perimeter air handlers can be mixed with outdoor air; each is equipped with an outdoor air supply duct which opens to the outside through the perimeter wall of the main building. Supply air and outdoor air volume may be adjusted by the position of dampers within the perimeter air handlers. Damper positions are controlled by wall thermostats. After mixing, supply and outdoor air is filtered by a flat panel foam filter with an estimated efficiency of 10%. The perimeter air handlers in classrooms were fitted with foam filters in 1991. After filtration, centrifugal fans in perimeter air handlers help distribute supply air into the occupied areas. Induction units found in all hallways and some offices do not contain fans. None of the perimeter air handlers or induction units are equipped with cooling or heating coils. Air returns to the basement air handler from classrooms and hallways through a grill at the base of the perimeter air handlers and induction units. A short length of duct at the base of these units directs return air into the tunnels and crawl spaces that house the supply air ducts. Return air flows to a return air chamber in the basement, where it is filtered before it re-enters the fan room, where it is mixed again with outdoor air and recycled to occupied areas. Four rooftop exhaust ducts were identified; the path of airflow to these ducts could not be confirmed.

Basement air handler return and outdoor air filters are extended-surface panel-type fibrous glass/ rock wool filters with an estimated dust spot efficiency of up to 40%. These filters have lower to medium capture efficiency for particulate under 3 µm in diameter. Therefore, they exhibit higher efficiency for spores and pollens greater than 10 µm.

Outdoor air enters the gymnasium air handler at grade level adjacent to a detached building (Classroom 51). Outdoor air flows past a bird screen and set of dampers before entering the gymnasium air handler fans. Outdoor air is not filtered. The gymnasium air handler had not been fitted with filters until the time of the NIOSH investigation. Return air is mixed with outdoor air in the fan room before entering two constant volume centrifugal fans. Supply air from the fans is heated by one gas-fired furnace as the air travels over furnace manifolds. Supply air then travels via unlined, in-roof ducts to gymnasium and locker areas. Ducted return air enters a concrete block ceiling plenum before re-entering the fan room, where it is mixed with outdoor air and recycled to occupied areas. No exhaust duct was identified.

Each detached classroom (Buildings 51 and 52) contains two in-wall electric heating and cooling units similar in appearance to window air conditioners. No outdoor air louvers were identified on the control panels of the units.

HVAC Maintenance and System Repairs

A contractor is primarily responsible for monitoring and changing system settings for the basement air handler. Settings are changed remotely from Columbus, Ohio, via a modem connected to a proprietary control system. The contractor added a return air filter bank, return air dampers, and outdoor air filters in 1995; before that time the basement air handler had been operated without filters. From about 1994 to 1995, the contractor added cooling coils to the basement air handler supply air duct, and a four-unit chiller was installed outside the building. In December 1996, the contractor initiated inspections and repairs to the four furnaces in the basement and completed work in January 1997.

According to one Mason County maintenance employee, inspections of the PPHS HVAC systems are not regularly scheduled and no maintenance records are available. Mason County employees maintain the mechanical components of the HVAC systems and change the basement air handler filters once per month. Other maintenance is provided on an as-needed basis if a problem with a system is recognized.

According to a maintenance employee, the perimeter air handlers had been operated without filters until about 1991, when county employees began to construct filter holders and installed washable foam filters. These filters are not washed on a regular basis. In 1995, the perimeter air handlers were vacuumed and some units were fitted with new motors. In July 1997, a contractor cleaned the basement air handler and gymnasium air handler ventilation systems by loosening and removing lint and dirt by vacuum and brush. Main air handler fans were painted and cooling coils were cleaned.

METHODS

Symptom surveys were distributed to employees on May 29, 1997. In addition, personal interviews of employees were conducted by the NIOSH project officer. An announcement was made over the public address system to notify building occupants that the surveys were available to employees. Employees picked up and returned the surveys at the administrative office.

Microbial contamination was considered as a possible cause for occupant symptoms. Since the HVAC systems were excessively dusty due to a lack of filtration over a period of many years, the investigators decided to perform bioaerosol sampling to identify any potential source of microbial contamination that could plausibly explain certain respiratory complaints among employees.

The environmental evaluation of July 21 - 25, 1997, was conducted outdoors and at various indoor locations. Respiratory complaint and non-complaint areas were established for the purpose of comparing environmental measurements between locations. If environmental data are significantly different between these locations, the differences may help identify a unique or hazardous environment in the complaint area that could help explain respiratory symptoms. Indoor locations were evaluated with symptom survey data to identify an area where no respiratory complaints were reported. The area identified was Room 106. Complaints in Room 106 centered on perimeter air handler fan noise, characterization of the air as "stale," and the observation that students were often "tired." Based on symptom survey data, Room 71 was identified as an area with respiratory complaints. Therefore, Room 71 was identified as a respiratory complaint area (shortened to "complaint" area) and Room 106 was identified as a non-respiratory complaint area (shortened to "non-compliant area"). Both the complaint and non-complaint areas are serviced by the basement air handler.

Other indoor sampling locations included the center of the gymnasium, and air handlers in the basement, gymnasium, and in Room 71. The building was mostly unoccupied during the evaluation. Building occupants were limited to four investigators from NIOSH, a maintenance crew, and one or two staff (about 16 people).

Non-aggressive (quiescent) sampling was performed on July 22 and 23, 1997. Quiescent sampling is performed without purposely disturbing surface or bulk dusts. Aggressive sampling, which is in an attempt to aerosolize and collect viable and non-viable microbial particulate, was performed on July 24, 1997. Aggressive sampling was performed while dusty filters were removed from the basement air handler return air filter bank and new filters were installed.

On July 22 and 24, 1997, viable bioaerosol samples were collected at complaint and non-complaint locations and outdoors during morning (9:00 - 10:00 a.m.) and afternoon (1:30 - 2:30 p.m.) periods. All microbiological samples were sealed and refrigerated immediately after collection, during shipment, and prior to analysis. Anderson single-stage N6 viable 400-hole impactors with a true 50 percent cutoff diameter of 0.65 microns were used to collect airborne fungi and thermophilic actinomycetes onto agar. The N6 was operated at a calibrated flow rate of 28.3 lpm. Samples were collected as side-by-side duplicates for one minute on July 22, 1997, and for three minutes on July 24, 1997. Tryptic Soy Agar (TSA) was used for enumeration of thermophilic actinomycetes, DG18 agar was used for xerophilic (grow in low moisture conditions) fungi, and Malt Extract Agar (MEA) was used for mesophilic fungi. Agar plates were incubated at 25 °C for fungi and 55 °C for thermophilic actinomycetes. Fungi were identified and enumerated.

On July 22 and 24, airborne spore samples were collected in the complaint area, non-complaint area, and outdoors. Samples were collected on July 22, 1997, for 100 minutes, and on July 24, 1997, for 71 minutes. Samples were collected using open-face short-cowled cassettes with 25 millimeter (mm) polyvinyl chloride (PVC) 0.8 micrometer (µm) pore filters at a calibrated flow rate of 28.3 lpm. Filters were cleared and fungal spores were characterized and enumerated.

Duplicate bulk dust samples were collected on July 23, 1997, for viable fungi characterization and enumeration. Bulks were collected onto ethylene oxide (EtO) sterilized 37 mm 0.8 µm pore PVC filters at a flow rate of 4.0 lpm until approximately a half teaspoon of material was collected on the filter. Samples were collected from the interior surfaces of the return duct inside the complaint area and the interior of the supply duct leading from the basement air handler (adjacent to and downstream from the cooling coils). Bulk dust was cultured onto Cornmeal Agar (CMA) and MEA for the enumeration of mesophilic fungi, and MEA and DG18 for enumeration of xerophilic fungi. Agar plates were incubated at 25 °C. Fungi were identified and enumerated.

Qualitative airborne particle concentrations were acquired in complaint and non-complaint areas by use of a portable DUSTTRAK™ Model 8520 Aerosol Monitor laser photometer with a particle size resolution of 0.1 to 10 µm. Particles were counted on July 22, 23, and 24, 1997, for two rounds beginning at approximately 9:45 a.m. and 2:00 p.m. for a period of 30 minutes. The purpose of this monitoring was to establish that both the complaint and non-complaint areas were sampled under conditions of similar dust loading.

Since the operation of the furnaces was identified by some occupants as a source of indoor air contamination, the environmental evaluation included disabling the chillers and firing the four natural gas furnaces on July 24, 1997, from approximately 9:30 a.m. to 3:00 p.m. Furnace operation coincided with the collection of volatile organic compounds (VOCs). Air samples were collected through thermal desorption tubes at a calibrated flow rate of 0.2 liters per minute (lpm). Samples were collected for approximately 30 minutes next to the furnace makeup air duct, inside the basement air handler next to the fan, in the gymnasium, and complaint/non-complaint areas on July 23 and 24, 1997. Samples were analyzed by gas chromatography and individual chemical compounds were identified.

On December 17, 1997, airflow and environmental measurements (CO_2 and CO concentrations, temperature, and %RH) were collected at several locations for two rounds beginning at approximately 9:30 a.m. and at 1:30 p.m. Carbon dioxide and CO were measured using a RKI Eagle gas monitor (RKI Instruments, Inc., Hayward, California). This portable, battery-operated instrument uses a non-dispersive infrared absorption detector to measure CO_2 in the range of 0 to 10,000 ppm and CO in the range of 0 to 500 ppm. Instrument zeroing and calibration were performed prior to and after use with zero air and a known concentration (2000 ppm CO_2, 50 ppm CO) span gas. Approximately 500 students and employees occupied the main building and an average of 23 students occupied each of two detached classrooms (51 and 52) which are adjacent to the main building. Chemical smoke was used to visualize air flow. Air flow measurements were performed to approximate the volume of outdoor air entering the main building through perimeter air handler outdoor air intakes. Flow measurements were obtained with an Alnor Model 50 electronic balometer with a range of 50 to 2000 cubic feet per minute (cfm) and an Airflow TA-2 thermal anemometer with a range of 0 to 6000 feet per minute (fpm).

EVALUATION CRITERIA

A number of published studies have reported a high prevalence of symptoms among occupants of office buildings.[1,2,3,4] NIOSH investigators have completed over 1200 investigations of the indoor environment in a wide variety of settings since 1971. However, the great majority of these investigations have been conducted since 1979.

Scientists investigating indoor environmental problems believe that there are multiple factors contributing to building-related occupant complaints.[5,6] Among these factors are imprecisely defined characteristics of HVAC systems, cumulative effects of exposure to low concentrations of multiple chemical pollutants, odors, elevated concentrations of particulate matter, microbiological contamination, and physical factors such as thermal comfort, lighting, and noise.[4,5,6,7,7] Reports are not conclusive as to whether increases of outdoor air above currently recommended amounts are beneficial.[8] However, rates lower than recommended amounts appear to increase the rates of complaints and symptoms in some studies.[9] Design, maintenance, and operation of HVAC systems are critical to their proper functioning and provision of healthy and thermally comfortable indoor environments. Indoor environmental pollutants can arise from either indoor or outdoor sources.[10]

There are also reports describing results which show that occupant perceptions of the indoor environment are more closely related to the occurrence of symptoms than the measurement of any indoor contaminant or condition.[11] Some studies have shown relationships between psychological, social, and organizational factors in the workplace and the occurrence of symptoms and comfort complaints.[12,13]

Less often, an illness may be found to be specifically related to something in the building environment. Some examples of potentially building-related illnesses are allergic rhinitis, allergic asthma, hypersensitivity pneumonitis, Legionnaires' disease, Pontiac fever, CO poisoning, and irritant reaction to boiler corrosion inhibitors. The first three conditions can be caused by various microorganisms or other organic material. Legionnaires' disease and Pontiac fever are caused by Legionella bacteria. Sources of CO include vehicle exhaust and inadequately ventilated kerosene heaters or other fuel-burning appliances. Exposure to boiler additives can occur if boiler steam is used for humidification or is released by accident.

Problems that NIOSH investigators have found in the non-industrial indoor environment have included poor air quality due to ventilation system deficiencies, overcrowding, VOCs from office furnishings, office machines, structural components of the building and contents, tobacco smoke, microbiological contamination, and outdoor air pollutants; comfort problems due to improper temperature and %RH conditions, poor lighting, and unacceptable noise levels; adverse ergonomic conditions; and job-related psychosocial stressors. In most cases, however, no environmental cause of the reported health effects could be determined.

Standards specifically for the non-industrial indoor environment do not exist. NIOSH, the Occupational Safety and Health Administration (OSHA), and the American Conference of Governmental Industrial Hygienists (ACGIH) have published regulatory standards or recommended limits for occupational exposures.[14,15,16] With few exceptions, pollutant concentrations observed in the office work environment fall well below these published occupational standards or recommended exposure limits. The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) has published recommended building ventilation and thermal comfort guidelines.[17,18] The ACGIH has also developed a manual of guidelines for approaching investigations of building-related symptoms that might be caused by airborne living organisms or their effluents.[19]

Measurement of indoor environmental contaminants has rarely proved to be helpful, in the general case, in determining the cause of symptoms and complaints except where there are strong or unusual sources, or a proven relationship between a contaminant and a building-related illness. However, measuring ventilation and comfort indicators such as CO_2, temperature, and %RH is useful in the early stages of an investigation in providing information relative to the proper functioning and control of HVAC systems. The basis for measurements of certain contaminants that were detected during this evaluation are listed below.

Carbon Dioxide

Carbon dioxide is a normal constituent of exhaled breath and, if monitored, can be used as a screening technique to evaluate whether adequate quantities of outdoor air are being introduced into an occupied space. ASHRAE's most recently published ventilation standard, ASHRAE 62-1989, Ventilation for Acceptable Indoor Air Quality, recommends outdoor air supply rates of 20 cubic feet per minute per person (cfm/person) for office spaces, and 15 cfm/person for reception areas, classrooms, libraries, auditoriums, and corridors.[19] Maintaining the recommended ASHRAE outdoor air supply rates should provide for acceptable indoor air quality when the outdoor air is of good quality and there are no significant indoor emission sources.

Indoor CO_2 concentrations are normally higher than the generally constant ambient outdoor air CO_2 concentration (range 300-350 ppm). Carbon dioxide concentration is used as an indicator of the adequacy of outdoor air supplied to occupied areas. When indoor CO_2 concentrations exceed 800 ppm in areas where the only known source is exhaled breath, inadequate ventilation is suspected.[20] Elevated CO_2 concentrations suggest that other indoor contaminants may also be increased. It is important to note that CO_2 is not an effective indicator of ventilation adequacy if the ventilated area is not occupied at its usual level.

Temperature and Relative Humidity

Temperature and %RH measurements are often collected as part of an indoor environmental quality (IEQ) investigation because these parameters affect the perception of comfort in an indoor environment. The perception of thermal comfort is related to one's metabolic heat production, the transfer of heat to the environment, physiological adjustments, and body temperature.[21] Heat transfer from the body to the environment is influenced by factors such as temperature, humidity, air movement, personal activities, and clothing. The American National Standards Institute (ANSI)/ASHRAE Standard 55-1981 specifies conditions in which 80% or more of the occupants would be expected to find the environment thermally acceptable.[18] Assuming slow air movement and 50%RH, the operative temperatures recommended by ASHRAE range from 68 to 74.5°F in the winter, and from 73 to 79°F in the summer. The difference between the two is largely due to seasonal clothing selection. ASHRAE also recommends that %RH be maintained between 30 and 60 %.[18] Since excessive humidity can support the growth of microorganisms, limiting humidity to 50%RH or less will help limit the growth of certain microorganisms which may be pathogenic or allergenic.

Microbiological Contaminants

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 a nutrient substrate. Under the appropriate conditions (optimum temperature, pH, and with sufficient moisture and available nutrients) saprophytic microorganism populations can be amplified. Through various mechanisms, these organisms can then be disseminated as individual cells or in association with soil, dust, or water. In the outdoor environment, the levels of microbial aerosols will vary according to the geographic location, climatic conditions, and surrounding activity. Indoors, the concentration of certain microorganisms may vary somewhat as a function of the cleanliness of the HVAC system and the numbers and activity level of the occupants. With the exception of certain human-shed bacteria, indoor levels are expected to be below outdoor levels (depending on HVAC system filter efficiency) with consistently similar ranking among the microbial species.[22,23]

Some individuals manifest increased immunologic responses to antigenic agents encountered in the environment. These responses and the subsequent expression of allergic disease is based, partly, on a genetic predisposition.[24] Allergic diseases typically associated with exposures in indoor environments include allergic rhinitis (nasal allergy), allergic asthma, allergic bronchopulmonary aspergillosis (ABPA), and extrinsic allergic alveolitis (hypersensitivity pneumonitis).[7] Allergic respiratory diseases resulting from exposures to microbial agents have been documented in agricultural, biotechnology, office, and home environments.[25,26,27,28,29,30,31,32]

Individual symptoms vary according to disease. Allergic rhinitis is characterized by paroxysms of sneezing; itching of the nose, eyes, palate, or pharynx; nasal stuffiness with partial or total airflow obstruction; and rhinorrhea (runny nose) with postnasal drainage. Allergic asthma is characterized by episodic or prolonged wheezing and shortness of breath in response to bronchial (airways) narrowing. Allergic bronchopulmonary aspergillosis is characterized by cough, lassitude, low-grade fever, and wheezing.[7,33] Heavy exposures to airborne microorganisms can cause an acute form of extrinsic allergic alveolitis which is characterized by chills, fever, malaise, cough, and dyspnea (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.[34]

Acceptable levels of airborne microorganisms have not been established, primarily because allergic reactions can occur even with relatively low air concentrations of allergens, and individuals differ with respect to immunogenic susceptibilities. The current strategy for on-site evaluation of environmental microbial contamination involves an inspection to identify sources (reservoirs) of microbial growth and potential routes of dissemination. In those locations where contamination is visibly evident or suspected, bulk samples may be collected to identify the predominant species (fungi, bacteria, and thermophilic actinomycetes). In limited situations, air samples may be collected to document the presence of a suspected microbial contaminant. Air sample results can be evaluated epidemiologically by comparing those from the "complaint areas" to those from non-complaint areas, or by relating exposure to immunologic findings.

Volatile Organic Compounds

Volatile organic compounds describe a large class of chemicals which are organic (i.e., containing carbon) and have a sufficiently high vapor pressure to allow some of the compound to exist in the gaseous state at room temperature. These compounds are emitted in varying concentrations from numerous indoor sources including, but not limited to, carpeting, fabrics, adhesives, solvents, paints, cleaners, waxes, cigarettes, and combustion sources.

Indoor environmental quality studies have measured wide ranges of VOC concentrations in indoor air as well as differences in the mixtures of chemicals which are present. Research also suggests that the irritant potency of these VOC mixtures can vary. While in some instances it may be useful to identify some of the individual chemicals which may be present, the concept of total volatile organic compounds (TVOC) has been used in an attempt to predict certain types of health effects.[36] The use of this TVOC indicator, however, has never been standardized.

Some researchers have compared levels of TVOCs with human responses (such as headache and irritative symptoms of the eyes, nose, and throat). However, neither NIOSH nor the Occupational Safety and Health Administration currently have specific exposure criteria for VOC mixtures in the nonindustrial environment. Research conducted in Europe suggests that complaints by building occupants may be more likely to occur when TVOC concentrations increase.[37] It should be emphasized that the highly variable nature of these complex VOC mixtures can greatly affect their irritancy potential. Considering the difficulty in interpreting TVOC measurements, caution should be used in attempting to associate health effects (beyond nonspecific sensory irritation) with specific TVOC levels.

OBSERVATIONS

May and July 1997

In general, classrooms appeared to be in good condition; visible surfaces had slight dust. Carpeting appeared to be worn but not dirty. Evidence of water damage and microbial growth was observed on one ceiling tile outside of room 107, and on ceiling tiles in the hallway outside of the gymnasium air handler fan room. Inspection of the area above the tiles indicates a roof leak as a probable source of water.

In May, basement air handler outdoor air dampers were nearly 100% closed and rusted in place. Damper actuators were not connected to the basement air handler HVAC control system and were not functioning. The outdoor air intake bird and insect screen needed cleaning. The outdoor air filter rack had been installed in reverse, such that air filters were pushed out of position or had fallen completely out of the rack. In July 1997, the outdoor air dampers were 100% open. The dampers were still difficult to move and the actuators were not functioning.

The basement air handler was dusty. Debris and dust cake had accumulated on the fan housing and blades, and to a lesser extent within the outdoor air and supply ducts. Ducts were held securely in place with no noticeable air leakage. Water had accumulated within an older section of supply duct. The source was a leaking water pipe. No gross (visible) microbial growth had resulted from the moisture. A cake of compacted dust had accumulated on the exterior of supply ducts in the return airways. Air handler and return air chamber access doors and panels were not well sealed.

A thick mat of fibrous, dusty material lined the bottom of the return airway crawl spaces. In the fan room, return air dampers, actuators, filter racks, and ducts installed in 1995 by Columbus were operational and in good physical condition.

The basement air handler cooling coils and drain pans were free of slime and accumulated water. A pit in the floor of the mechanical room collected water from the cooling coils; the pit also collected rain water that sometimes washed into the room from an outdoor stairwell. The drain at the base of the stairwell was clogged with mud. The pit held approximately 8" of water. A sump pump in the pit was operational. The cooling coil chillers were approximately 15 feet from the outdoor air intake. A walled-off section of the lower floor adjacent to the fan room was used for storage (i.e. lawn mower, weed eater, janitorial and school supplies, etc.).

The gymnasium air handler had never been fitted with filters and no filter rack had been installed. The damper actuator system had an air pressure leak. This system was in worse physical condition than the basement air handler; dust cake was thick on the fan housings and blades, and within supply and return ducts and plenums. The outdoor air damper was about 95% closed and the actuator mechanism was frozen. Supply duct dampers were open and the actuators were operational.

The perimeter air handlers were generally noisy and dusty. Bushings which support the fan motor shafts were one obvious source of the noise. Foam filters were clean. According to maintenance employees, the filters were not regularly cleaned. Most of the perimeter air handler fans had been manually switched off due to the noise they emit, therefore the perimeter air handlers were not actively distributing air into occupied areas. All perimeter air handler outdoor air dampers were 100% closed during the environmental evaluation. Among six perimeter air handlers inspected, linkages were generally in good condition and actuators moved supply and outdoor air dampers when thermostats were adjusted.

December 1997

The basement air handler was no longer dusty. Debris and dust cake had been removed from fan blades, the fan housing, and from within the outdoor air and supply ducts. The fan had been painted. Much of the cake of compacted dust which had accumulated on the exterior of supply ducts had been removed, as well as the fibrous, dusty material which lined the bottom of the crawl spaces. Outdoor air dampers were 100% open, however damper actuators were not functioning. Outdoor air filters were not secure; none were held securely in place and many had fallen out of the filter rack or were out of position. The water pipe leak which dripped water into the supply air duct had been repaired.

The gymnasium air handler was not inspected. The air handler was not operating and the outdoor air damper was about 95% closed.

Five perimeter air handlers were opened and visually inspected. Interior components were generally dusty and foam filters were fairly clean. Fans in three perimeter air handlers were operating during morning hours, fans in six perimeter air handlers were operating during the afternoon. All other fan units had been manually switched off.

RESULTS

Interviews and Symptom Surveys

Twenty-six female teachers (mean age 45), and 9 male teachers (mean age 50) returned a completed symptom survey, a participation of 71%. Interviews and symptom surveys revealed that employees were dissatisfied with the quantity of surface dust, temperature variations, odors, noise associated with the HVAC systems, and inoperation of perimeter air handler fans. Odors were linked to the operation of gas-fired furnaces.

Employees reported a variety of symptoms associated with their presence in PPHS. Employee complaints were predominantly located in sections A, B, and D (Figure 1), which are serviced by the basement air handler and several perimeter air handlers. Symptoms included headache, unusual fatigue, ear/nose/throat irritation or burning, chest tightness, wheezing, chest colds and illnesses, body ache, shortness-of-breath, chills and/or fever, chronic phlegm, chronic cough, feeling faint, lightheadedness, sleepiness, sneezing, nosebleeds, and eye irritation. Reports of physician-diagnosed conditions included bronchitis, pneumonia, hayfever, asthma, and “other chest illnesses.” Respiratory conditions reportedly diminished when employees were away from PPHS. Occupant complaints were reported to have increased or developed subsequent to a furnace explosion in 1982, which caused soot to be distributed throughout the ventilation system and building interior.

Environmental

July 1997 Environmental Assessment Results

Microbial Sampling

Several airborne fungi that were not clearly dominant in the indoor air ranged from 12 to approximately 400 CFU/m^3. Average concentrations of the same airborne genera were similar in magnitude between complaint, non-complaint, and outdoor areas. Bulk sampling detected certain dominant fungi that were not present in elevated airborne concentrations indoors compared to outdoors. Spore counts during quiescent sampling were lower indoors than outdoors. During aggressive sampling, certain spores were present in indoor air that were not detected in outdoor air. However, indoor spore counts of these fungi were not considered to be elevated relative to the total structures detected outdoors. The results of quiescent air sampling demonstrated that thermophilic actinomycetes concentrations could be marginally elevated indoors relative to outdoors. An exposure problem for thermophilic actinomycetes cannot be ruled out since thermophilic actinomycetes is unusual in the indoor environment and has been implicated in cases of hypersensitivity pneumonitis.

See the text and Tables 1 through 14 in the Appendices for a more detailed description of the microbial sampling and statistical analyses of the data.

Qualitative Particle Concentrations

Mean qualitative aerosol concentrations were very similar between complaint and non-complaint areas (Figure 2). Similar aerosol concentrations during morning (~9:45 a.m.) and afternoon (~2:00 p.m.) periods indicate that bioaerosol measurements were not biased between these areas due to aerosol loading.

Volatile Organic Compounds

After the furnace was fired, qualitative concentrations of propane, butane, and benzene in the basement air handler next to the fan increased appreciably compared to trace concentrations detected before the furnace was fired. After the furnace was fired, concentrations of acetone, propene, and isopropanol increased appreciably in complaint/non-complaint areas, with lesser but increased concentrations of methanol, isobutane, and ethanol compared to trace concentrations detected before the furnace was fired.

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Temperature and Relative Humidity

Indoor temperature measurements in the main building ranged from 70 to 81^{N}F. Temperatures inside detached classrooms ranged from 60 to 67^{N}F, and outdoor temperatures ranged from 44 to 64^{N}F (Figure 3). Indoor %RH in the main building ranged from 16 to 33%. Humidity inside detached classrooms ranged from 25 to 55%, and outdoor relative humidity ranged from 18 to 38% (Figure 4).

Ventilation

Indoor CO_2 measurements in the main building ranged from 700 to 2200 ppm. Inside detached classrooms, CO_2 ranged from 600 to 3800 ppm, and outdoor measurements ranged from 300 to 400 ppm (Figure 5). No CO was detected in any area within the main and detached buildings. In the main building, natural ventilation was primarily supplied by open windows in five classrooms and one open outside door in one classroom. Twenty-seven perimeter air handlers did not supply outdoor air to the building. Five perimeter air handlers actually *exhausted* a total of 350 cfm of air from the building through outdoor air *intakes*. A reliable measurement of outdoor air flow into the basement air handler could not be obtained. The gymnasium air handler was not operating and the gymnasium air handlers' indoor air intake dampers were about 95% closed. Smoke tests indicate that the detached classrooms (Buildings 51 and 52) were not mechanically ventilated with outdoor air. During the afternoon, both classrooms were naturally ventilated by open windows.

DISCUSSION

May and July 1997 Environmental Assessment

In May 1997, the poor condition of HVAC systems was indicated by heavily dust contaminated HVAC components, and by outdoor air intake dampers in the basement air handler and perimeter air handlers that were closed. The absence of a program of scheduled maintenance, maintenance log, and operation manuals for HVAC systems most likely contributed to the deterioration of the air quality at PPHS. Since July 1997, ducts and air handlers have been cleaned of much of the excessive debris that had accumulated within the air distribution systems.

No fungi or thermophilic actinomycetes were more than marginally (less than 10 times) higher in concentration indoors compared to outdoors. The majority of both mean fungal counts by genus/species and pooled fungal counts were lower indoors than outdoors. Environmental sampling indicated that indoor microbial concentrations could become elevated compared to the outdoors, and that certain microbes which require moist conditions to remain viable were present.

Concentrations of VOCs were not quanititatively measured during furnace firing. However, it is unlikely that the concentrations of chemical compounds emitted by the furnaces are elevated such that these chemicals are a significant health threat to building occupants. It is likely that the odor of these chemicals has triggered symptoms in certain individuals. Symptoms related to odors might range from discomfort, headaches and irritation, to anger and nausea.[38] Odors detected during furnace firing are likely to be related to increased ambient air concentrations of acetone, propane, propene, and isopropanol and lesser concentrations of ethanol, methanol, and isobutane.

December 1997 Environmental Assessment

On December 17, 1997, mean CO_2 concentrations in the main building ranged from 700 to 2200 ppm with a mean of 1300 ppm, compared to an outdoor range of 300 to 400 ppm with a mean of 350 ppm. The average CO_2 concentration in main building classrooms with closed windows and doors and an average of 18 students was 1500 ppm. In the morning hours, only 3 of 32 perimeter air handlers had fans operating. Six of 32 were operating in the afternoon. Fans are typically not operated due to the noise they create. In addition, perimeter air handler supply registers in many classrooms were blocked by papers, books, clothes, plants, or other objects.

When indoor CO_2 concentrations exceed 800 ppm in areas where the only known source is exhaled breath, inadequate ventilation is suspected. Fifty-three of 58 CO_2 measurements within PPHS exceeded 800 ppm (Figure 5). The CO_2 concentration in supply air downstream of the furnaces was 650 ppm, so elevated CO_2 concentrations by furnace combustion was not indicated. Delivery of a sufficient volume of outdoor air is necessary in any indoor environment to dilute pollutants that are released by equipment, building materials, furnishings, products, and people. The ASHRAE Standard for Acceptable Indoor Air Quality recommends outdoor air flow rates in cfm/person for a variety of applications in educational institutions. These flow rates range from 15 cfm/person for classrooms, up to 60 cfm/person for smoking lounges.

The elevated CO_2 concentrations in the main building indicated that it was significantly underventilated, even though the basement air handler outdoor air intake dampers were 100% open during the December 1997 evaluation. The underventilation of the main building was at least partially due to no outdoor air intake from the 32 perimeter air handlers, poor distribution of outdoor air from the basement air handler since perimeter air handler fans were typically off, and blocked perimeter air handler supply registers.

The average CO_2 concentration between the two detached classrooms (51 and 52) with closed windows and doors and an average of 28 students was 3625 ppm. The cause for elevated levels of CO_2 in the detached classrooms is likely to be closed windows which are the only source of outdoor air unless the in-wall heating and cooling units in these classrooms are fitted with outdoor air dampers. Intermittent use of natural ventilation by open windows dropped CO_2 concentrations from 3800 to 600 ppm.

Indoor temperatures in the main building ranged from 70 to 81^{N}F with a mean of 76^{N}F. Relative humidity ranged from 16 to 33% with a mean of 23 %. At every measurement location in the main building, combined temperature and relative humidity levels were outside of the acceptable winter operative ranges illustrated in the ASHRAE thermal comfort chart (Figure 6). The ASHRAE thermal comfort chart specifies the acceptable (20% dissatisfaction criteria) ranges of operative temperature and humidity for persons performing mainly sedentary activity while clothed in typical summer or winter clothing. Non-conformity to the ASHRAE thermal comfort criterion in the main building was primarily the result of average indoor RH levels in the low 20s (Figure 4). However, RHs in this range are not uncommon for buildings in cold climates that do not have humidification systems. The December 1997 evaluation indicates that the combined basement air handler and perimeter air handler temperature control system is not adequately responsive to conditions within the occupied areas. Several classroom doors were open to the hallways, therefore thermostats which are located next to open doors and hallways did not adequately gauge actual room conditions.

For occupants wearing typical winter clothing (heavy slacks, long sleeves, and sweater), ASHRAE recommends that temperatures range from 68 to 74.5^{N}F at 50%RH. Slightly higher temperatures (68.5 to 76^{N}F) are acceptable at a lower limit of 30% RH (Figure 6). Relative humidity should be limited within 30 to 60% based on dew point (to prevent condensation on surfaces), comfort, respiratory health, and mold growth. A lack of humidity control is a likely cause of discomfort, and may contribute to nosebleeds and eye irritation experienced by some occupants.

CONCLUSIONS AND RECOMMENDATIONS

The National Institute for Occupational Safety and Health conducted three surveys at Point Pleasant High School in Point Pleasant, West Virginia, in response to a request by employees reporting headache, sinus problems, upper respiratory problems, dizziness, tiredness, and burning, itchy eyes. Symptoms reported by employees in May 1997 included headache, unusual fatigue, ear/nose/throat irritation or burning, chest tightness, wheezing, chest colds and illnesses, body ache, shortness of breath, chills and/or fever, chronic phlegm, chronic cough, feeling faint, lightheaded, sleepiness, sneezing, nosebleeds, and eye irritation.

On the basis of the data obtained during the July 1997 environmental survey, the NIOSH investigators did not find clear evidence that employee symptoms were caused by microbial contaminants. In addition, there were no environmental conditions measured in the complaint area that indicated that a unique and hazardous environment exists in that area when compared to the non-complaint area.

Reports of building-related health complaints have become increasingly common in recent years; unfortunately, the causes of these symptoms have not been clearly identified. As discussed in the criteria section of this report, many factors are suspected (e.g., volatile organic compounds, formaldehyde, microbial proliferation within buildings, inadequate volumes of outdoor air, etc.). While it has been difficult to identify concentrations of specific contaminants that are associated with the occurrence of symptoms, it is felt by many researchers in the field that the occurrence of symptoms among building occupants can be lessened by providing a properly maintained interior environment. Adequate control of the temperature is a particularly important aspect of employee comfort.

Environmental conditions and deficiencies found by the NIOSH investigators may help explain certain symptoms reported by PPHS employees. Based on the results and observations of this evaluation, the following recommendations are offered to correct those deficiencies and optimize employee comfort:

1. Current design air flow and temperature controls should be verified by an engineering firm. The firm should balance and adjust all HVAC systems to ensure that they will operate such that ASHRAE recommended standards are satisfied. These ASHRAE standards include recommended outdoor air flow per occupant, and seasonal recommended limits for indoor temperature and relative humidity. Any changes in the systems which affect current designs should be recorded as an addendum to existing HVAC documentation. Personnel performing the testing and balancing should be certified by the National Environmental Balancing Bureau (NEBB) or other equivalent certifying organization. Once completed, the engineering firm should submit a certified report that the systems have been tested, adjusted, and balanced in accordance with the latest building industry standards. In addition, the report should provide recommendations for maintaining classroom doors and windows in a closed or open position.

2. Repair perimeter air handler fans such that noise associated with the operation of the fans does not discourage their use. In the interim, use free standing fans to enhance air mixing in rooms where perimeter air handler fans are too noisy to operate. After repairs, ensure all perimeter air handler fans are turned on to enhance distribution and mixing of supply and return air from the basement air handler. Remove any objects from on top of induction units or perimeter air handlers and ensure that supply registers and return air grills are free from any obstruction to air flow.

3. Monitor CO_2 concentrations to determine if perimeter air handler fan operation and/or free standing fan operation improves the delivery of outdoor air to occupied areas. If CO_2 concentrations in these areas with improved air flow do not drop to below 800 ppm under conditions of normal occupancy, perimeter air handler outdoor air dampers should remain open at a minimum setting that maintains CO_2 concentrations below 800 ppm.

4. One full-time person should be responsible for the mechanical systems in the school to ensure that the systems are adequately maintained. This person should be formally trained in the operation, hardware, and controls of the HVAC system.

5. Access to the systems' control panel and individual thermostats should be restricted to authorized individuals.

6. Ensure all HVAC systems have outdoor air filters that are securely fastened into filter racks that minimize blow-by of unfiltered air. Filters in the basement air handler and gymnasium air handler should be 50 to 70% efficient (according to the ASHRAE dust spot efficiency test) in order to remove most microbial particulate from the airstream.

7. Perimeter air handler filter frames should fit tightly within their slots to minimize blow-by. Filters should be upgraded from the foam-type currently in use. Upgraded filters should be higher efficiency filters within the limit of pressure drop the systems can handle.

8. Maintain relative humidity levels to 50%RH or less within HVAC fan rooms, ducts, plenums, and perimeter air handlers to aid in the inhibition of fungal growth.

9. Set up and maintain information files on the building's HVAC systems. Files should include up-to-date mechanical and control system drawings, manufacturers product literature on major components, operating parameters, system operating methods, maintenance schedules and records, and a record of any changes to the

systems. Complaints and their disposition should be kept in these files.

10. Maintain a free-flowing drain at the base of the below-grade stairwell that partially houses the basement air handler outdoor air intake.

11. When cleaning and sanitizing HVAC components, ensure that the HVAC system is not operating until it is cleaned, sanitized, and dried. Loosen and remove dirt and debris, then sanitize using a dilute aqueous household bleach solution (10% bleach in water). Bacterial endospores, produced by some thermophilic actinomycetes, may be slightly resistant to chlorine disinfectants; therefore, surfaces should be kept moist with the bleach solution for a sufficient contact time to allow for disinfection to occur (about 10 to 15 minutes). A clean water rinse should follow cleaning and sanitizing.

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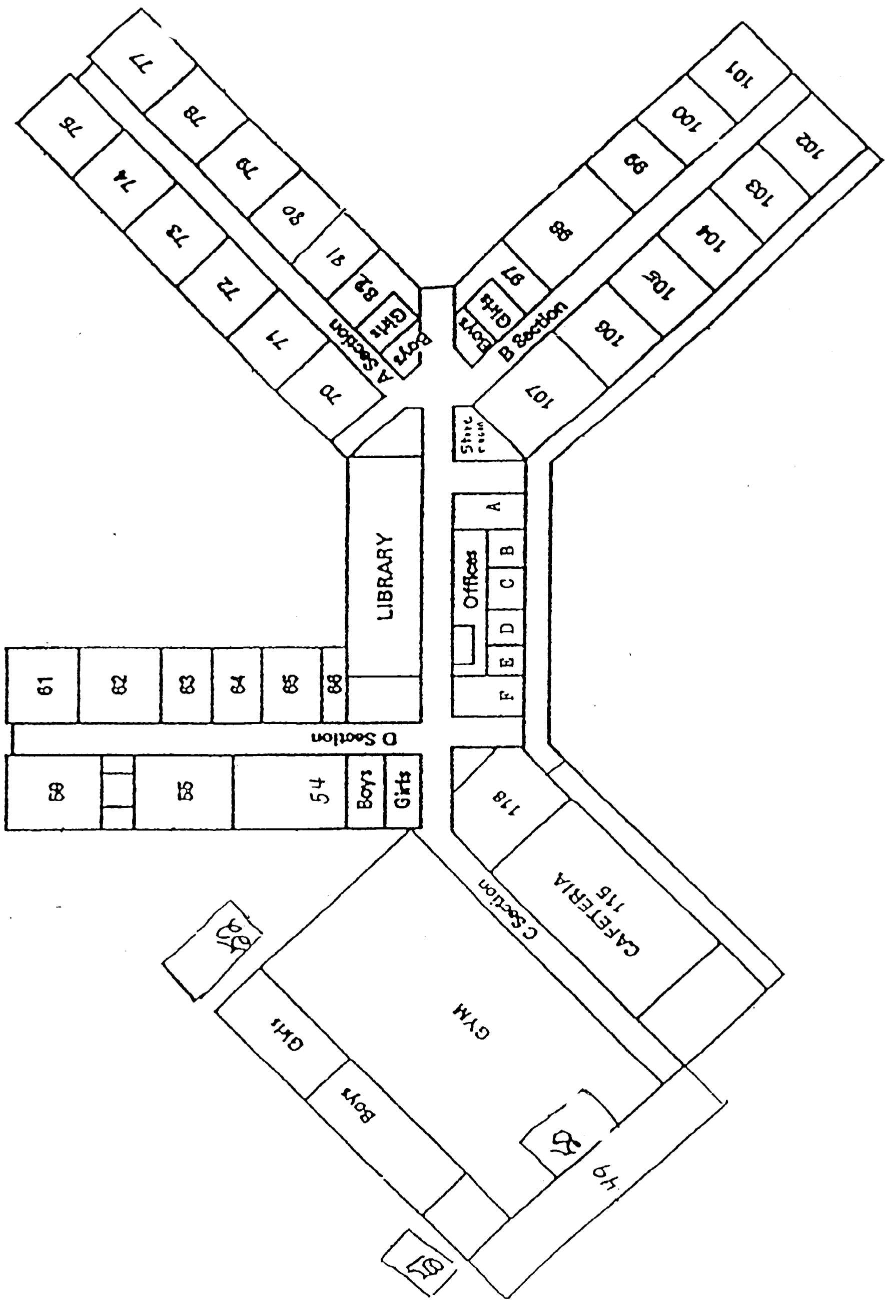


Figure 1. PPHS Floor Plan

Figure 2. Mean Qualitative Particle Concentrations (mg/m3) in Complaint and Non-complaint Areas, July 22-24, 1997

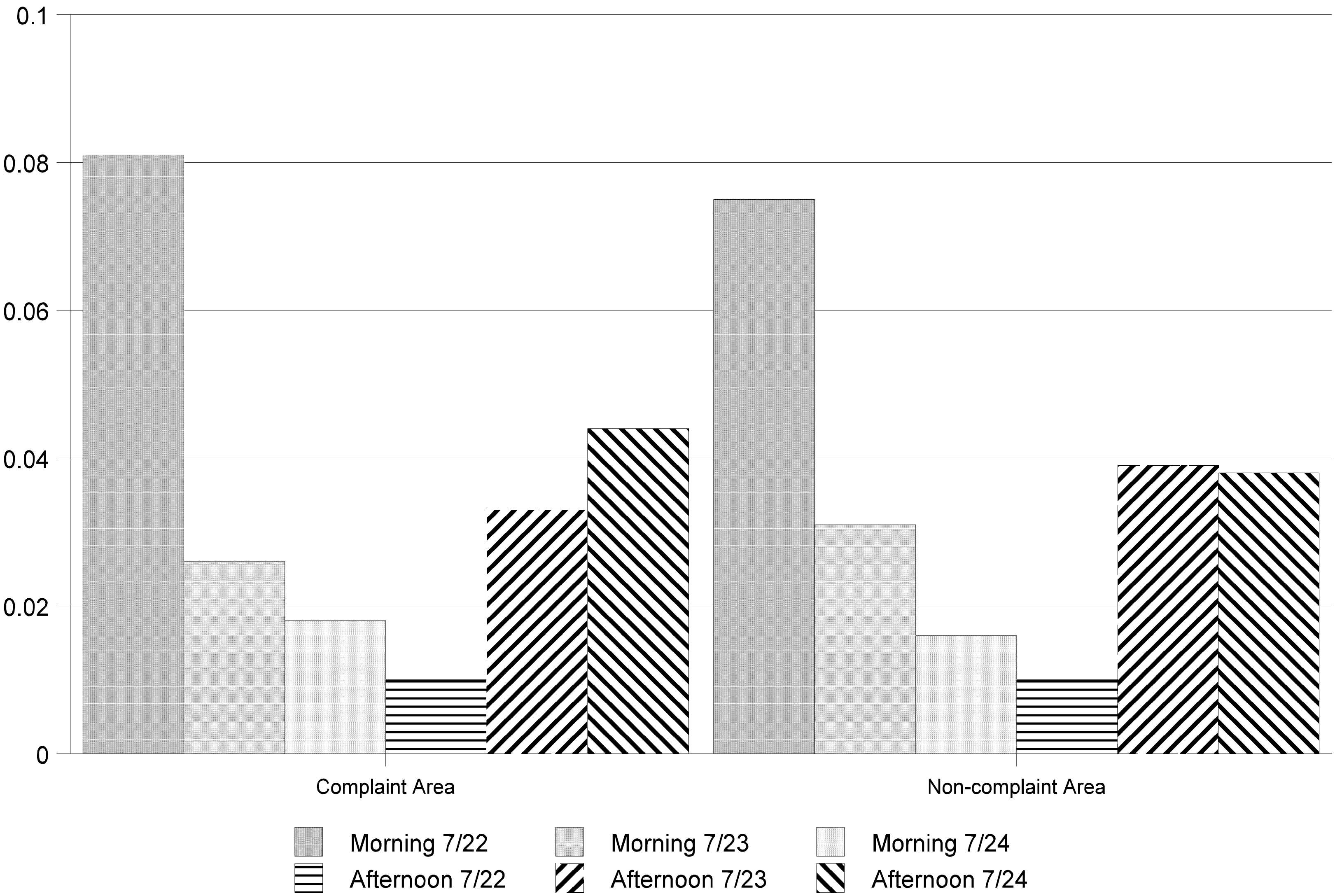


Figure 3. Temperature (°F) at Various Locations, December 17, 1997

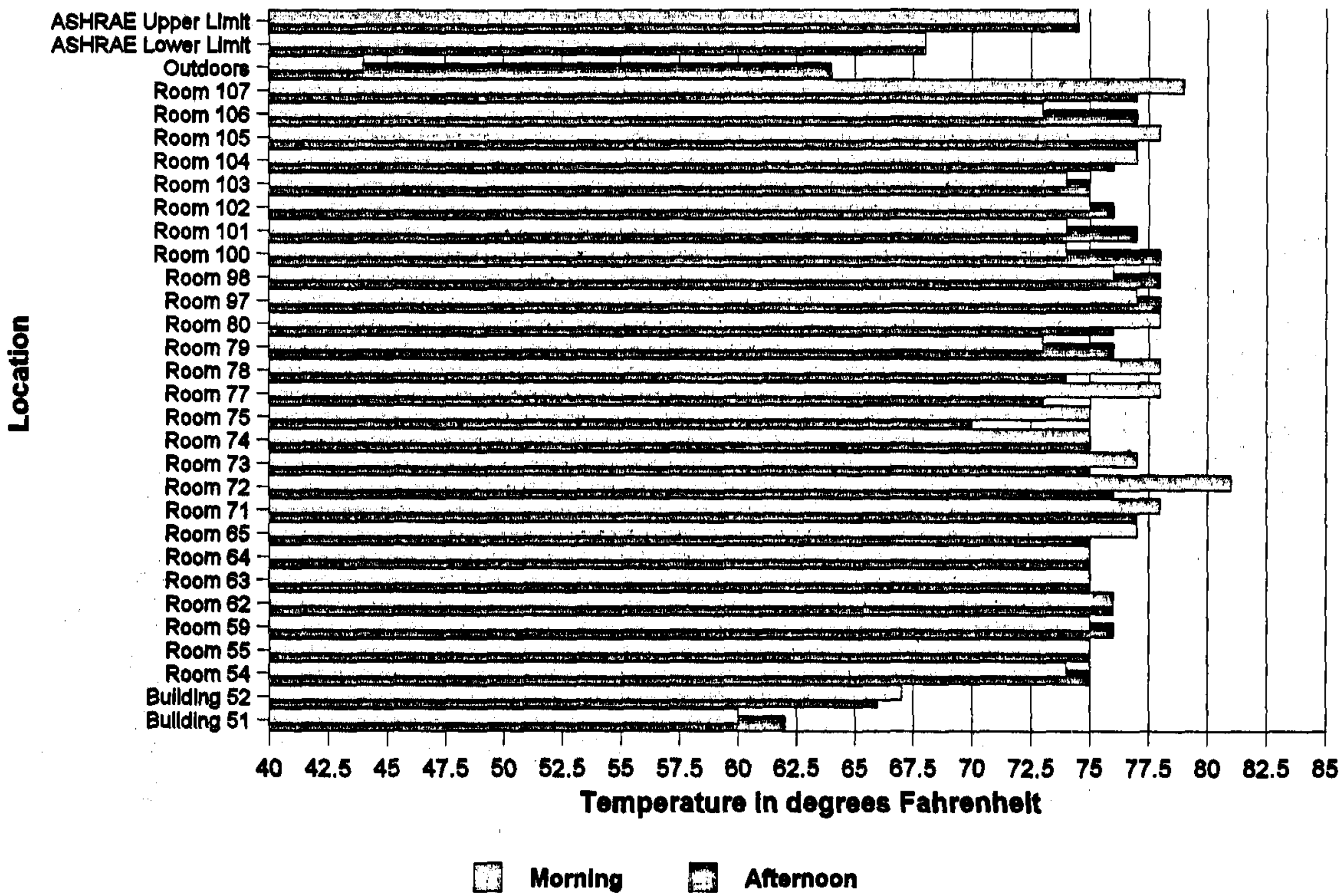


Figure 4. Relative Humidity (RH%) at Various Locations, December 17, 1997

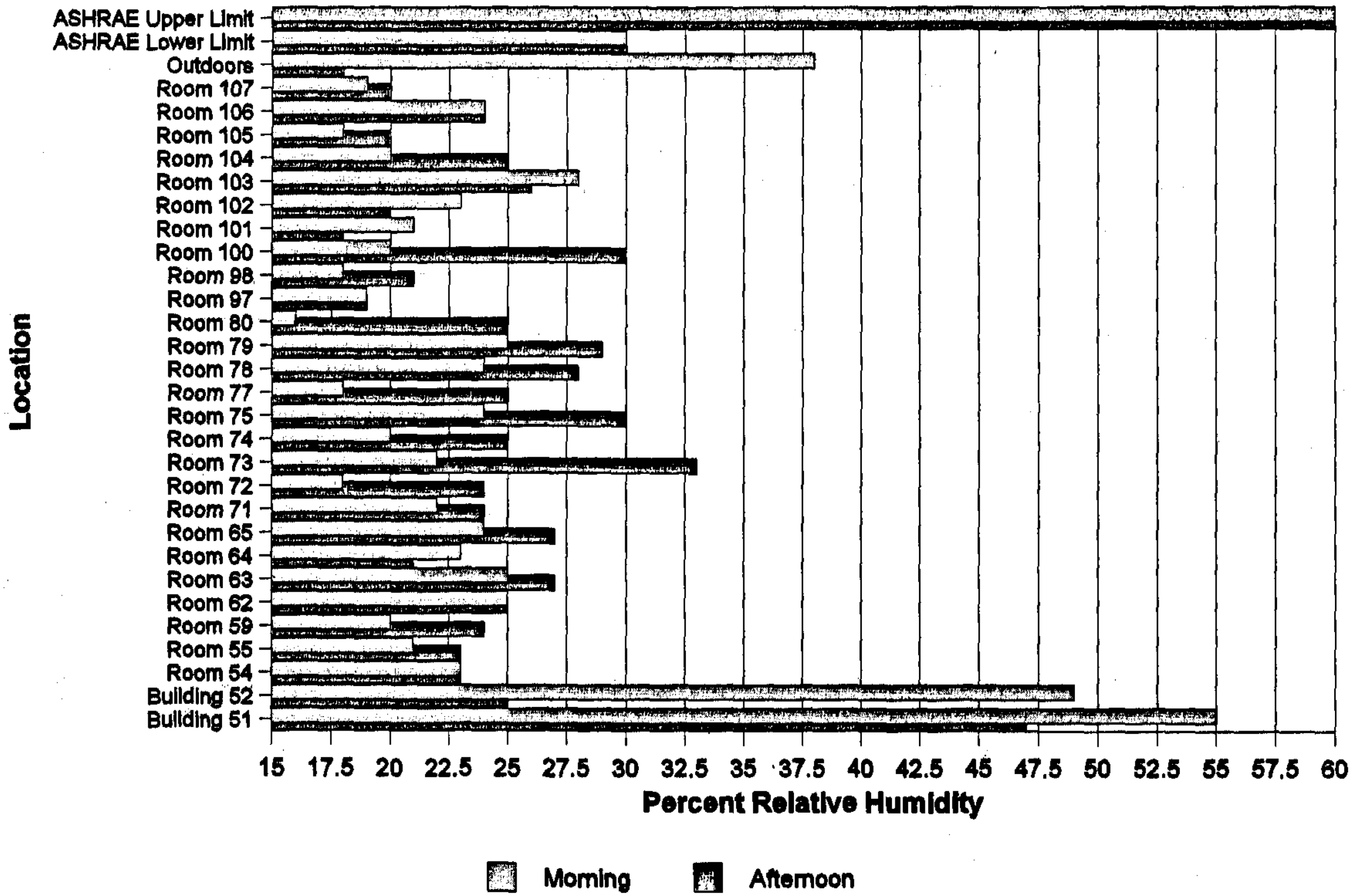


Figure 5. Carbon Dioxide Concentrations (ppm) at Various Locations, December 17, 1997

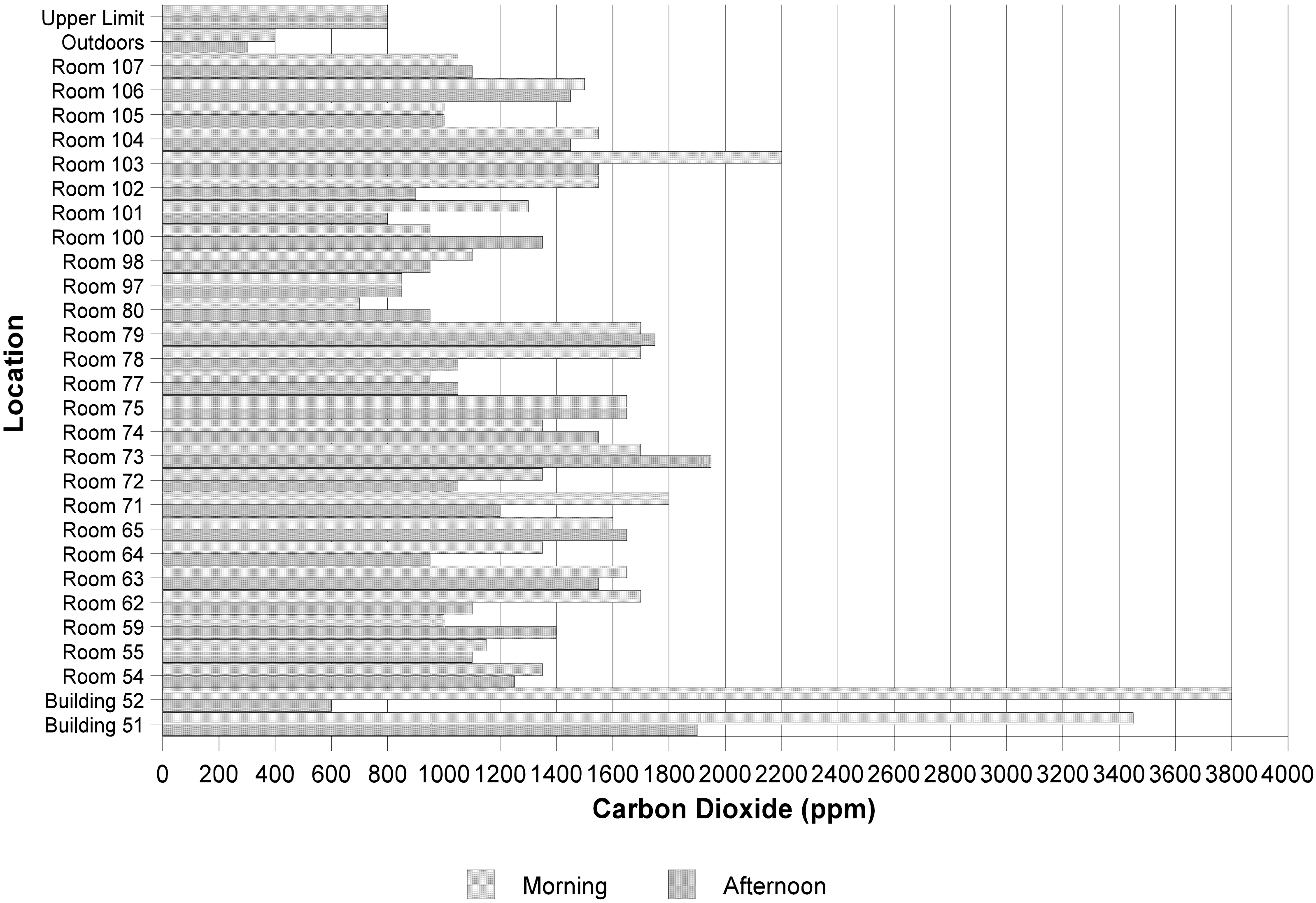
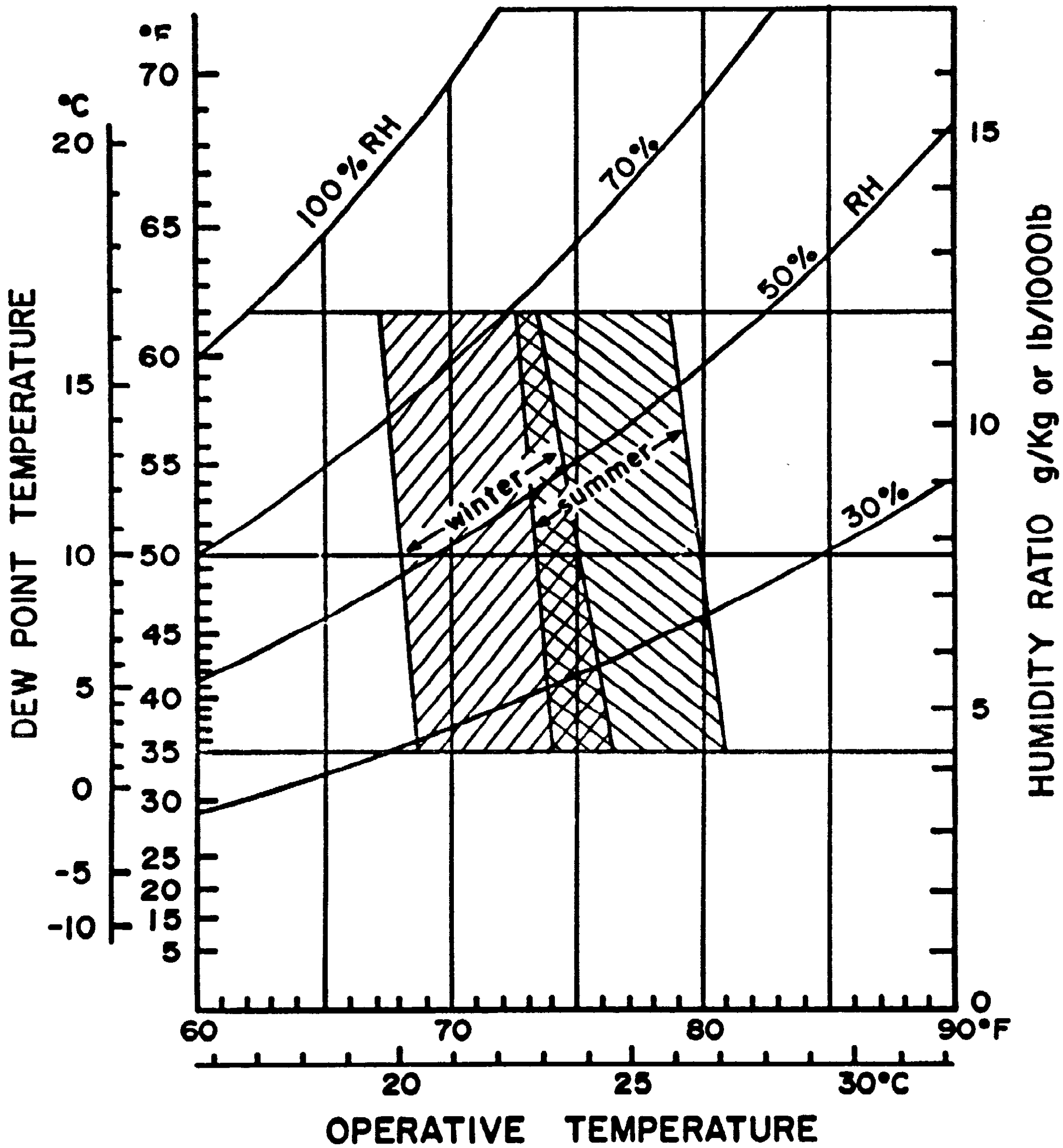


Figure 6. ASHRAE Thermal Comfort Chart



APPENDICES

Microbial Sampling Data Results

Fungi sample results are presented in Tables 1 - 4 and 7 - 12. The tables include the following information, if available:

- ***Type of organism (genera or species).***
- ***Concentration.***
- ***Water activity [High meaning growth under high humidity, Low meaning growth under low humidity]***
- ***Detection in indoor environments [FE means frequently encountered, LC means less common][37]***

Concentrations of the same fungi between locations were assessed by calculation of the Spearman non-parametric rank correlation coefficient (r_s). This statistic was applied to a minimum of four genus/species comparisons between locations; therefore it was limited to air samples of viable fungi (Tables 1 - 4). The null hypothesis was $r_s = 0$, meaning concentrations of fungi of the same type are not similar between locations (no association). The criteria for an association was calculated with a two-tailed t-test statistic, to the 0.05 level of significance. These statistics are presented in Tables 5 and 6.

Air Sampling for Fungi

Tables 1 - 4 present average airborne fungi concentrations which were calculated from two sets of two side-by-side replicate samples; one collected in the morning between 9 and 10 a.m. and the other in the afternoon between 1 and 3 p.m., for an average concentration of 4 samples. Tables include a rank order from highest average concentration in colony forming units per cubic meter of air (CFU/m^3) to lowest, in descending order, according to a special protocol for the purpose of calculating r_s.

Tables 1 and 2 present data collected during quiescent conditions. Table 1 presents data obtained with MEA media for mesophilic fungi. Table 2 presents data obtained with DG18 media for xerophilic fungi. Tables 3 and 4 present data collected during aggressive sampling conditions. Table 3 presents data for mesophilic fungi and Table 4 presents data for xerophilic fungi. Tables 5 and 6 present the strength of associations between fungal concentrations between locations.

Bulk Sampling for Fungi

Tables 7 - 10 present bulk dust sampling data. Table 7 presents data obtained with MEA media for xerophilic fungi. Table 8 presents data obtained with DG18 media for xerophilic fungi. Table 9 presents data obtained with MEA media for mesophilic fungi. Table 10 presents data obtained with CMA media for mesophilic fungi.

Air Sampling for Fungal Spores

Tables 11 and 12 present airborne fungal spore sampling data. Table 11 presents data collected during quiescent sampling conditions. Table 12 presents data collected during aggressive sampling conditions.

Air Sampling for Thermophilic Actinomycetes and Bacillus

Airborne bacteria sampling data are presented in Table 13 (quiescent sampling) and Table 14 (aggressive sampling).

Table 1. Air Sampling Data for Viable Mesophilic Fungi; Quiescent Sampling, 84.9 liters, MEA media

	Indoor Complaint Area		Indoor Non-Complaint Area		Outdoors	Genera Characteristics	
Genera	*Rank*	*Average Concentration (CFU/m^3)*	*Rank*	*Average Concentration (CFU/m^3)*	*Average Concentration (CFU/m^3)*	*Water Activity*	*Frequency of Detection Indoors*
Cladosporium	1	1873	1	1040	undetermined[2] dominant[3]	High	Frequently Encountered (FE)
Epicoccum nigrum	2	83	2	83	undetermined present[4]	High	FE
Alternaria	3	59	3	43	undetermined present	High	FE
Pithomycetes	4.5	24	4	35	undetermined		Less Common (LC)
Penicillium	4.5	24	6.5	12	undetermined present	Low to High	FE
Fusarium	6.5	12	5	31	undetermined present	High	FE
yeasts	6.5	12	6.5	12	undetermined	High	FE
Acremonium	no rank[5]	0	no rank	12	undetermined	High	LC
sterile fungi	no rank	0	no rank	12	undetermined		
Rhodoturula	no rank	0	no rank	12	undetermined	High	FE

[1]Not applicable.
[2]Outdoor samples were overloaded.
[3]Predominant type of fungi, although not quantified.
[4]Present but not quantified.
[5]Fungi genus/species not included in the non-parametric test.

Table 2. Air Sampling Data for Viable Xerophilic Fungi; Quiescent Sampling, 84.9 liters, DG18 media

	Indoor Complaint Area		Indoor Non-Complaint Area		Outdoors	Genera Characteristics	
Genera	Rank	Average Concentration (CFU/m^3)	Rank	Average Concentration (CFU/m^3)	Average Concentration (CFU/m^3)	Water Activity	Frequency of Detection Indoors
Cladosporium	1	1746	1	1440	undetermined[2] dominant[3]	High	Frequently Encountered (FE)
Penicillium	2	41	4.5	24	undetermined	Low to High	FE
Wallemia sebi	no rank[4]	41	no rank	0	undetermined	Low	FE
Epicoccum nigrum	3	24	2	43	present[5]		FE
Eurotium (Aspergillus) rubrum	no rank	20	no rank	0	undetermined	Low	FE
Fusarium	4.5	18	4.5	24	present	High	FE
sterile fungi	4.5	18	6	12	undetermined		FE
Alternaria	6	16	4.5	24	present	High	FE
yeasts	7	12	3	35	undetermined	High	FE
Rhodoturula	no rank	12	no rank	0	undetermined	High	FE
Aspergillus restrictus	no rank	0	no rank	12	undetermined	Low	FE
Curvularia	no rank	0	no rank	12	undetermined		Less Common (LC)
Aspergillus niger	no rank	0	no rank	0	present	Low	FE
Cunninghamella	no rank	0	no rank	0	present	High	
Mucor	no rank	0	no rank	0	present	High	FE

[1]Not applicable.
[2]Outdoor samples were overloaded.
[3]Predominant type of fungi, although not quantified.
[4]Fungi genus/species not included in the non-parametric test.
[5]Present but not quantified.

Table 3. Air Sampling Data for Viable Mesophilic Fungi; Aggressive Sampling, 28.3 liters, MEA media

	Indoor Complaint Area		*Indoor Non-Complaint Area*		*Outdoors*		*Genera Characteristics*	
Genera	*Rank*	*Average Concentration (CFU/m³)*	*Rank*	*Average Concentration (CFU/m³)*	*Rank*	*Average Concentration (CFU/m³)*	*Water Activity*	*Frequency of Detection Indoors*
Cladosporium	*1*	*362*	*1*	*371*	*1*	*5777*	*High*	*Freqently Encountered (FE)*
Basidiomycetes	*2*	*141*	*2.5*	*106*	*4*	*318*		*Less Common (LC)*
Penicillium	*3*	*59*	*4.5*	*53*	*2*	*477*	*Low to High*	*FE*
yeasts	*4*	*53*	*2.5*	*106*	*5*	*142*	*High*	*FE*
Epicoccum nigrum	*5.5*	*35*	*6.5*	*35*	*3*	*398*		*FE*
sterile fungi	*5.5*	*35*	*6.5*	*35*	*7*	*53*		
Rhodoturula	*5.5*	*35*	*no rank*[1]	*0*	*6*	*59*	*High*	*FE*
Curvularia	*5.5*	*35*	*no rank*	*0*	*8.5*	*35*		*LC*
Tritirachium	*no rank*	*0*	*4.5*	*53*	*8.5*	*35*		*LC*
Fusarium	*no rank*	*0*	*no rank*	*0*	*no rank*	*53*	*High*	*FE*
Alternaria	*no rank*	*0*	*no rank*	*0*	*no rank*	*53*	*High*	*FE*
Phoma	*no rank*	*0*	*no rank*	*0*	*no rank*	*53*	*High*	*FE*

[1]*Fungi genus/species not included in the non-parametric test.*

Table 4. Air Sampling Data for Viable Xerophilic Fungi; Aggressive Sampling, 28.3 liters, DG18 media

	Indoor Complaint Area		Indoor Non-Complaint Area		Outdoors		Genera Characteristics	
Genera	*Rank*	*Average Concentration (CFU/m^3)*	*Rank*	*Average Concentration (CFU/m^3)*	*Rank*	*Average Concentration (CFU/m^3)*	*Water Activity*	*Frequency of Detection Indoors*
Cladosporium	1	203	2	240	1	1820	High	Frequently Encountered (FE)
Basidiomycetes	2	141	3	71	5	106		
Penicillium	3	89	4.5	53	3	365	Low to High	FE
Tritirachium	4	71	6.5	35	9.5	35		Less Common (LC)
Epicoccum nigrum	5	53	1	400	6	89		FE
yeasts	6	47	4.5	53	4	124	High	FE
sterile fungi	7.5	35	6.5	35	8	53		
Rhodoturula	7.5	35	6.5	35	2	742	High	FE
Phoma	no rank[1]	0	6.5	35	7	71	High	FE
Curvularia	no rank	0	6.5	35	9.5	35		LC
Fusarium	no rank	0	6.5	35	9.5	35	High	FE
Alternaria	no rank	0	no rank	35	no rank	0	High	FE
Acremonium	no rank	0	no rank	35	no rank	0	High	LC
Aureobasidium pullulans	no rank	0	no rank	0	no rank	35	High	FE
Botrytis	no rank	0	no rank	0	no rank	35		LC
Aspergillus versicolor	no rank	0	no rank	0	no rank	35	Low	FE

[1]Fungi genus/species not included in the non-parametric test.

Table 5. Spearman Non-parametric Rank Results for Xerophilic Fungi

	Xerophilic Fungi; Aggressive Sampling			*Xerophilic Fungi; Quiescent Sampling*
Statistic	*Complaint vs Non-Complaint*	*Complaint vs Outdoors*	*Non-Complaint vs Outdoors*	*Complaint vs Non-Complaint*
n (number of samples)	*8*	*8*	*11*	*7*
r_s (Spearmans' coefficient)	*0.605*	*0.275*	*0.582*	*0.374*
t (critical value)	*1.86*	*0.702*	*2.15*	*0.902*
p value	*0.112*	*0.509*	*0.604*	*0.409*
Associated?[1]	*No*	*No*	*No*	*No*

[1]*Association evaluated to the 0.05 level of significance.*

Table 6. Spearman Non-parametric Rank Results for Mesophilic Fungi

	Mesophilic Fungi; Aggressive Sampling			*Mesophilic Fungi, Quiescent Sampling*
Statistic	*Complaint vs Non-Complaint*	*Complaint vs Outdoors*	*Non-Complaint vs Outdoors*	*Complaint vs Non-Complaint*
n (number of samples)	*6*	*8*	*7*	*7*
r_s (Spearmans' coefficient)	*0.896*	*0.736*	*0.385*	*0.374*
t (critical value)	*4.03*	*2.66*	*0.934*	*0.902*
p value	*0.016*	*0.038*	*0.393*	*0.409*
Associated?[1]	*Yes*	*Yes*	*No*	*No*

[1]Association evaluated to the 0.05 level of significance.

Table 7. Bulk Dust Sampling Data for Viable Xerophilic Fungi; MEA media

	Complaint Return Duct	*Main Supply Duct*	*Genera Characteristics*	
Genera	*Concentration (CFU/gram)*	*Concentration (CFU/gram)*	*Water Activity*	*Frequency of Detection Indoors*
Cladosporium	*18447*	*27885*	*High*	*Frequently Encountered (FE)*
Penicillium	*17476*	*2885*	*High*	*FE*
Epicoccum nigrum	*3883*	*0*		*FE*
Pithomyces	*971*	*0*		*Less Common (LC)*
sterile fungi	*0*	*962*		
yeasts	*0*	*962*	*High*	*FE*
Acremonium	*0*	*962*	*High*	*LC*
Aspergillus fumigatus	*0*	*962*	*Low to High*	*FE*

Table 8. Bulk Dust Sampling Data for Viable Xerophilic Fungi; DG18 media

	Complaint Return Duct	*Main Supply Duct*	*Genera Characteristics*	
Genera	*Concentration (CFU/gram)*	*Concentration (CFU/gram)*	*Water Activity*	*Frequency of Detection Indoors*
Cladosporium	*17476*	*41346*	*High*	*Frequently Encountered (FE)*
Penicillium	*7767*	*1923*	*Low to High*	*FE*
Epicoccum nigrum	*2913*	*0*		*FE*
Eurotium (Aspergillus) amstelodami	*1942*	*0*	*Low*	*FE*
Aureobasidium pullulans	*971*	*962*	*High*	*FE*
Rhizopus stolonifer	*971*	*0*	*High*	*FE*
sterile fungi	*0*	*962*		
Rhodoturula	*0*	*962*	*High*	*FE*

Table 9. Bulk Dust Sampling Data for Viable Mesophilic Fungi; MEA media

	Complaint Return Duct	*Main Supply Duct*	*Genera Characteristics*	
Genera	*Concentration (CFU/gram)*	*Concentration (CFU/gram)*	*Water Activity*	*Frequency of Detection Indoors*
Penicillium	*21296*	*0*	*Low to High*	*Frequently Encountered (FE)*
Cladosporium	*20370*	*42453*	*High*	*FE*
Epicoccum nigrum	*1852*	*1887*		*FE*
Trichoderma koningii	*926*	*0*	*High*	*FE*
Chaetomium	*926*	*0*		*FE*
Rhodotorula	*0*	*1887*	*High*	*FE*
yeasts	*0*	*943*	*High*	*FE*

Table 10. Bulk Dust Sampling Data for Viable Mesophilic Fungi; CMA media

	Complaint Return Duct	Main Supply Duct	Genera Characteristics	
Genera	Concentration (CFU/gram)	Concentration (CFU/gram)	Water Activity	Frequency of Detection Indoors
Penicillium	27778	0	Low to High	Frequently Encountered (FE)
Cladosporium	20370	42453	High	FE
Aureobasidium sydowii	2778	0		
sterile fungi	926	943		
yeasts	926	0	High	FE
Rhodotorula	0	943	High	FE
Rhinocladiella	0	943		

Table 11. Airborne Spore Count Data for Fungi; Quiescent Sampling, 2900 liters

	Outdoors	*Indoor Complaint Area*	*Indoor Non-Complaint Area*	*Genera Characteristics*	
Genera	*Concentration (spores/m³)*	*Concentration (spores/m³)*	*Concentration (spores/m³)*	*Water Activity*	*Frequency of Detection Indoors*
Cladosporium	*8333*	*347*	*168*	*High*	*Frequently Encountered (FE)*
unknown	*1307*	*347*	*0*		
basidiospores	*980*	*0*	*0*		
Alternaria	*645*	*0*	*0*	*High*	*FE*
Epicoccum	*327*	*0*	*0*		*FE*
Ganoderma	*163*	*0*	*0*		
ascospores	*163*	*0*	*0*		
hyphal fragments	*163*	*0*	*0*		
total structures	*12097*	*693*	*168*		

Table 12. Airborne Spore Count Data for Fungi; Aggressive Sampling, 2000 liters

	Outdoors	*Indoor Complaint Area*	*Indoor Non-Complaint Area*	*Genera Characteristics*	
Genera	*Concentration (spores/m^3)*	*Concentration (spores/m^3)*	*Concentration (spores/m^3)*	*Water Activity*	*Frequency of Detection Indoors*
basidiospores	*5127*	*0*	*0*		
ascospores	*1465*	*217*	*488*		
Asp-Pen like	*0*	*217*	*0*	*Low to High*	*Frequently Encountered (FE)*
Cladosporium	*0*	*217*	*0*	*High*	*FE*
Drechslera / Bipolaris	*0*	*217*	*0*		
Alternaria	*0*	*0*	*244*	*High*	*FE*
total structures	*7080*	*867*	*732*		

Table 13. Airborne Actinomycetes and Bacillus; Quiescent Sampling, 84.9 liters, TSA media

	Indoor Complaint Area	Indoor Non-Complaint Area	Outdoors	Genera Characteristics	
Genera	Average Concentration (CFU/m^3)	Average Concentration (CFU/m^3)	Average Concentration (CFU/m^3)	Water Activity	Frequency of Detection Indoors
Thermophilic Actinomycetes	197	174	75	High	
Bacillus	12	0	0		

Table 14. Airborne Actinomycetes and Bacillus; Aggressive Sampling, 28.3 liters, TSA media

	Indoor Complaint Area	Indoor Non-Complaint Area	Outdoors	Genera Characteristics	
Genera	Average Concentration (CFU/m^3)	Average Concentration (CFU/m^3)	Average Concentration (CFU/m^3)	Water Activity	Frequency of Detection Indoors
Thermophilic Actinomycetes	256	389	460	High	
Bacillus	35	35	35		

Microbial Sampling Data Analysis

Bioaerosol sampling data were assessed by associating concentrations and types of fungi between locations, comparing the types of indoor fungi at PPHS to fungi commonly detected in other indoor environments, comparing indoor and outdoor airborne fungi concentrations and identifying fungi which tend grow in humid environments.

Several types of fungi were unique to certain indoor or outdoor sampling locations. Epicoccum nigrum was marginally elevated in the non-complaint area when compared to outdoor and complaint areas (see Table 4). Cladosporium was the dominant airborne indoor fungi during quiescent sampling. Cladosporium was also dominant outdoors.

Wallemia sebi (41 CFU/m^3) was unique only to the complaint area air, and Aspergillus restrictus (12 CFU/m^3) was unique to the non-complaint area air; neither was detected in other air or bulk samples. These low water activity fungi are frequently encountered indoors. Their unique presence in the complaint and non-complaint areas does not present a special risk for occupants of these areas. Concentrations of these fungi were similar to others that were not dominant in the indoor air. The Botrytis, Aspergillus versicolor, Mucor, Cunninghamella, and Aspergillus niger fungi were unique to outdoor air samples.

Spearmans' non-parametric correlation statistics are presented in Table 5 (for Xerophilic fungi) and Table 6 (for Mesophilic fungi), under columns which compare fungal concentrations between two locations. At the bottom of each table, the row "Associated?" describes the results of the Spearman test. The word "No" indicates that no association (similarity) exists with at least 95% confidence.

The Spearmans' correlation coefficient (r_s) for complaint versus non-complaint area fungi concentrations revealed a strong correlation (0.896) for mesophilic fungi (Table 6) and a weaker correlation (0.605) for xerophilics during aggressive sampling. The association (similarity) in concentrations of fungi between these areas was significant ($p < 0.05$) for mesophilics, and very close to passing the test for significance ($p = 0.112$) for xerophilics. Based on the strength of the associations, filter changing which disturbs and distribute dust within the basement air handler HVAC system is likely to expose complaint and non-complaint areas to similar types and concentrations of fungi. Correlations between complaint and non-complaint areas during quiescent sampling were weak and demonstrated no significant association.

Correlations between indoor and outdoor concentrations measured during aggressive sampling conditions indicated that mesophilics in the complaint area were weakly correlated (0.736) with the outdoors and the association was significant ($p < 0.05$). Comparisons of outdoor mesophilics to those in the non-complaint area, and comparisons of xerophilics between complaint and non-complaint areas were weak and demonstrated no significant association.

Bulk sampling detected two dominant and roughly equal concentrations of Cladosporium and Penicillium in the complaint return duct dust. Penicillium concentrations were one order of magnitude higher in the complaint supply compared to the main supply. Conditions in the complaint supply may favor the growth of Penicillium. However, airborne concentrations were not elevated indoors compared to outdoors.

Pithomyces (less common) was detected in both complaint return bulk dust and in the air of the complaint and non-complaint areas. Eurotium (frequently encountered) was unique to the complaint area return dust and air. Neither of these fungi were dominant in the indoor air; they do not indicate microbial contamination.

Four fungi were unique to complaint area return duct dust; Rhizopus stolonifer, Trichoderma koningii, Chaetomium, and Aureobasidium sydowii. These fungi were not detected in any other air or bulk samples. Excessive humidity could promote the growth of two of these fungi. Cladosporium was the dominant fungi in the main supply duct dust. Aspergillus fumigatus and Rhinocladiella were unique to the main supply dust and were not detected in any other air or bulk samples.

Spore counts during quiescent sampling were lower indoors than outdoors. During aggressive sampling, certain spores were present in indoor air that were not detected in outdoor air. These include Drechslera / Bipolaris and spores characterized as Aspergillus-Penicillium. Indoor counts of these fungi were not considered to be elevated relative to the total structures detected outdoors.

The results of quiescent air sampling demonstrated that thermophilic actinomycetes concentrations could be marginally elevated indoors relative to outdoors. Dissemination of this fungi occurred in the complaint and non-complaint areas. During aggressive sampling, indoor concentrations were not elevated in relation to outdoor concentrations. The detection of thermophilic actinomycetes indicates excessive moisture. An exposure problem cannot be ruled out since thermophilic actinomycetes is unusual in the indoor environment and has been implicated in cases of hypersensitivity pneumonitis.

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