BIOAEROSOL INVESTIGATIONS
COLUMBIA PLAZA

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ABSTRACT

A building with a long history of both specific and nonspecific complaints ascribed to indoor air pollution was intensively studied during March and July of 1987. The building was overtly contaminated with fungus growth and had a history of flooding and excessive humidity. Sampling sites were chosen based on management's perception of problem and problem-free areas and on preliminary analysis of a self-administered questionnaire. Four sites were sampled on each of three floors, two with high complaint rates and one with few complaints. Duplicate Andersen culture plate samples (using separate media designed to detect fungi, bacteria and thermophilic actinomycetes), single spore trap samples, relative humidity and CO_2 measurements were taken at least 6 times at each site over three consecutive days during March (heating season) and July (cooling season).

Unusual bioaerosol exposure situations were found on both sampling occasions. In March, Thermoactinomyces levels far exceeded those outdoors at all building sites. In July, Sporobolomyces were abundant at several sampling sites. Specific sources of these organisms were not determined. Both of these organisms have been implicated in building related hypersensitivity pneumonitis. Fungi obviously contaminating surfaces were not elevated in ambient air, but levels increased with agitation of contaminated materials.

Although hypersensitivity pneumonitis was not documented in this building, conditions were similar to other situations where disease epidemics have occurred. Potential sources of these organisms (central air handling unit drip pans, peripheral and vertical fan coil unit drip pans and filters) should be maintained clean and dry at all times. Relative humidity should not be allowed to exceed 60% at any time, and a relative humidity of less than 50% is preferable.

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I. INTRODUCTION

The "sick" or "tight" building syndrome and building related illness continue to be of increasing concern. While a number of consultants in the private sector, as well as a few academicians, and individuals in government agencies are solving, or attempting to solve, problems in this area on a case by case basis, published research results are still extremely limited, especially concerning the role of bioaerosols. The ACGIH has begun to formulate a standard protocol to be used in approaching cases of sick building syndrome [Burge et al. 1987] but the protocol is primarily based on personal experience of the committee members, and not on field-tested methods. Studies presented here were designed to begin the development of a tested procedure for assessing sick or tight building syndrome and epidemics of building related illness that may involve microbial aerosols.

A. BACKGROUND

1. Indoor Air Quality Related Symptoms

Terms used to describe non-industrial occupational disease attributed to poor indoor air quality have not been standardized. We prefer to use tight building syndrome (TBS) for cases where symptoms cannot be assigned to a specific pollutant, and that are the result of inadequate fresh air ventilation (although the actual cause of symptoms may be the accumulation of a mixture of low level pollutants). The term sick building syndrome (SBS) is frequently used for these problems, especially in the lay press [Toufexis 1988]. Building related illness refers to cases where objective clinical findings make clear the etiology of the disease. Into this category fall legionnaire's disease, hypersensitivity pneumonitis, exposure to toxic levels of carbon monoxide, etc.

In general, symptoms of tight building syndrome include mucous membrane irritation, headaches, fatigue, nausea and dizziness. Mucous membrane irritation is often manifested as "dry" throat, stuffy sinuses, and burning eyes [Kreiss & Hodgson 1984, Bardana & Montanaro 1986, USEPA 1987]. In most cases,the actual environmental factor inducing these symptoms is unknown. Buildup of CO_2, unknown volatile organic compounds, cigarette smoke, relative humidity that is either too low or too high, and thermal discomfort are often blamed [Baetjer 1968, USEPA 1987, Turiel 1985, Samet 1987]. Whatever the actual cause, increasing fresh air ventilation rates to areas where symptoms occur usually solves the problem.

Building related illness can be classified into hypersensitivity disease, infectious disease, toxic syndromes, and psychogenic illness [Burge 1988]. Hypersensitivity diseases that have been reported from buildings include hypersensitivity pneumonitis, humidifier fever, allergic asthma, allergic rhinitis, and rarely, allergic dermatitis [Kreiss & Hodgson 1984].

Hypersensitivity pneumonitis (HP) is characterized by acute recurrent pneumonias, cough, shortness of breath, fatigue, all associated with building occupancy [Middleton et al. 1978; Salvaggio 1987]. Laboratory findings include restrictive pulmonary function, reduced diffusing capacity, increased white blood cell count, interstitial infiltrates on X-ray, and, often, IgG antibodies to offending antigens. HP is caused by inhalation of antigens which induce an inappropriate antibody response [Arnow et al. 1978]. A wide variety of proteins, glycoproteins, lipoproteins, or even complex carbohydrates have been implicated in HP. The antigens are often derived from microbial contamination in the building [Burge 1988]. Often, contamination of the ventilation system itself is the source of airborne antigen [Morey 1984]. Microbes that are frequently implicated in HP include free-living amoebae [Flaherty et al 1984; Sykora et al. 1982], thermophilic actinomycetes [Fink et al. 1971], Bacillus species [Johnson et al. 1980], and a number of saprophytic fungi [Patterson et al. 1981]. It should be noted that intact microbial cells (spores) are not necessary to produce disease. Hypersensitivity pneumonitis is a serious, potentially life-threatening disease, and its occurrence in a building is sufficient cause to immediately remove symptomatic people from the building and begin investigations to discover the source of contamination.

Humidifier fever is a poorly defined disease possibly related to HP but with less severe symptoms which include fever, chills, muscle aches and malaise [Edwards 1976, 1980]. No prominent pulmonary symptoms occur, and X-ray findings are negative. Elevated levels of antigen-specific IgG do occur in some cases. Humidifier fever may be caused by the same types of antigen exposure as is HP. In addition, exposure to bacterial endotoxins can produce the symptoms of humidifier fever [Rylander et al. 1978]. While probably not life-threatening of itself, humidifier fever does indicate contamination, and results in discomfort, lost work time, and may lead to more serious disease. The presence of documented humidifier fever should immediately precipitate investigations leading to corrective action.

Allergic asthma is characterized by reversible wheezing, chest tightness, and cough that occur in response to allergen challenge [Salvaggio 1981]. Laboratory findings include increased reactivity to methacholine or histamine challenge, positive skin test to offending antigens, and elevated antigen-specific IgE [Middleton et al. 1978]. Asthma can also be induced by irritants as described for tight building syndrome. Therefore, the presence of building associated allergic asthma is not sufficient to assume microbial contamination.

Allergic rhinitis produces itchy watery eyes and nose and often fatigue. Elevated antigen-specific IgE and associated positive skin tests are diagnostic [Middleton et al. 1978]. Fungus spores are frequently a cause of allergic rhinitis as well as asthma. In general, except in months where outside exposure does not occur (winter with snow), it is difficult to assign building related contamination as a cause for rhinitis. Outdoor exposures are almost always equal to or higher than indoors [Solomon and Burge 1984], and, apparently, only a few spores are necessary to elicit response in highly sensitive individuals.

Infectious diseases are less commonly associated with building-related illness. Those that are fall into three general categories: 1) transmission of human source viruses (e.g., measles transmission through ventilation systems in clinical settings) [Riley 1982]; 2) accumulation of human source pathogens (e.g., influenza transmission in crowded interiors) [Moser et al. 1979]; or 3) building or adjacent contamination with facultative pathogens (e.g., Legionella) [Frazer 1985]. These diseases are readily diagnosed by most physicians, and investigations of building associations are relatively straight-forward since the specific etiologic agents are known.

Toxic syndromes, which do constitute illness, range from CO poisoning, which is well-defined, to biological toxin exposure, which is poorly defined and which may play a role in symptoms of tight building syndrome, humidifier fever, or HP. Carbon monoxide exposure in buildings usually results from attached garages that feed exhaust fumes into buildings due to negative pressure situations or air intakes adjacent to loading docks or major traffic arteries [Nagda 1985]. Biological toxin exposure requires serious and continuing contamination with toxin producing strains of microorganisms [Burge et al. 1981]. Acanthamoeba and gram negative bacterial endotoxins have been implicated in building related disease [Flaherty et al. 1984; Rylander et al. 1978]. Acute or chronic toxicosis resulting from airborne mycotoxins has yet to be clearly documented.

Psychogenic illness is almost always associated with any building-related epidemic, especially when symptoms are difficult to document physiologically (such as is usually the case in tight building syndrome). Building-related psychogenic illness can result from anxiety produced when co-workers experience symptoms or disease or from other job-related stresses [Colligan 1981]. The actual diseases may be unrelated to building occupancy (such as clusters of unrelated cancers). Psychogenic illness can obscure patterns of real symptom occurrence that might be valuable clues leading to sources of problems.

A second class of building-related psychogenic illness results when physicians tell their patients that they are reacting to "something" (usually chemicals) in their environment, whether at work or at home. This diagnosis results either from frustration (the physician may not know what is wrong), or, more often, from a belief that many symptoms traditionally considered psychogenic are, in fact, caused by

environmental factors (clinical ecology, environmental medicine). Unfortunately, no research supports these beliefs, and even extensive environmental investigations fail to find any substantive cause for the symptoms [Terr 1986, 1987].

2. History of Microbial Aerosol Investigations

Two major problems have plagued those doing research in bioaerosols: 1) technology applied to sampling for biological aerosols has lagged far behind that applied to non-living air pollutants, and 2) almost total reliance has historically been placed on viable particulate collections in the indoor environment, while total particulate counts have dominated research in the outdoor air.

a. Technology

In spite of the fact that, as far as sample collection is concerned, the same principles apply, most people attempting to assess nonpathogenic bioaerosols have ignored the large information base available on particulate sampling. For many years, gravitational settling has been used in most bioaerosol investigations, especially those dealing with non-pathogenic forms in other than hospital environments. The limitations of this sampling modality have been clearly set forth elsewhere [Burge & Solomon 1987] and will not be extensively discussed here. It is sufficient to say that settle plate or settle slide samples never produce a quantitative estimate of bioaerosol levels, and are equally unreliable as qualitative estimators.

A second technology problem involves the use of reasonably well-designed equipment without proper calibration, and for purposes beyond design capabilities. For example, the rotorod sampler, a rotating impactor which is very efficient for collecting airborne pollen, is the instrument most often used by allergists to assess outdoor fungus spore levels. Unfortunately, the instrument is efficient only for particles in excess of 15 μm, while more than half of airborne fungus spore types are smaller than 10 μm.

b. Viable vs Particulate Collections

One usually thinks of bioaerosols in terms of the fact that they are (often) living organisms. However, unless infectious agents are involved, viability probably has little to do with their health effects. Virtually all indoor air sampling for bioaerosols has utilized some kind of culture plate sampling, either direct (culture plate impactors) or indirect (filter cassette or liquid impinger samples that are subsequently cultured). It has become clear that the use of culture plate sampling alone not only qualitatively misrepresents the air spora (because only those cells that are alive and that are able to grow on the culture medium provided are recovered), but quantitatively underestimates levels by factors that increase logarithmically as levels increase [Burge & Solomon 1977]. While technology is available that could

make direct spore sampling straight forward (although sample analysis will continue to be a skilled task), only one such sampler is currently on the market (Burkard spore traps).

B. RATIONALE

1. Site Selection

The purpose of the studies presented here was to assess the microbial status of a multistory office building. We used a building that had a long history of both specific and non-specific complaints (although none could be directly attributable to bioaerosols), and overt microbial contamination (mold growing on environmental surfaces). In addition, the building is scheduled for extensive renovation presenting the option of repeat sampling after recommended changes have been made.

2. Investigative Approach

The original plan was to utilize questionnaire results to select sampling sites. Since questionnaire data were not available before the initial sampling event, we chose floors based on floor managements' conception of complaint levels (two floors with high complaint levels, one with few complaints). We assessed each floor at multiple sites using both cultural and particulate techniques. Ideally, continuously operating monitors should be used to document changes in aerosol levels of any pollutant. However, such monitors are not available for bioaerosols. To attempt to minimize errors imposed by the necessity of using "grab" samples, we used duplicate samples at each site on each occasion and sampled each site at least 6 times over a three-day period. We collected samples once during the heating season and once during the cooling season. This design was aimed at both temporal and spatial mapping of microbial aerosols in the building.

II. MATERIALS

A. SITE DESCRIPTION

1. The Building

Columbia Plaza is a Washington, D.C. office complex occupied by several government agencies each with its own administration, and is managed by the General Services Administration, and leased from a private firm. The complex consists of a 15 story tower with two below grade garage levels and two lower units, each with three garage levels. Our investigations were restricted to the tower (Figure 1).

The three floors chosen for study were floor 2, occupied by the Equal Employment Opportunities Commission (EEOC), floor 5 occupied by the Bureau of Mines (BOM), and floor 13, occupied by the State Department (SD).

2. The Ventilation System

Heating, ventilation and air conditioning (HVAC) for this building was accomplished by several systems. The primary HVAC function was provided by four main fan units (MFU) located on the top (15th) level of the building. MFU Nos. 1 and 2 served floors 14 and 15, and MFU Nos. 3 and 4 served floors 1-13.

The MFU's operated with 100% outside air intake and did not recirculate airflow. These units provided heating, cooling, dehumidification, and filtering of outside air. The MFU systems provided "once through" airflow at a design rate of about 1.7 building air changes per hour (ACH), based upon unit capacity and building volume.

Supply air ventilation from the MFU's was distributed to building levels through vertical shafts with openings to each level. Booster fans were located at the floor openings to facilitate airflow from the shaft to a plenum space above the ceiling on each floor. Fresh air distribution was designed and originally installed to be accomplished through ceiling registers between the occupied space and the pressurized plenums. However, distribution was adversely affected by problems resulting from many damaged and missing ceiling tiles, modifications including ducted subsystems, equipment malfunctions, and ceiling alterations made by occupants in attempts to enhance their comfort in temperature, humidity, and air movement. Air distribution was further complicated on floors 1-4, for which the ceiling plenum space was common to two adjacent buildings in the office complex.

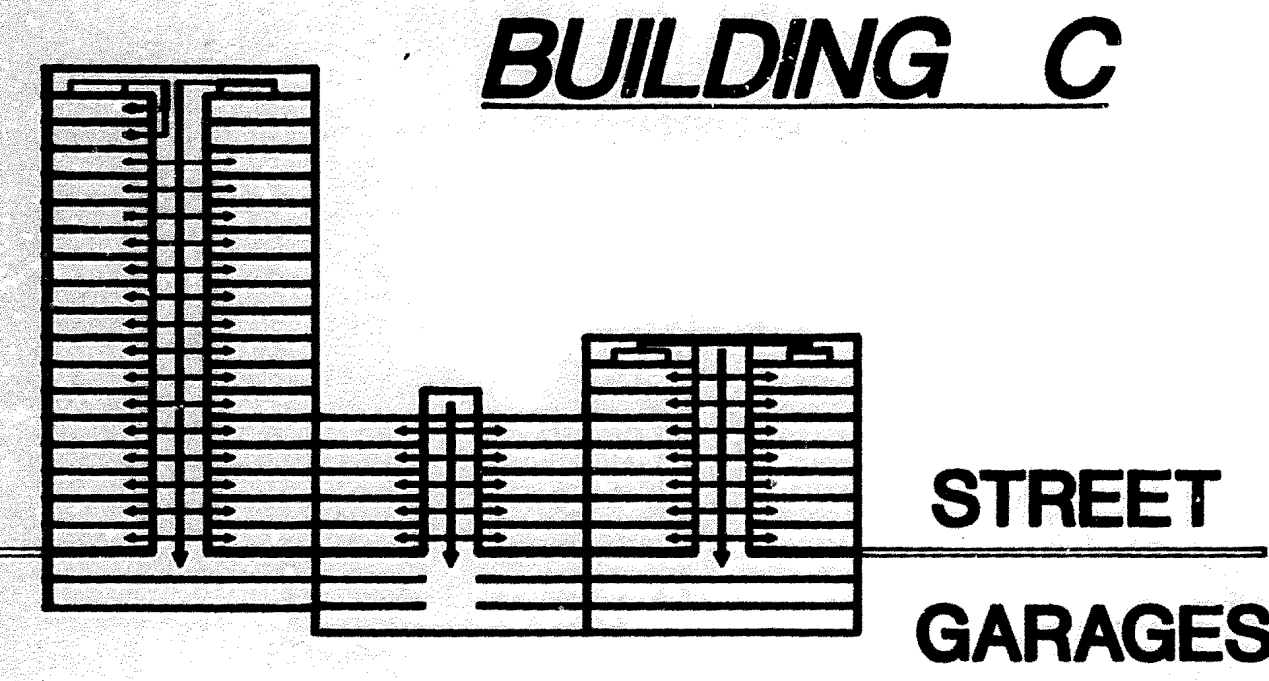

Figure 1. A DIAGRAMMATIC REPRESENTATION OF THE COLUMBIA PLAZA OFFICE BUILDING COMPLEX

Relief (exhaust) ventilation from the building levels was provided in two ways: 1) discharge into the parking garage below the occupied floors (below ground level), and 2) exhaust from the bathrooms and kitchen. The bathroom and kitchen exhaust systems vented to the roof and had relatively small capacity compared to that of the garage and MFU systems. The garage relief ventilation system utilized two vertical stacks which ran the entire height of the building. Each stack terminated in the garage with a booster fan to draw air from the building and into the garage. These stacks were reported to be of somewhat confusing and inefficient design. Additional exhaust fans were located between the garage and the outside to discharge air from the garage at ground level.

Additional HVAC was provided by two types of systems located on all building levels: 1) vertical fan units (VFU), and 2) peripheral fan units (PFU). The VFU's were 100% recirculating systems to provide air movement, cooling, and dehumidification. Several VFU's operated on each floor of the building. The VFU's drew air in from an intake opening near the floor and/or from the pressurized plenum above the ceiling. The VFU's typically had three speeds and thermostat control operated by local occupants. The PFU's were located against outside walls but could not take in or discharge air to the outside. There were roughly three PFU's for each VFU. The PFU's were strictly recirculating units to provide local (peripheral) heating, cooling and air movement. The PFU's were operated by local occupants.

Previous, extensive studies of ventilation for this building have concluded that the systems did not provide sufficient fresh air supply and that a ducted distribution system was needed. It was also generally concluded that the primary air handling systems were not capable of sufficient humidity reduction.

B. COMPLAINT HISTORY

The study building has been a focus of air quality controversy for over 10 years, and has a long complaint history. The first major problem with air quality involved CO leaking into occupied space from the garage levels. Leakage occurred due to inadequate garage ventilation, excessive openings between the garage and office space, and depressurization of the lower occupied floors. In spite of an accident/fire prevention office notice that a severe problem existed and an order to evacuate the affected offices, the situation was not brought under control for four years essentially because 1) levels of CO were low enough to make questionable claims of serious health effects, and 2) management remained unconvinced that an ongoing problem existed and did not want to spend the money necessary to make ventilation system changes. In fact, exhaust odor penetrating an office building does constitute a serious problem in that it affects comfort, worker attitudes, and productivity.

A second major problem has been persistent flooding of the second floor which caused obvious mold growth on walls and carpets, and resulted in serious concern in occupants for potential health effects. One report from a physician indicated the possibility of hypersensitivity pneumonitis from one flooding incident. However, no physical examinations were done, and no supporting evidence is available to document the presence of this disease. In spite of several repair efforts, sporadic leaks and floods persist.

These two relatively clear-cut problems and the long delays and battles required for their solution set the stage for major dissatisfaction with comfort conditions in the building (and, incidentally, a wide range of probably psychogenic complaints). Complaints from several floors became so prevalent, that the first outside consultant was hired to examine the CO problem as well as complaints of stale air. Complaints continued, and gradually, concern for generalized mold contamination in the building began to emerge. Over a period of nine years, a sequence of 10 outside consultants were called in to examine the building and recommend remedial actions (Table 1).

All consultants agreed (although not all presented supporting data) that the fresh air supply and distribution system was inadequate. In other words, tight building syndrome was likely. These remain the primary concerns today.

Various consultants disagreed whether or not the building was mold contaminated and on the health effects of potential contamination. Several consultants used surface swab samples to assess microbial status. Of the consultants that used volumetric devices to collect air samples, none found ambient bioaerosols much in excess of 200 colony forming units per cubic meter of air (cfu/m^3) (Figure 2). Two of these consultants were able to generate elevated fungal spore levels (20000 cfu/m^3 of air) by agitating vertical or peripheral fan coil unit components. All but one of the consultants ascribed building health effects to 1) inadequate fresh air and 2) excessive mold in the building. These statements were made in the absence of direct evidence of microbially induced disease, and low levels of ambient bioaerosols. Needless to say, many occupants became convinced that mold was causing their building-related symptoms.

Table 1
A history of complaints in Columbia Plaza related to possible biological contamination

DATE	SOURCE	RECOMMENDATION OR REQUEST
Feb 78	Management	Low relative humidity; use humidification
May 78	Consultant A	Pressurize building with respect garage; check fans; replace missing ceiling tiles.
Jan 79	Consultant B	Air sampling for molds; unknown health effects; lower relative humidity; use chlorox.
June 80	Consultant C	Maintain positive pressure; decrease relative humidity; install new HVAC
Dec 80	Consultant D	Molds present, causing concern; concern over inadequate ventilation; need HVAC improvement.
May 81	Management	Modify HVAC to lower relative humidity and isolate garage; contract for June 81.
May 81	Management	Install individual solenoids and thermostats so VFCU fans can run all the time.
Nov 81	Consultant E	Swab samples: > mold floors 1-4 than 5-15. Pattern indicates supply air source (evidence?); dry out building and monitor complaints
Jan 83	Consultant F	Air samples; low level mold except in disturbed VFU's; clean units, routine filter change.
Sept 83	Consultant F	Fix leaks, improve maintenance, replace ceiling tiles, operate AHU all the time; reduce RH, use partitions instead of walls; increase filtration efficiency.
Feb 84	Consultant D	Three employees entitled to compensation due to A. niger exposure.

Feb-Apr 85	Consultant F	AHU are operating all the time; VFU filters changed bi-monthly; moisture incursion controlled; most tiles replaced; CO_2 up in some areas; increase preventative maintenance; replace sound linings; open plan ventilation; control RH; Provide adequate ventilation air.
May 85	Consultant G	Swab and filter sampling; molds present; (?many misconceptions re molds and allergens); 35 cfu/m^3 maximum mold level measured.
Feb 86	Consultant G	Mold on cheese cloth cover of vent
Mar 86	Consultant H	"Contamination" but no documentation; air exchange rate low (no doc); chillers inadequate; plenum system nonfunctional; fiberglass in main AHU moldy and disintegrating; Eye, nose, throat irritations, cough, shortness of breath, fatigue (source of info?); inadequate ventilation and RH control; modify or abandon bldg.
Apr 86	Management	Project description: Replace HVAC system with duct 100% outside air; replace soundliners.
May 86	Management	Phasing plan for renovation during occupancy.
May 86	Consultant K	More mold species indoors than out; treat carpet, walls with biocides.
June 86	Consultant L	<air flow due to 100% fresh air design (<0.5 air changes/hour); Redesign HVAC; teach occupants about thermostats.

At the time our studies began, then, no clear evidence of bioaerosol induced disease was available, no ambient elevations in bioaerosol levels had been discovered, and yet many building occupants were convinced that mold growth in the building represented a severe health risk.

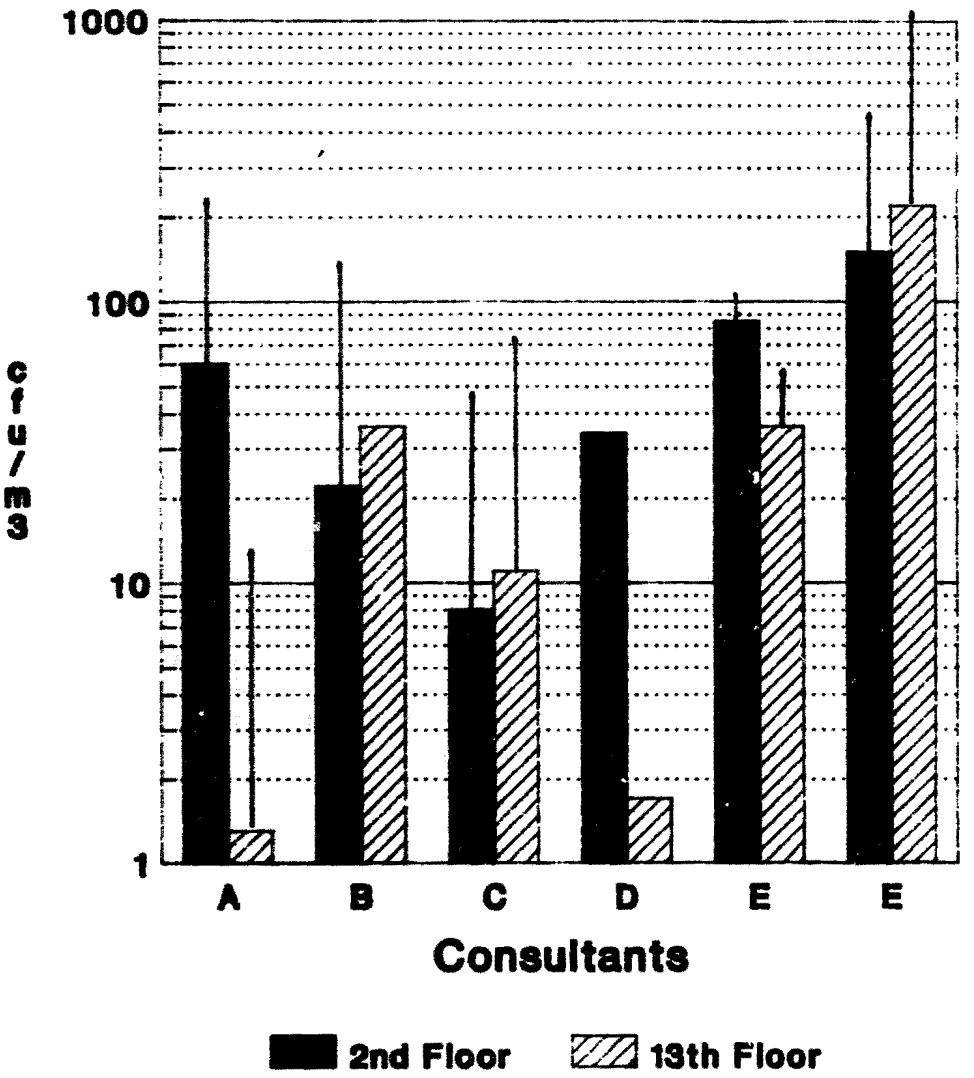

Figure 2. VOLUMETRIC FUNGUS SPORE RECOVERIES BY 5 DIFFERENT AIR QUALITY CONSULTANTS IN COLUMBIA PLAZA

III. METHODS

A. QUESTIONNAIRES

A sample of the questionnaire, designed by NIOSH personnel, is presented in Figure 3. Questionnaires were supplied to the building by NIOSH, and individuals within each agency were delegated to distribute them. Department heads were urged to recommend that the questionnaires be completed. All questionnaires were then mailed to NIOSH, then by NIOSH to the University of Michigan.

Each questionnaire was analyzed separately as follows: Questions 1-5 were scored yes, no or no answer. Question 6 scoring was based on frequency of occurrence: always = 5, frequently = 4, occasionally = 3, rarely = 2, never = 1, no answer = 0. A discomfort score (Dscore) was calculated by summing the greater of too much or too little air movement, too hot or too cold temperature, too much or too little humidity, stuffiness, and odor. Question 7 was scored yes or no for each subcategory.

Question 8, medical conditions, was scored as follows: each symptom was scored as 1 if a mark appeared in at least one time-status column except "when you waken", "weekends only," or "no specific trend". Symptom scores were calculated in three categories: hypersensitivity pneumonitis (aching joints, chest tightness, cold or flu symptoms, difficulty breathing, fever/chills, and wheezing); symptoms that are known to be attributable to bioaerosols excluding hypersensitivity pneumonitis and infectious disease (aching joints, chest tightness, cough, difficulty breathing, eye irritation, fatigue/drowsiness, headache, hearing disturbances, sinus congestion, sneezing or running nose, wheezing); and tight building syndrome (cough, dizziness, dry nose or throat, eye irritation, fatigue/drowsiness, headache, nausea, sinus congestion, sneezing or running nose, sore throat). Scores within each category were added, the total divided by the total possible for that category, and the ratio multiplied times 100. For example, if one of the bioaerosol symptoms was positive, the score for the bioaerosol category was (1/11)x100, or 9. No attempt was made to evaluate any individual's health status.

All questionnaire data was entered into DataBase III+ which was subsequently programmed to calculate discomfort and symptom scores, and to produce general summations and averages. A subfile including floor, agency, age, sex, smoking status, discomfort status, discomfort score, hay fever, other allergies, and scores for hypersensitivity pneumonitis, bioaerosol-related symptoms, and tight building syndrome symptoms, was transferred to Systat for additional data analysis.

DEPARTMENT OF HEALTH & HUMAN SERVICES

Public Health Service

Centers for Disease Control
National Institute for Occupational
Safety and Health – ALOSH
944 Chestnut Ridge Road
Morgantown, WV 26505–2888

OFFICE BUILDING EVALUATION QUESTIONNAIRE
January 1987

INSTRUCTIONS: Please complete this form and return it in the accompanying envelope. Your answers are completely confidential and will be seen by NIOSH staff only.

Agency Affiliation: HHOC: _____ HHH: _____ AID: _____ State Depart: _____ Treasury: _____ GAO: _____

Office Location: Room Number: _____ in the: Low-rise: ___ High-rise: ___ Intermediate: ___

Age: _____ Sex: _____ Job Title:(Print) _____

PLEASE CHECK THE APPROPRIATE LINE

Are you a smoker?	1. No ____	1. Yes ____
a) If yes, do you smoke at your work area?	a) No ____	a) Yes ____
Do others smoke at your work area?	2. No ____	2. Yes ____
Do you live with a smoker?	3. No ____	3. Yes ____
Have you experienced any significant discomfort related to your current work environment?	4. No ____	4. Yes ____
If Yes:		
a) Have you had to change your usual work activities because of this?	a) No ____	a) Yes ____
b) Have you had to change your usual work location because of this?	b) No ____	b) Yes ____
If yes, what location did you move from?	Room Number: _____	
c) Have you requested a change because of this discomfort?	c) No ____	c) Yes ____
Are you presently taking any medication?	5. No ____	5. Yes ____

Environmental Conditions

At your desk, on most days:	ALWAYS	FREQUENTLY	OCCASIONALLY	RARELY	NEVER
a) There is too much air movement.	a)___	a)___	a)___	a)___	a)___
b) There is too little air movement.	b)___	b)___	b)___	b)___	b)___
c) The temperature is too hot.	c)___	c)___	c)___	c)___	c)___
d) The temperature is too cold.	d)___	d)___	d)___	d)___	d)___
e) There is too much humidity.	e)___	e)___	e)___	e)___	e)___
f) There is too little humidity.	f)___	f)___	f)___	f)___	f)___
g) The air feels stuffy.	g)___	g)___	g)___	g)___	g)___
h) It is too noisy.	h)___	h)___	h)___	h)___	h)___
i) The lights are too bright.	i)___	i)___	i)___	i)___	i)___
j) It is too dark.	j)___	j)___	j)___	j)___	j)___
k) The air has an unpleasant odor.	k)___	k)___	k)___	k)___	k)___

* PLEASE TURN PAGE AND ANSWER QUESTIONS ON REVERSE *

Figure 3A. THE QUESTIONNAIRE USED IN COLUMBIA PLAZA STUDIES (Front)

7. Do you have (or have a history of) any of the following?

a) _____ Hay fever or pollen allergies
b) _____ Skin allergies/dermatitis
c) _____ Other allergies
d) _____ Sinus problems

8. Medical Conditions

Do you usually have any of the following medical conditions? If so, please check ALL boxes that apply.

			WHEN DOES THIS COMPLAINT OCCUR?												WHEN DO YOU HAVE RELIEF FROM THIS PROBLEM?					
			When you awaken	Morning	Afternoon	Night	All day	Every day	Only on certain days	After holidays, weekends or vacations.	Weekdays only	Weekends only	No specific trend		Morning	Afternoon	Night	Immediately after leaving work.	Only on certain days	No specific trend
Aching joints	B	HP																		
Backache																				
Chest tightness	B	HP																		
Cold or flu		HP																		
Cough	B	T																		
Difficulty breathing	B	HP																		
Dizziness		T																		
Dry, flaking skin																				
Dry nose or throat		T																		
Eye irritation	B	T																		
Fatigue/drowsiness	B	T																		
Fever/chills		HP																		
Headache	B	T																		
Hearing disturbances	B																			
Nausea		T																		
Problem wearing contact lenses																				
Sinus congestion	B	T																		
Skin irritation/itching																				
Sneezing or running nose	B	T																		
Sore throat		T																		
Wheezing	B	HP																		

THANK YOU FOR TAKING THE TIME TO COMPLETE THIS QUESTIONNAIRE.

Figure 3B. THE QUESTIONNAIRE USED IN COLUMBIA PLAZA STUDIES (Back)

B. SAMPLING PLAN

Floors 2, 5 and 13 in the high-rise were chosen for intensive bioaerosol sampling. Floors 2 and 13 were the continuing focus of many complaints. Floor 2 had repeated episodes of flooding, one of which had occurred several weeks before our first sampling occasion. Floor 5 had complaints in past years, but administrative sources reported that problems had been solved.

Samples were taken in March and July of 1987. On each occasion, samples were collected 3 times each day on two days at each of 4 sites per floor. Sites were chosen to be near sample collection stations being used by the National Bureau of Standards for tracer gas ventilation measurements, and to be evenly spaced over each floor. Sites chosen for floor 5 are shown in Figure 4. Sites were comparable for the other floors.

Most samples were taken during ordinary activities at each site. One sample set was taken (using the Spiral Air System Sampler) comparing fungus spore and bacterial levels before and during agitation of vertical fan coil unit (VFCU) filters. Samples were taken at the diffuser serving the fan coil unit and in the adjacent ceiling plenum before filter agitation, and at the VFCU diffuser during filter agitation.

C. SAMPLING EQUIPMENT

Duplicate, 6th stage Andersen viable particle samplers (Andersen, Inc., Atlanta GA) and a Spiral Air Systems (SAS) portable culture plate sampler (Spiral System Instruments, Inc, Bethesda, MD) were used to collect airborne viable microorganisms. Two sixth stage sieve plates and two base plates of the original Andersen cascade culture plate impactor were purchased from Andersen, and spring clamps were designed to hold the single stage to the base plate. Two 0.1 hp pumps were purchased from Gast (Benton Harbor MI), and bolted into a suitcase. The pumps were wired into a timer so that they could be operated simultaneously for precisely measured units of time. The sampling trains were calibrated to one cubic foot per minute before and after each sampling occasion using a rotameter that had been previously calibrated by the manufacturer. Plastic 100cm petri dishes were filled with 45ml culture medium to bring the sampling surface within the recommended distance from the sieve plate holes. Samplers were run for 1 minute on each sampling occasion, resulting in a lower level of sensitivity of 35 colony forming units/m^3 of air. At each site, duplicate samples were collected on malt extract agar for mesophilic fungi (per liter distilled water: 20g malt extract [Difco, Detroit MI], 20g dextrose, 1g bacto-peptone [Difco], 15g granulated agar [BBL, Cockeysville MD]), nutrient agar for 37° bacteria (Difco), and casein soy peptone agar (BBL) for thermophilic bacteria including actinomycetes.

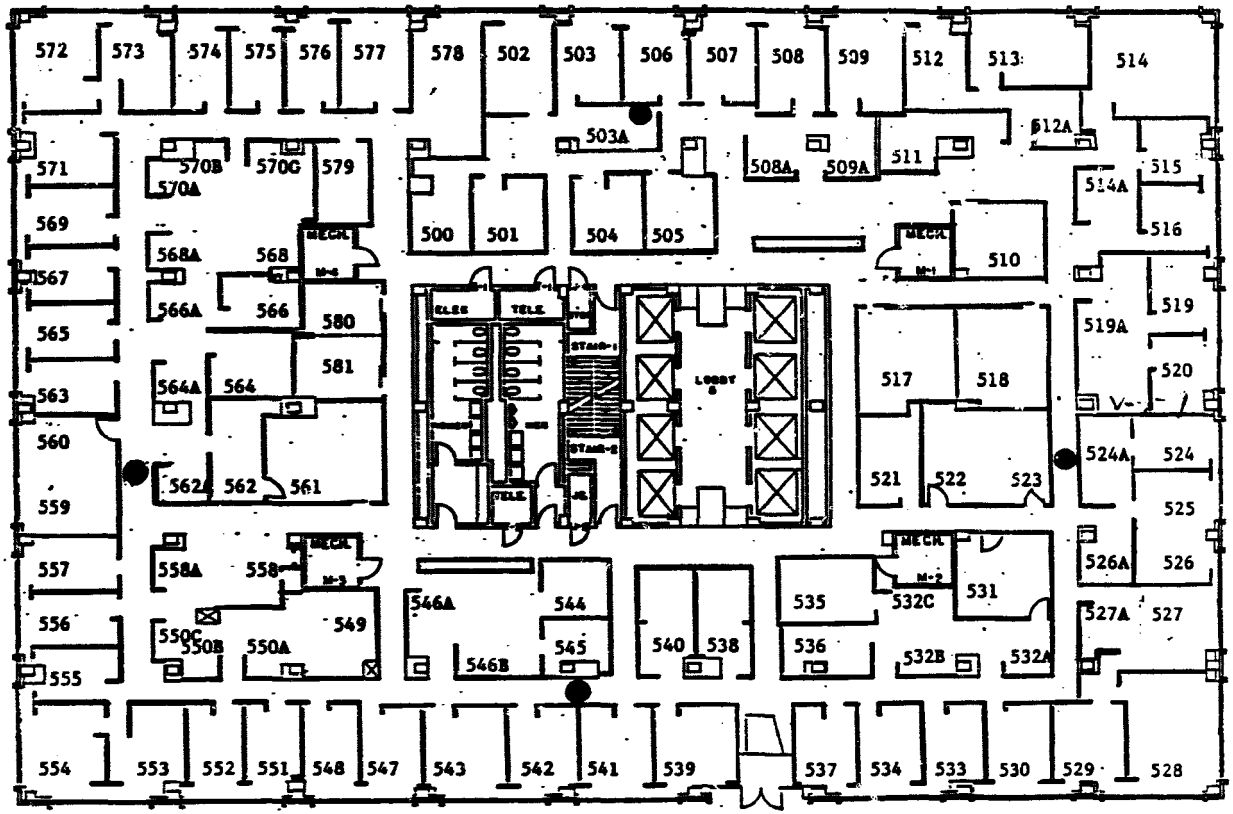

Figure 4. FIFTH FLOOR PLAN WITH SAMPLING SITES MARKED WITH BLACK DOTS

The SAS sampler was calibrated by exhausting a measured quantity of air from a plastic bag using the sampler. Specifically, a measured amount of air was introduced into a sealed plastic bag. The sampler was attached to the bag and operated until the bag was completely emptied. Sampling rate was determined as the average of 3 sequential determinations, and was within 10% of manufacturer's specifications (180 liters/min). Rodak plates were filled with 11ml malt extract agar for fungi and nutrient agar for bacteria. The sampler was run for 20 seconds at 180 liters/min. resulting in a sensitivity of 17 cfu/m^3 of air.

The Burkard personal spore trap (Burkard Manufacturing Co Ltd., Rickmansworth, England) was used for collection of particulate air samples that could be examined microscopically for fungus spores. The battery operated Burkard trap draws 10 liters of air per minute which impacts onto a microscope slide to which Melenex tape (Burkard) coated with Lubriseal stop cock grease has been affixed using gelvatol as an adhesive. The trap was run for 5 minutes during operation of the Andersen samplers for a lower limit of sensitivity of 40-70 particles/m^3 of air depending on how the samples were analyzed. Burkard samplers were recharged after each 30 minutes of operation and calibrated with rotameters supplied by the manufacturer.

Swab samples were collected by two methods: 1) sterile dry swabs were rubbed over an environmental surface, then streaked immediately onto malt extract agar. These plates were mailed to the lab by next day mail for incubation at room temperature. 2) Culturette swabs (American Scientific Products, McGaw Park IL) were wet with storage fluid from enclosed vial, rubbed over the environmental surface, replaced in the original tube, and transported to the lab by next day mail. These swabs were streaked onto malt extract agar the day they were received in the lab, and incubated at room temperature.

Relative humidity and temperature were measured using a battery-powered fan psychrometer that was run simultaneously with the Andersen samplers. Carbon dioxide was measured with a Fuji Infrared CO_2 gas analyzer, Model ZFT5. Carbon monoxide was measured using a G.E. carbon monoxide detector which appeared to be malfunctioning, and its use was discontinued after the first few sites.

D. SAMPLE HANDLING

Culture medium was made during the three days just prior to each sampling occasion and was mailed by overnight express to the site. All batches were checked for sterility by incubation at appropriate temperatures, and for ability to support growth of common airborne organisms (Cladosporium, Penicillium for Malt extract agar; Staphylococcus epidermidis for nutrient, Thermoactinomyces vulgaris for casein soy peptone agar). At the end of each sampling day, all exposed plates were mailed overnight express back to Michigan for incubation. Malt extract agar was incubated for 5-7 days at room temperature with near UV illumination (G.E. Grolights); nutrient agar at 35° for 24-48 hours in the dark, and casein soy peptone at 56° for 24-48 hours in plastic bags with sterile water added to prevent dessication. All colonies on each culture plate were enumerated. All sporulating fungi were identified to genus, or species where possible. Bacteria and thermophilic actinomycetes were only counted.

All counts were converted using Andersen's positive hole conversion chart [Andersen 1958] and colony forming units/m^3 of air sampled calculated. Individual taxon counts were converted by a proportionality method: totals for each taxon were divided by uncorrected total on the plate, resulting in the proportion of the total represented by that taxon. Total corrected counts were then multiplied by this proportion to obtain corrected taxon counts. Counts from SAS samples were converted in a similar manner using an in-house designed conversion program based on Andersen's formulas, and converted to cfu/m^3. The SAS used is about 40% as efficient as the Andersen (as measured in our laboratory in related studies) [Pan et al. 1987].

Burkard slides were mounted in Glycerine Jelly (5g gelatin, 40ml distilled water, 4g phenol, 156ml glycerine, 2ml Calberla's solution [Ted Brown Assoc, Palo Alto CA]) and examined microscopically with a 100x oil immersion objective. At least 10 traverses of the 1.5 x 14mm personal spore trap deposit were examined, all biological particles enumerated, and generic identifications made where possible. All counts were converted to spores per cubic meter of air sampled.

E. DATA STORAGE AND ANALYSIS

All data was initially entered into data books, then onto computer storage discs using Supercalc IV spreadsheets. Analysis utilized this software as well as some in-house designed auxiliary programs. As mentioned above, questionnaire data was analyzed using Dbase III+ and Systat.

IV. RESULTS

A. BUILDING OBSERVATIONS

1. Ventilation

Building fresh air capacity was estimated to be roughly 1/3 of the minimum guideline of 20 cfm per person recommended by ASHRAE (American Society of Heating, Refrigerating, and Air Conditioning Engineers; Standard No. 61-1981). Operational failure or shut-down of one or more MFU would be expected to cause severe reductions in fresh air to the building. Poor distribution was the inevitable consequence of the non-ducted air supply system. Damaged and missing ceiling tiles and ceiling modifications made by occupants disrupted airflow distribution substantially.

The primary ventilation system appeared to be well-maintained. However, all the vertical fan coil units examined were in poor condition, with very dirty fiberglass, sound lining, and cooling coils. The main air handling units were shut off at night and on weekends. Many of the vertical and peripheral fan coil units were not functioning. Many ceiling tiles were missing on both 2 and 13. Tiles adjacent to diffusers were blackened with carbon particles and/or other debris.

2. The Building

Access to the building was on level 2 through a security area with smooth surfaced flooring. All three floors studied were carpeted. Carpeting on floors 2 and 13 was in poor condition, with large wrinkles in traffic paths. Carpet tiles had been installed on 5 and were in good condition. Levels 2 and 13 had floor to ceiling walls enclosing individual offices. Floor 5 had partitions approximately 5 feet high, with only a few enclosed offices. Floor 2 was below grade and had no windows. Floors 2 and 13 were untidy, and Floor 13 was very crowded, with file cabinets intruding into walkways. Floor 5 was neat and well-organized with wide walkways between the semi-enclosed offices.

Evidence of recent flooding was present on floor 2. A few ceiling tiles on each floor appeared water damaged. Mold spores and hyphae had accumulated on surfaces adjacent to the vertical fan coil unit diffusers throughout all three floors.

Lights were left on at all times on floor 2, apparently to "prevent the mold growth that would come with darkness."

B. QUESTIONNAIRES

A total of 679 questionnaires were returned. Data derived from these is presented in Tables 2-7.

Table 2

Percentage of 679 Questionnaires Returned

SEX	SMOKER	DISCOMFORT	HAYFEVER	ALLERGY
Female 52	yes 20	yes 50	yes 34	yes 15
Male 44	no 78	no 42	no 62	no 82
na 4	na 4	na 8	na 4	na 3

na = no answer given

Table 3

Percentage of Complete Questionnaires Returned

	TOTAL #	FEMALES	SMOKERS	DISCOMFORT (YES)	HAYFEVER (YES)	ALLERGY (YES)
EEOC	206	57	18	58	37	13
FLOOR 2	57	58	12	70	37	18
BOM	225	42	25	42	37	14
FLOOR 5	42	50	26	36	38	10
SD	68	50	15	54	40	25
FLOOR 13	46	59	17	57	39	26

EEOC=Equal Employment Opportunities Commission
BOM=Bureau of Mines
SD=State Department.

Table 4

Pearson Chi Square Probabilities For Each Variable vs. Discomfort.

	OVERALL	SD	EEOC	BOM
SEX	0.038	0.783	0.367	0.247
SMOKER	0.266′			
HAYFEVER	0.004			
ALLERGY	0.000			

Table 5

Pearson Chi Square Probabilities Comparing Selected Floors and Agencies

	SEX	SMOKING	DISCOMFORT	HAYFEVER	ALLERGY
BOM/EEOC		0.000	0.081	0.001	0.4[illegible]12
FLOOR 5/2		0.472	0.282	0.001	0.3[illegible]02
BOM/SD	0.142	0.164	0.079	0.753	0.149
FLOOR 5/13	0.375	0.499	0.041	0.952	0.156

Table 6

Independent T-tests

	SEX	SMOKING	DISCOMFORT	HAYFEVER	ALLERGY
DScore	0.000 f>m	0.000 no>yes	0.000 yes>no	0.003 yes>no	0.281 ns
Age	0.000 m>f	0.554 ns	0.044 young>old	0.186 ns	0.552 ns

Table 7

Independent T-tests
Comparing Selected Floors and Agencies

	BOM/EEOC	FLOORS 5/2	BOM/SD	FLOORS 5/13
DScore	0.000 EEOC>BOM	0.241 ns	0.000 SD>BOM	0.000 13>5
Age	0.004 BOM older	0.891 ns	0.011 BOM older	0.877 ns

Overall, females slightly exceeded males, less than 1/3 of occupants returning questionnaires smoked, 34% reported hayfever, and 15% other allergies. BOM had more men, more smokers, and less discomfort than the SD or EEOC. Floor 2 was primarily occupied by EEOC, 5 by BOM and 13 by SD. Comparing floors and agencies, fewer BOM men worked on floor 5 than on other reporting floors. Discomfort among EEOC personnel was centered on floor 2 rather than within the agency. Two thirds of SD questionnaires were returned from the 13th floor (although SD occupies several floors in the building) due to a bias on the part of the internal distributor. (See comment on page 45.)

Overall, females were more often uncomfortable than males, but this difference did not hold for the three agencies analyzed separately. Discomfort was not related to smoking but was strongly related to both hayfever and other allergies.

Using BOM as a reference agency, differences between sex and discomfort were significant for EEOC (fewer men and more discomfort in EEOC) but not for SD. Using BOM floor 5 as a reference, differences between discomfort were significant for both Floor 2 (EEOC) and Floor 13 (SD) (more discomfort on 2 and 13).

Histograms displaying population frequencies for numeric data are presented in Figure 5.

Only Age and Dscore are normally distributed. HP data contains so many zero values that it is not amenable to statistical analysis. Bioaerosol and TBS data have been log and square root transformed, but not normalized. We have therefore used exclusively nonparametric tests on these data sets.

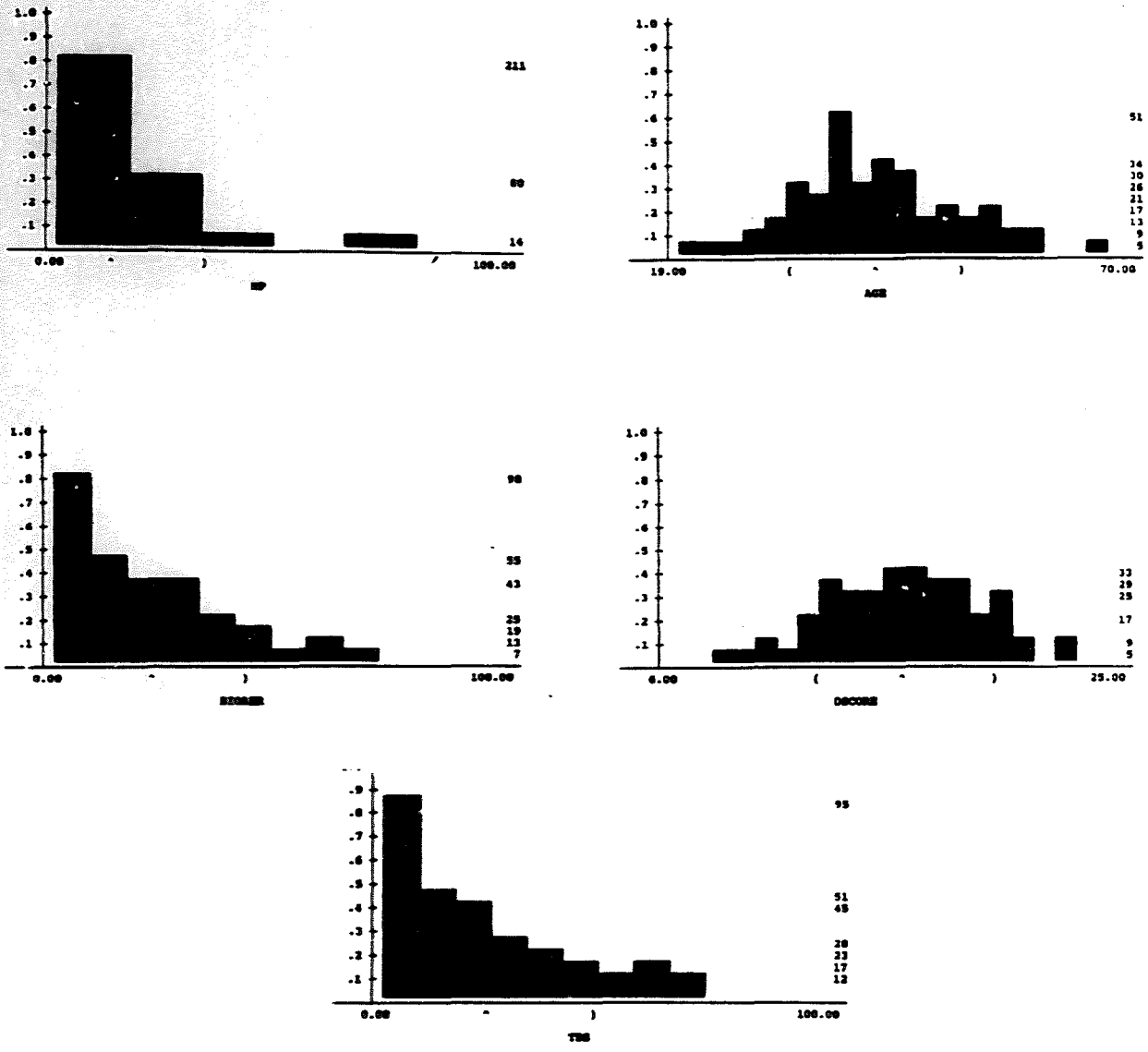

Figure 5. HISTOGRAMS OF NUMERIC QUESTIONNAIRE DATA (Age, Discomfort Score, and Symptom Scores for Hypersensitivity Pneumonitis, Bioaerosols, and Tight Building Syndrome)

By independent T-test, overall, Dscores were higher for females, nonsmokers, and those reporting discomfort and hayfever. In addition, men tended to be older than women, and younger people more often reported discomfort. Comparing agencies, BOM had lower Dscores and were older than either EEOC or SD. Dscores are box-plotted by floor in Figure 6.

Dscores vary significantly between floors (Kruskal-Wallis p=0.000) with floor 13>2>11. Dscore differences between floor 5 and floors 2 and 13 were significant only for floor 13 (13>5). TBS and Bioaerosol scores are box-plotted in Figures 7 and 8. For both variables floor related differences were significant at p=0.005 (Bioaer) and p=0.018 (TBS). For both variables, floors 2, 3, and 4 were highest. There were no floor related age differences.

The discomfort question and the Dscore, both designed as measures of satisfaction/dissatisfaction and comfort/discomfort were highly correlated, and Chi square tests utilizing the discomfort question generally parallelled results obtained using T-tests and the Dscore.

C. BIOAEROSOLS

1. Viable Fungi

Viable fungi recovered on Andersen samples for all sampling sites and all occasions are presented in Figure 9. Average levels were below 1000 (log 3) for all but one sample site (1317, July) and below 100 for 6 of 12 sites. 10 of 12 sites had levels below 100 in March, while 8 of 12 were below 100 for July. Second and thirteenth floor levels were highest in July, 5th floor levels were highest in March.

Figures 10 - 12 present data from March for each of the sampling occasions for the four sites on each floor. Only one site exceeded 1000 cfu/m^3 (floor 5, 6am day 2) and recoveries at one site varied by as much as two orders of magnitude. Maximum site to site difference occurred at site 210, 9am, day 2. No consistent pattern related either to time of day or day was apparent for floors 2 and 5. Levels gradually fell on Floor 13 from morning of day 1 through afternoon of day 2.

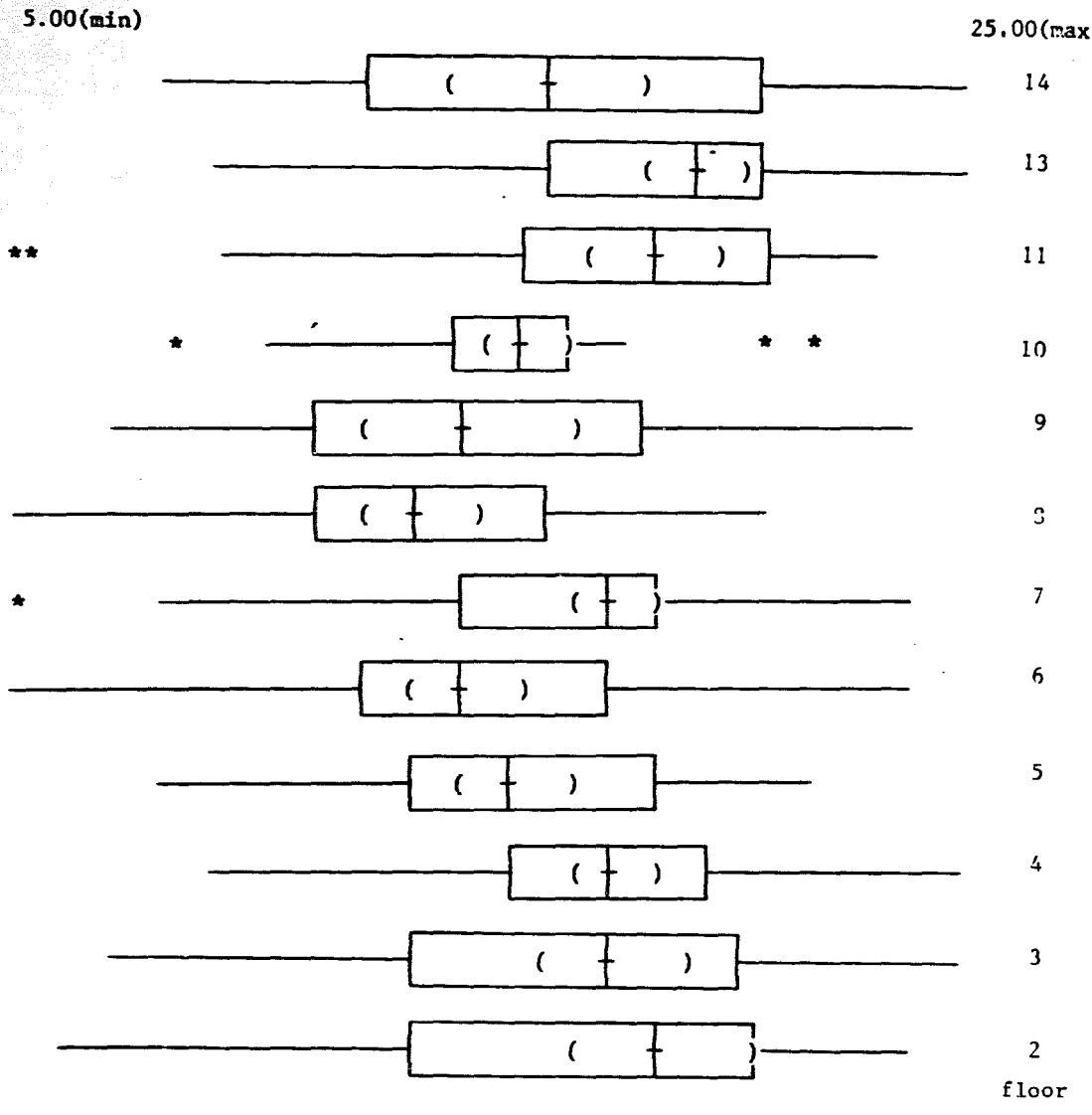

Figure 6. BOX PLOT OF DSCORES BY FLOOR (n=482)
(Vertical line = median; Boxes enclose hinges; Parentheses enclose 95% confidence intervals; * represent outliers.)

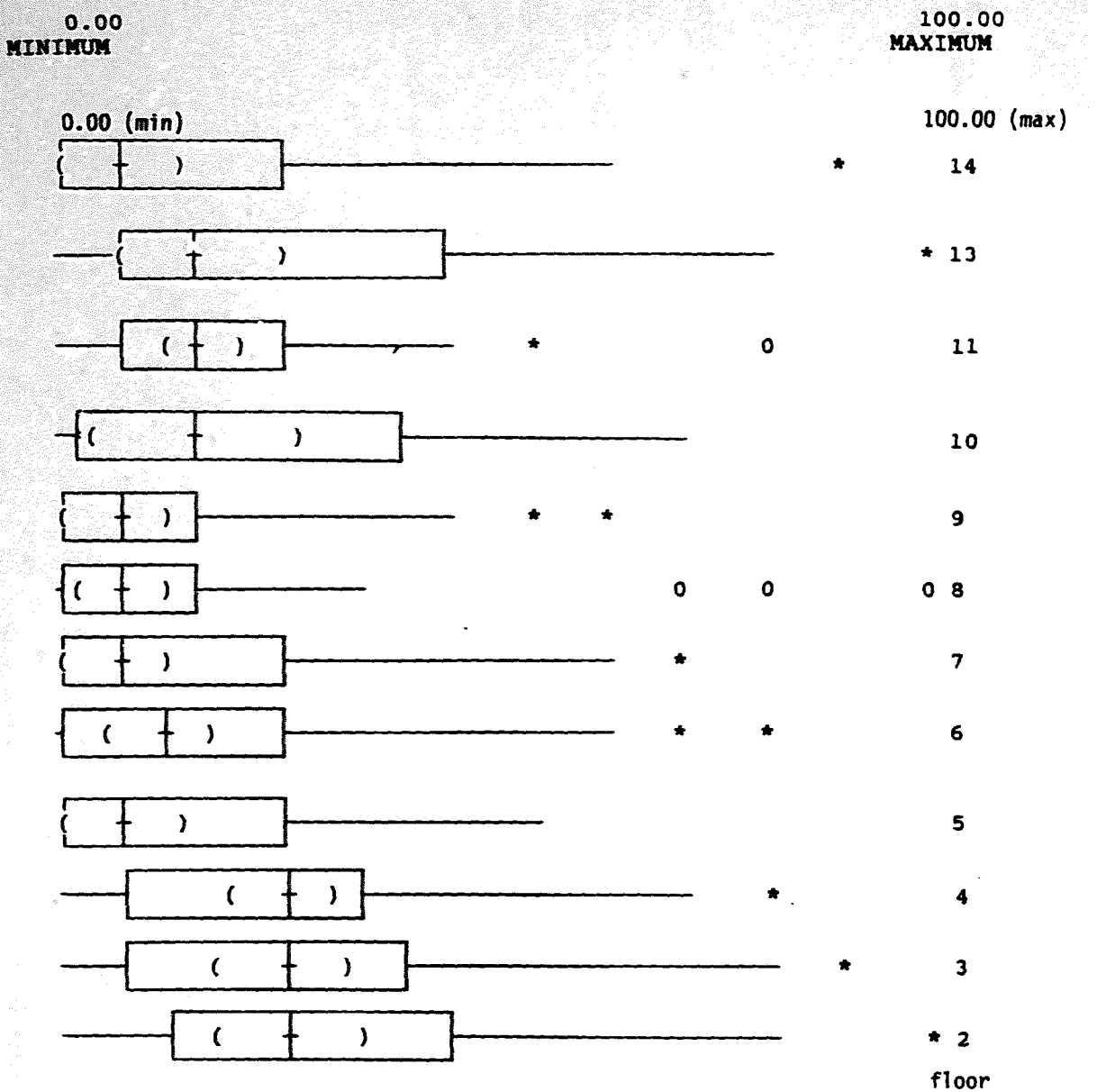

Figure 7. BOX PLOT OF BIOAEROSOL SYMPTOM SCORES BY FLOOR (See Figure 6 for explanation)

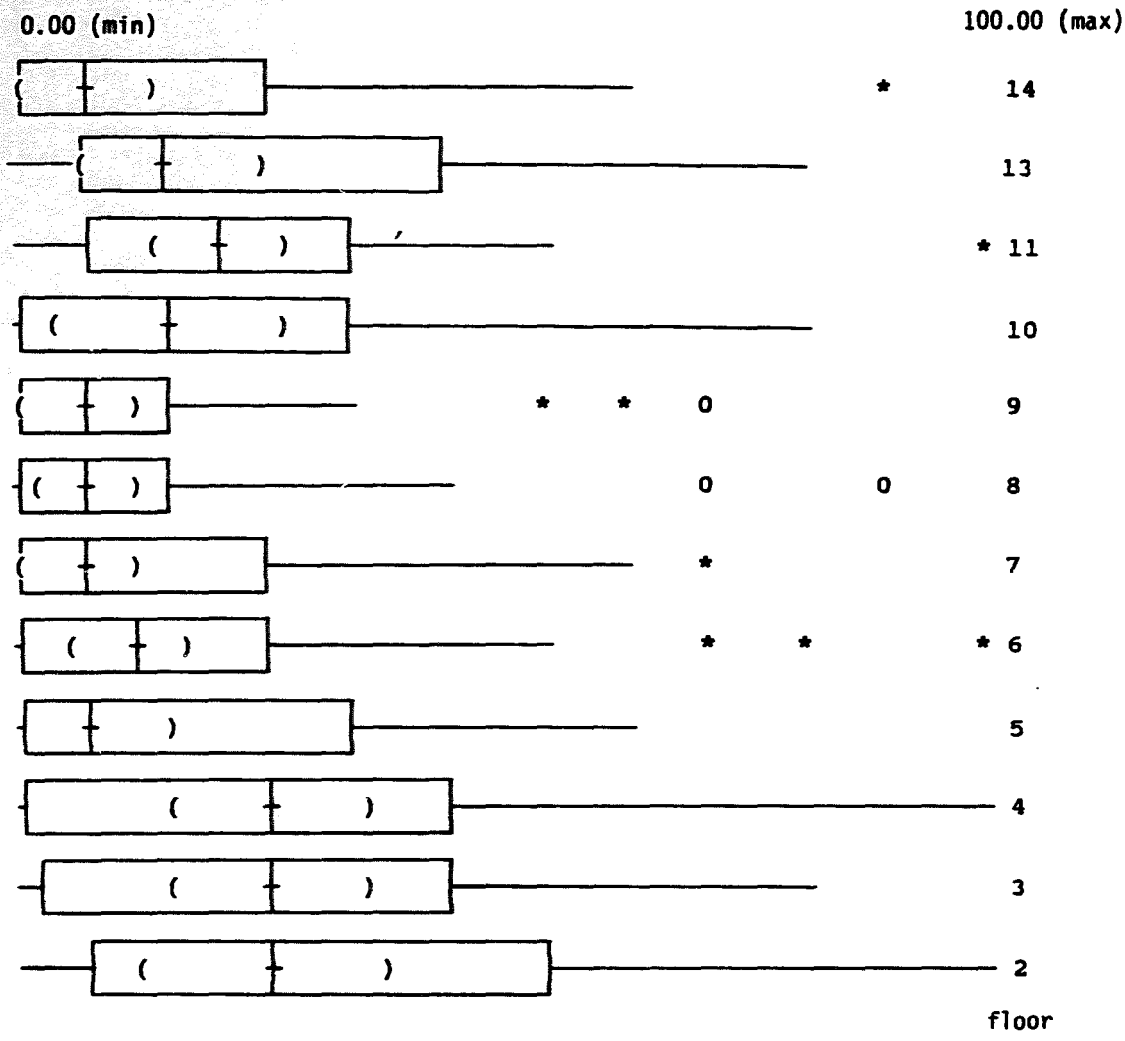

Figure 8. BOX PLOT OF TIGHT BUILDING SYNDROME SYMPTOM SCORES BY FLOOR
(See Figure 6 for explanation)

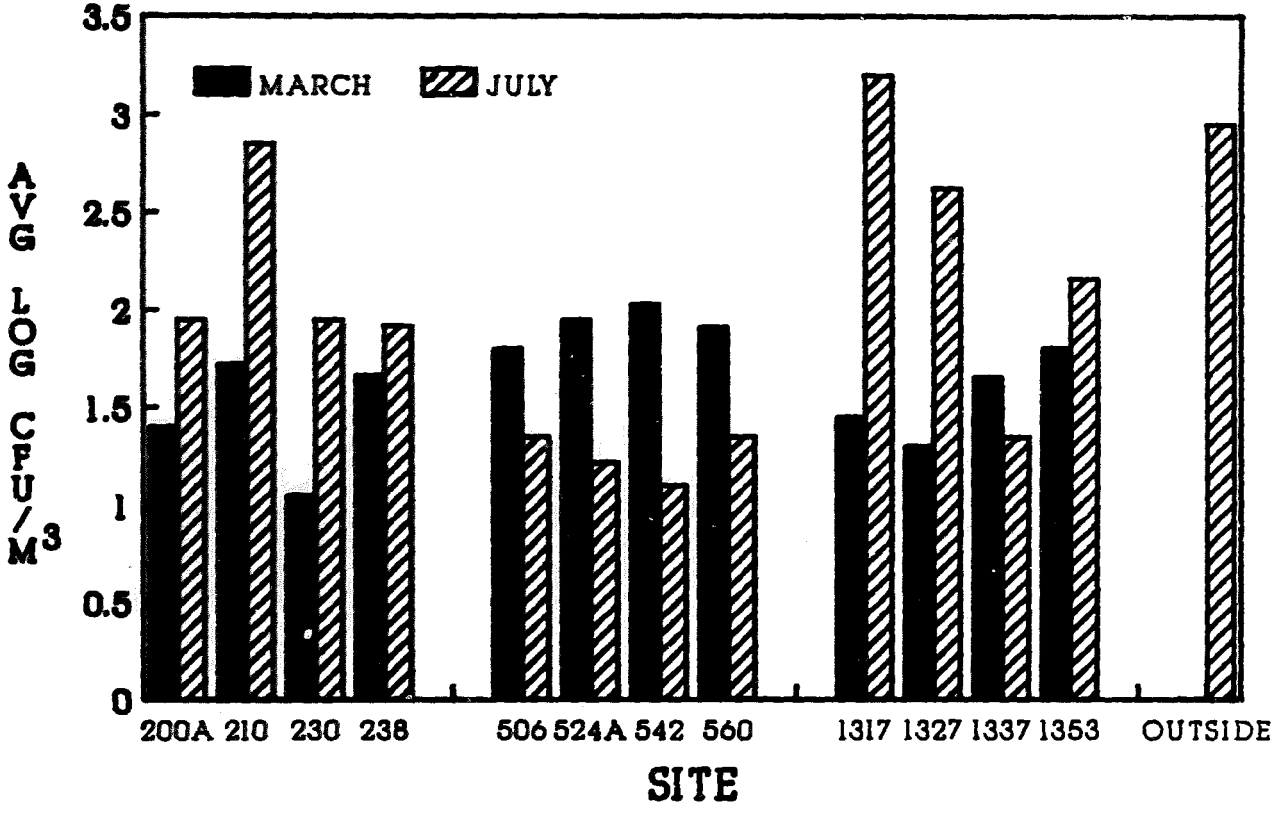

Figure 9. SITE AVERAGES FOR ALL COLUMBIA PLAZA ANDERSEN SAMPLES FOR FUNGI
(CFU = Colony Forming Units)

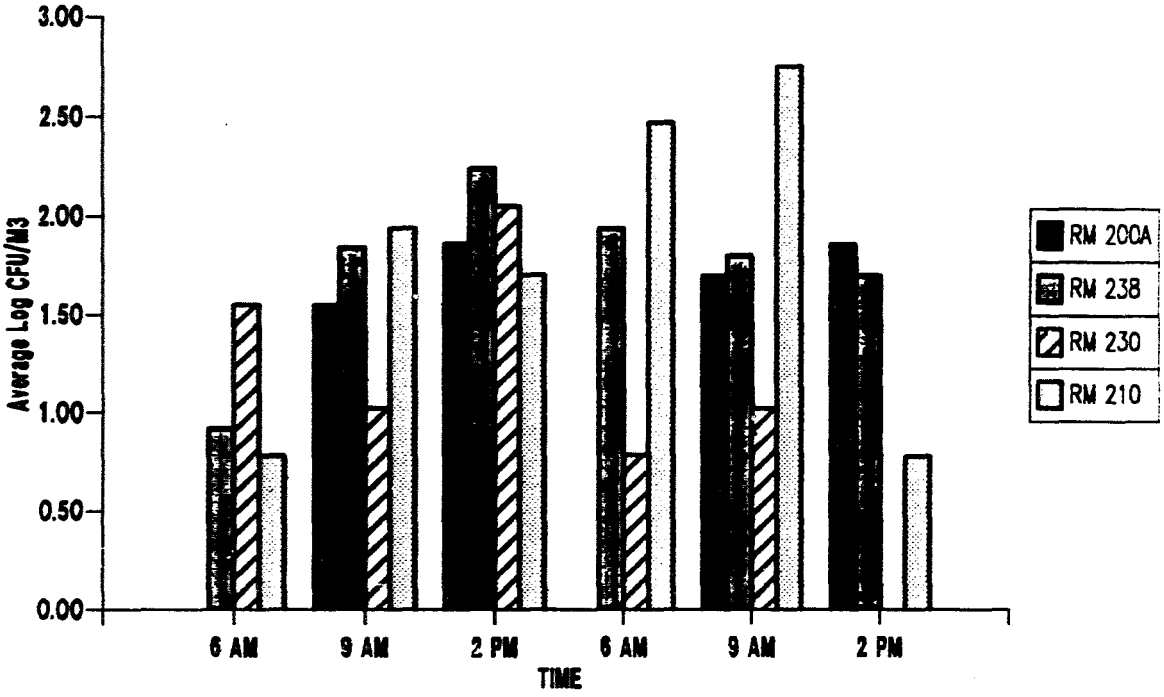

Figure 10. ANDERSEN SAMPLES FOR FUNGI FOR FLOOR 2 SAMPLE SITES, MARCH SAMPLING PERIOD

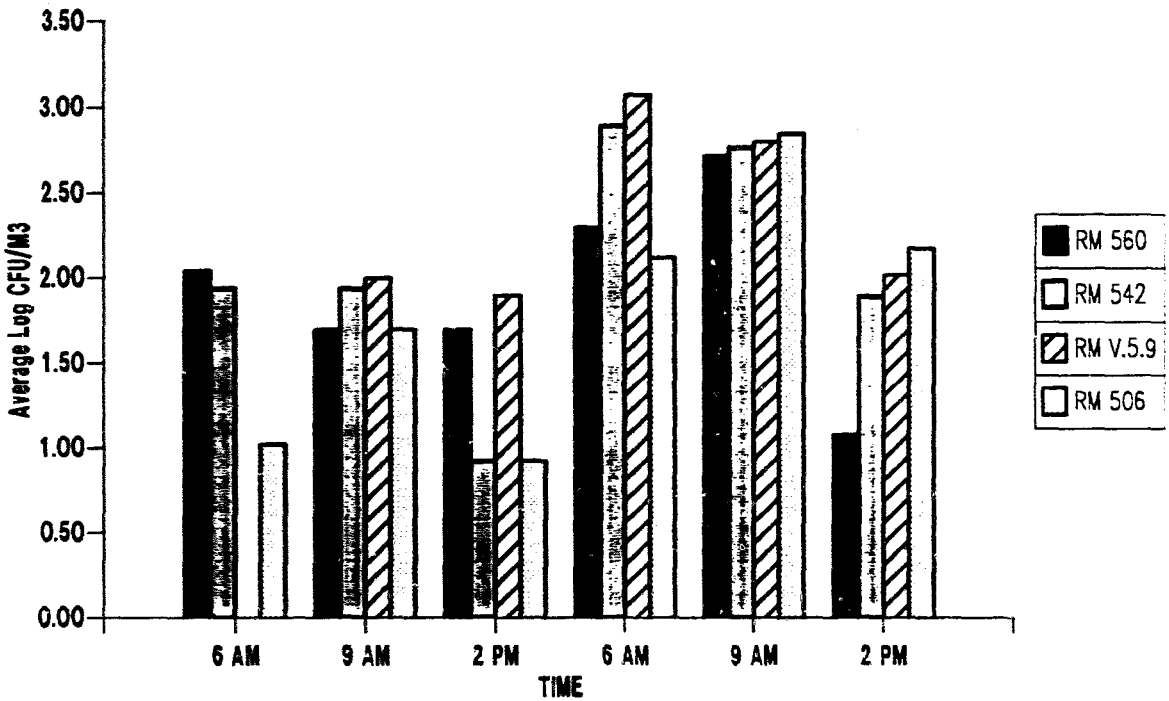

Figure 11. ANDERSEN SAMPLES FOR FUNGI FOR FLOOR 5 SAMPLE SITES, MARCH SAMPLING PERIOD

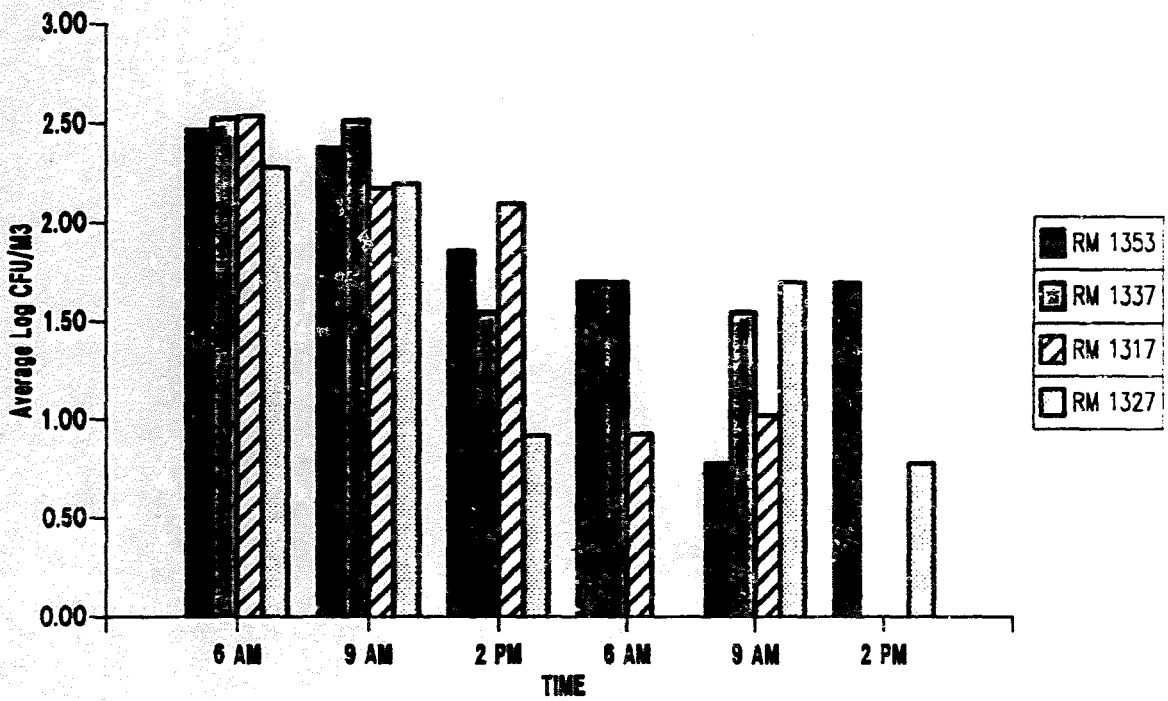

Figure 12. ANDERSEN SAMPLES FOR FUNGI FOR FLOOR 13 SAMPLE SITES, MARCH SAMPLING PERIOD

Similar data is presented in Figures 13-15 for July samples. In July, sites 210 and 1317 consistently exceeded 1000 without relation to time or day. Single site variability did not reach two orders of magnitude for July samples. However, site to site variability exceeded 2 logs for two sampling occasions on Floor 13.

Fungus spore levels in outside air, routinely measured only for July, exceeded indoor levels at all sites for all time periods, except site 1317 (Figure 16).

SAS samples were taken to compare levels of viable fungi in ceiling plenums, VFCU ductwork (undisturbed) and VFCU ductwork during filter disturbance. Two sets of samples were taken on each floor:

Table 8

Fungi Recovered in Connection With Agitation of Vertical Fan Coil Units.

(log cfu/m3 (average, 4 samples))

SITE	FLOOR 2	FLOOR 5	FLOOR 13
Plenum	0.61	0.76	1.04
VFCU (no Activity)	1.51	1.34	1.32
VFCU (Activity)	3.05	3.90	3.68

(Note: The upper limit for the SAS sampler is 4.34 cfu/m3; levels in VFCU (activity) category represent underestimates since at least one plate in each set exceeded this value.)

Rank order of taxa recovered during March and July sampling occasions is presented in Table 9.

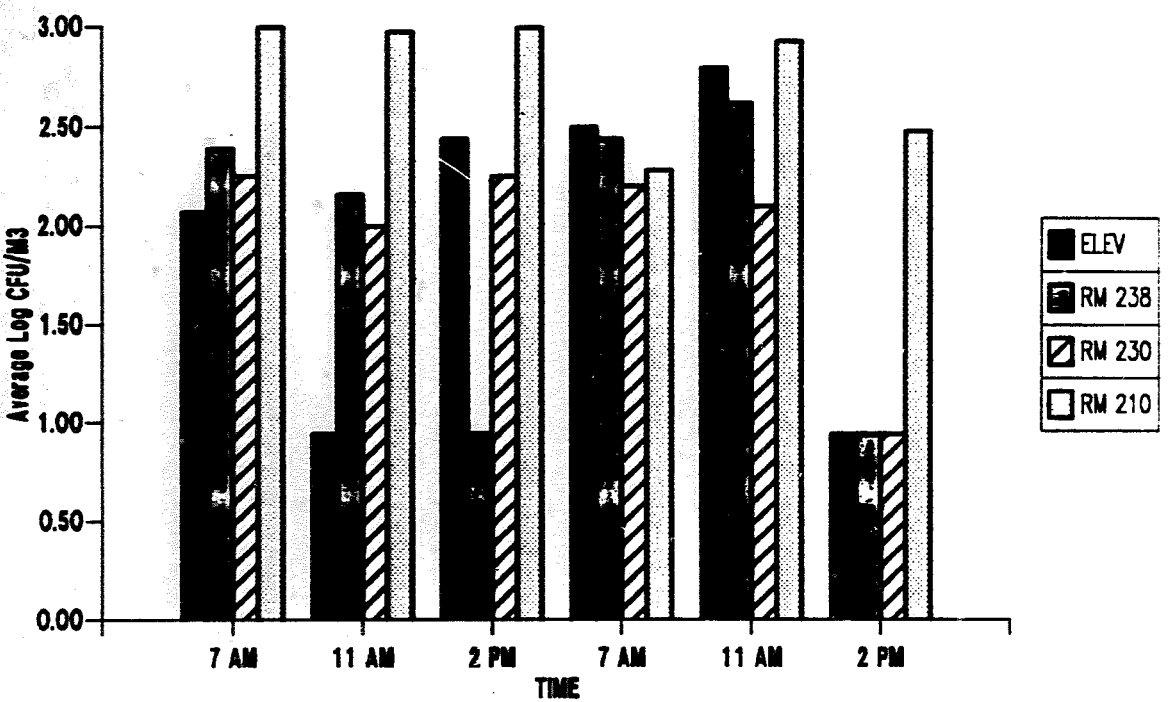

Figure 13. ANDERSEN SAMPLES FOR FUNGI FOR 2ND FLOOR SITES, JULY SAMPLE PERIOD

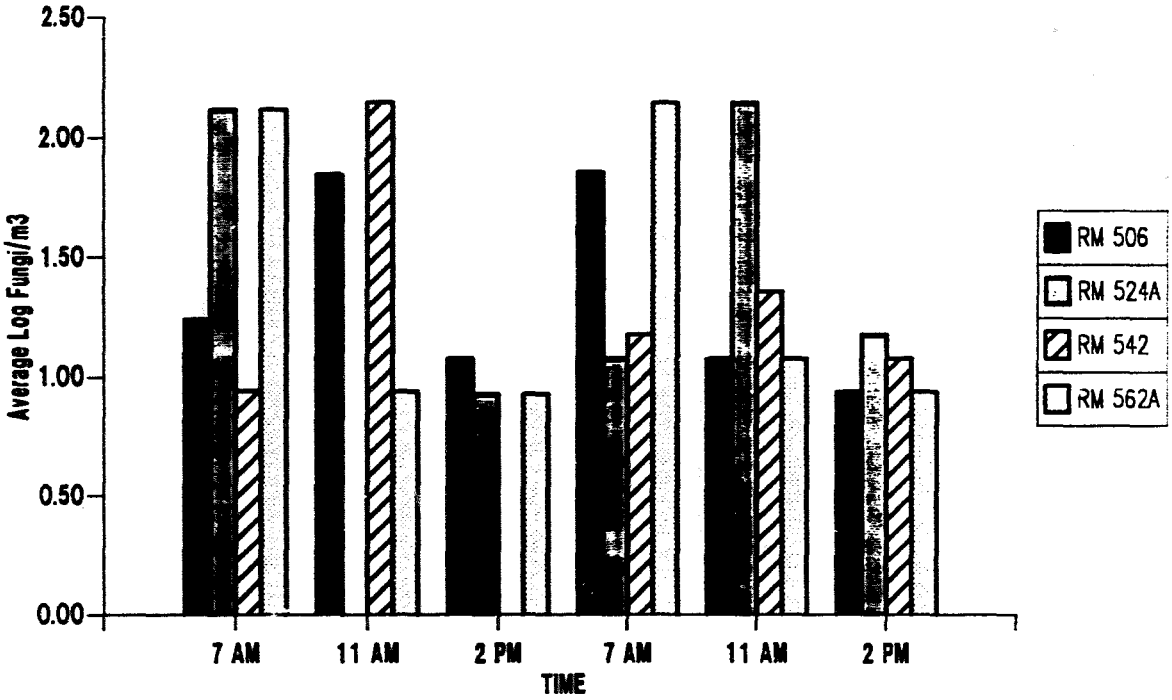

Figure 14. ANDERSEN SAMPLES FOR FUNGI FOR 5TH FLOOR SITES, JULY SAMPLE PERIOD

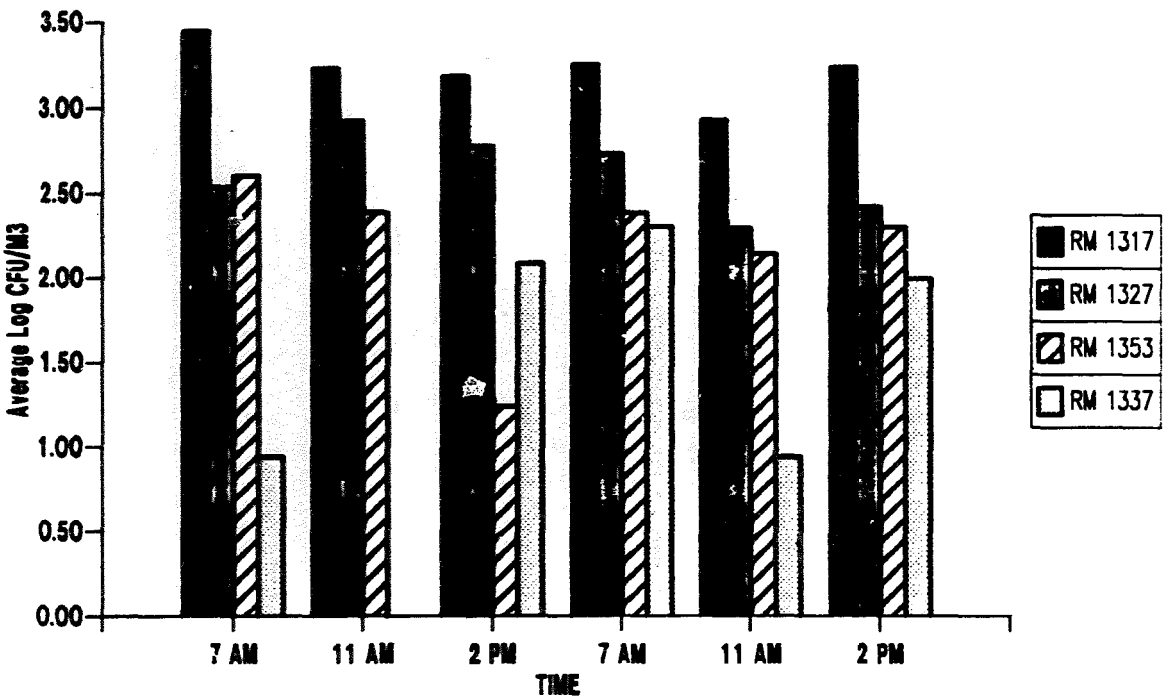

Figure 15. ANDERSEN SAMPLES FOR FUNGI FOR 13TH FLOOR SITES, JULY SAMPLE PERIOD

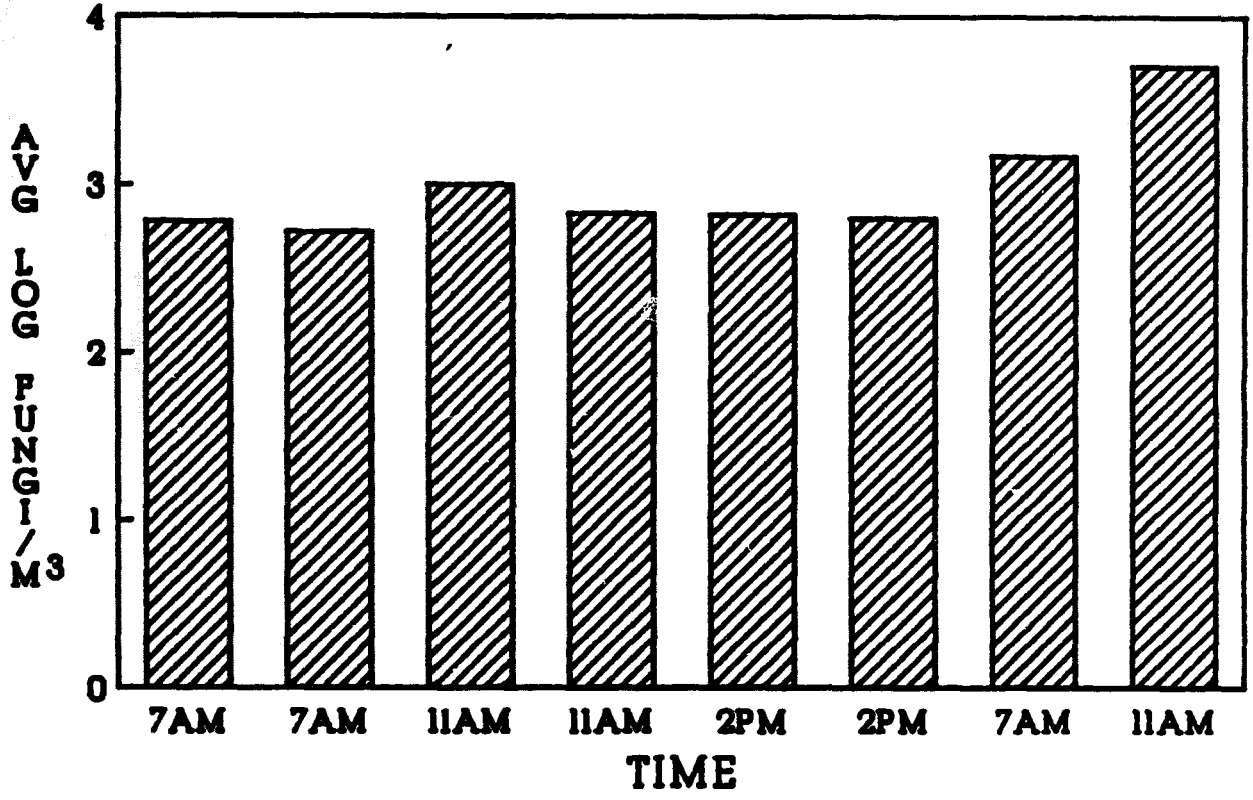

Figure 16. OUTDOOR ANDERSEN SAMPLES FOR FUNGI FOR JULY SAMPLE PERIOD

Table 9

Rank Order of Fungus Taxa Recovered in March and July

(% Recoveries of Listed Taxa)

TAXON	MARCH	JULY
Penicillium	33	8
Sporobolomyces	25	86
Cladosporium	22	4
Aspergillus	14	1
Alternaria	3	1
Aureobasidium	3	0

Penicillium / Sporobolomyces / Cladosporium comprised 80% of spores in March, Sporobolomyces / Cladosporium in June, and Sporobolomyces alone in July. Note that decreases in ranking of a genus does not mean that absolute levels decrease. The very low Cladosporium percentages for July reflect the abundant Sporobolomyces, not especially low Cladosporium counts. Table 10 lists taxa recovered more than once, and levels and sites of maximum recoveries:

Table 10

Taxa Recovered More Than Once On Malt Agar During Summer Sampling.

TAXON	# TIMES RECOVERED	CFU/M^3 (Range)	SITE OF MAX RECOVERY	SITE OF HIGHEST MEDIAN
Alternaria	13	35-560	Outside	Outside
Aspergillus fumigatus	2	35	Outside	
A. niger	5	35-70	Outside	Outside
Bacteria	44	35-630	Outside	1317
Cladosporium	23	35-700	Outside	Outside
Epicoccum	7	35-70	Outside	Outside
nonsporulating	51	35-420	Outside	Outside
Penicillium	32	35-490	238	El. lobby
Sporobolomyce	77	35-1365	1317	1317
Yeast	4	35-70	Outside	Outside

A comparison of taxa recovered by two different swab techniques as well as air sampling is presented in Table 11. Swab samples were taken using two methods: sterile dry swabbing applied immediately to culture medium in small petri plates, and

sterile, wet "Culturette" swabs which were returned to the laboratory within 24 hours for culturing.

Table 11

A Comparison of Dry and Wet Swab Sampling With Simultaneous Air Sampling for Viable Fungi

TAXON	DRY SWAB	CULTURETTE	AIR
	% of Total Recoveries		
Penicillium	55	68	33
Cladosporium	39	12	22
Aureobasidium	0	15	3
Aspergillus	5	5	14
Sporobolomyces	0	0	25

Cladosporium was dominant for all modalities. However, second ranked (air) Sporobolomyces is absent from both surface swab sets and Aureobasidium is over-represented on culturettes.

2. Fungus Spores

The Burkard trap is efficient when spore levels consistently exceed 1000, which, in general, was not the case for these samples. Therefore, only 10 percent of Burkard spore trap slides were counted. In no case did spore counts exceed levels expected from Andersen data.

3. Bacteria and Actinomycetes

Average thermophilic actinomycete recoveries for March and July are presented in Figures 17 and 18. In March, levels for all sites exceeded 700 cfu/m^3 and 1000 cfu/m^3 for 7 of 12 sites. Average levels were highest for floor 5, lowest for floor 13. It appears that one site on floor five was especially contaminated. However, when averages for all sites for each time period are plotted (Figure 18) it is apparent that sites sampled early Monday morning were highest (near 10,000 cfu/m^3) and that levels gradually declined during the course of sampling to around 1000 cfu/m^3 on Tuesday afternoon.

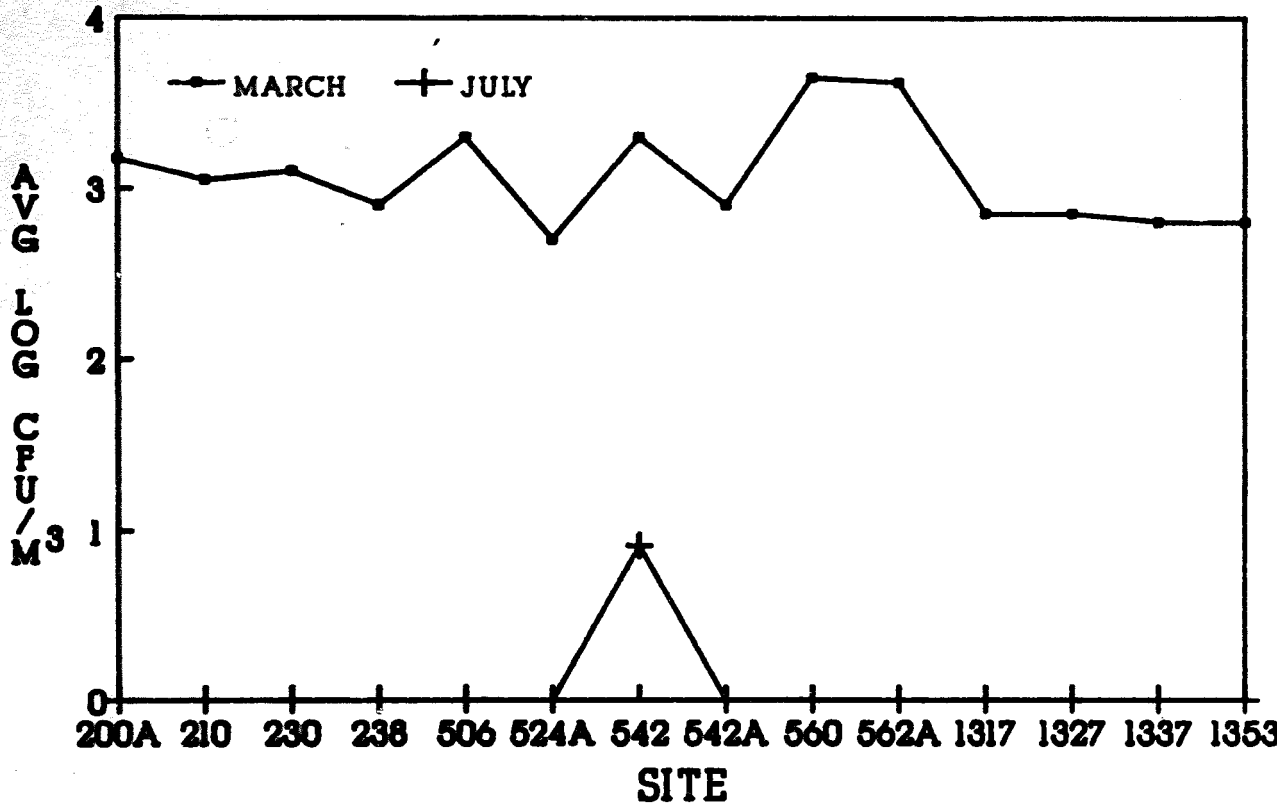

Figure 17. AVERAGE THERMOPHILIC ACTINOMYCETE ANDERSEN RECOVERIES FOR MARCH AND JULY ARRANGED BY SITE

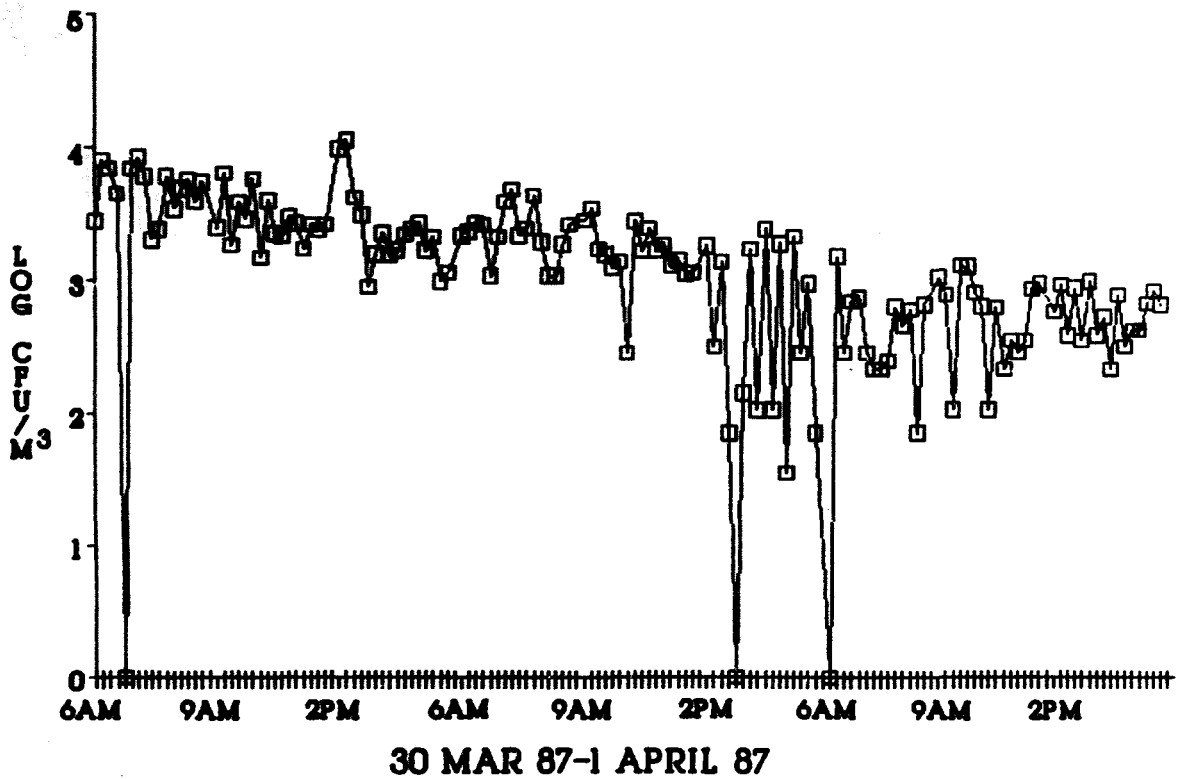

Figure 18. AVERAGE THERMOPHILIC ACTINOMYCETE ANDERSEN RECOVERIES FOR MARCH ARRANGED BY TIME OF SAMPLING

Accurate assessment of non-actinomycete bacteria is not possible from the March sampling occasion because of the over-abundance of actinomycetes that grew on the bacterial (nutrient, 37°) plates. Available data on bacterial levels from July is presented in Figure 19. Levels exceed 300 on two occasions for floor 5, 3 for floor 2 and 4 for 13. Levels exceeded 1000 cfu/m^3 for one site on one occasion on floor 13.

D. OTHER ENVIRONMENTAL VARIABLES

Average levels of CO_2 (parts per million), % relative humidity, and temperature (degrees C) are presented in Table 12. CO_2 and relative humidity were highest for floor 13, but differences were not significant. CO levels, measured for some sites in March, were very low and the reliability of the instrument was questionable.

Table 12

Carbon Dioxide and Relative Humidity Levels
March and July

		MARCH		JULY	
		CO_2	%RH	CO_2	%RH
Floor 2	Average	429	37.7	441	63.7
	S.D.	117	12.8	89	2.9
Floor 5	Average	428	41.5	426	63.7
	S.D.	102	5.1	83	2.3
Floor 13	Average	506	33.6	457	69.0
	S.D.	197	8.6	140	5.6

E. CORRELATIONS

Relationships between potentially human-source bacteria and CO_2 levels are presented in Figure 20. There is no significant correlation between these two variables.

Log cfu/m^3 (viable fungi) are directly correlated with relative humidity for July (Kruskal-Wallis, p=0.000) but not for March.

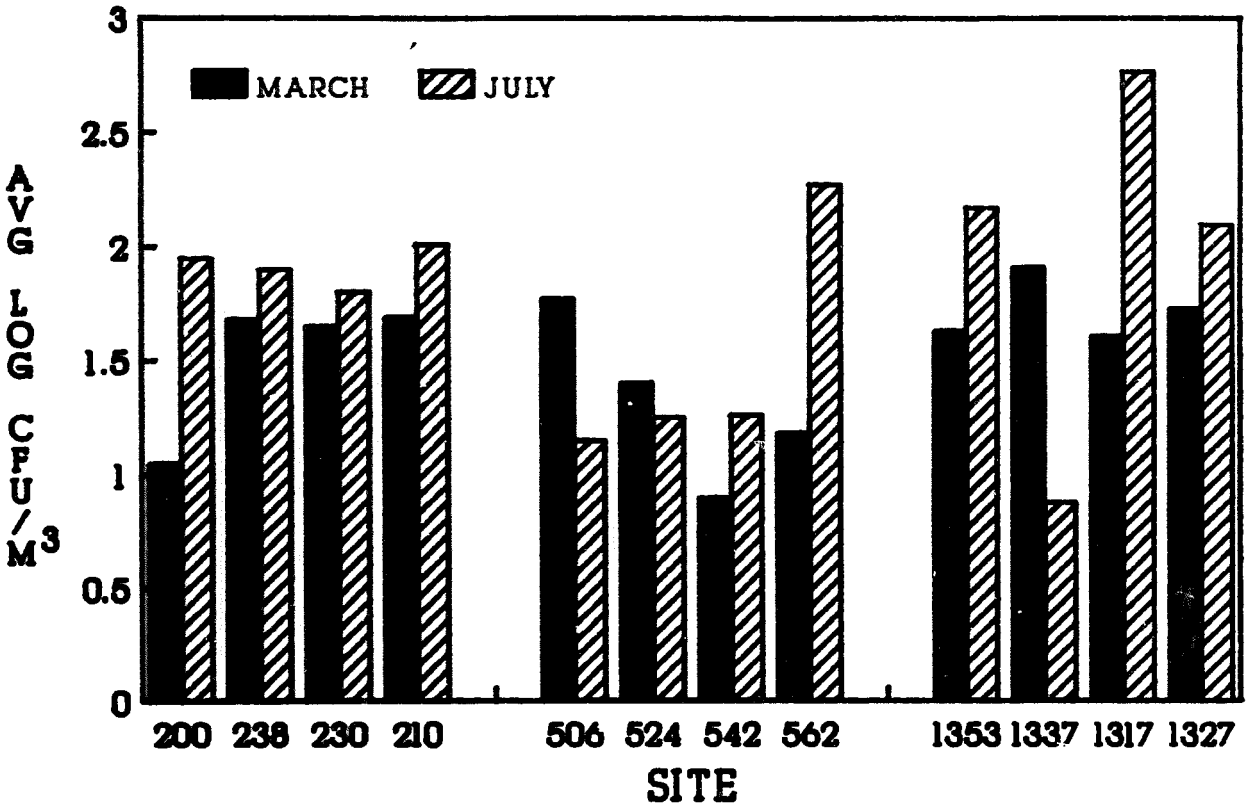

Figure 19. BACTERIA RECOVERED AT 35° ON ANDERSEN SAMPLES FOR JULY ARRANGED BY SITE

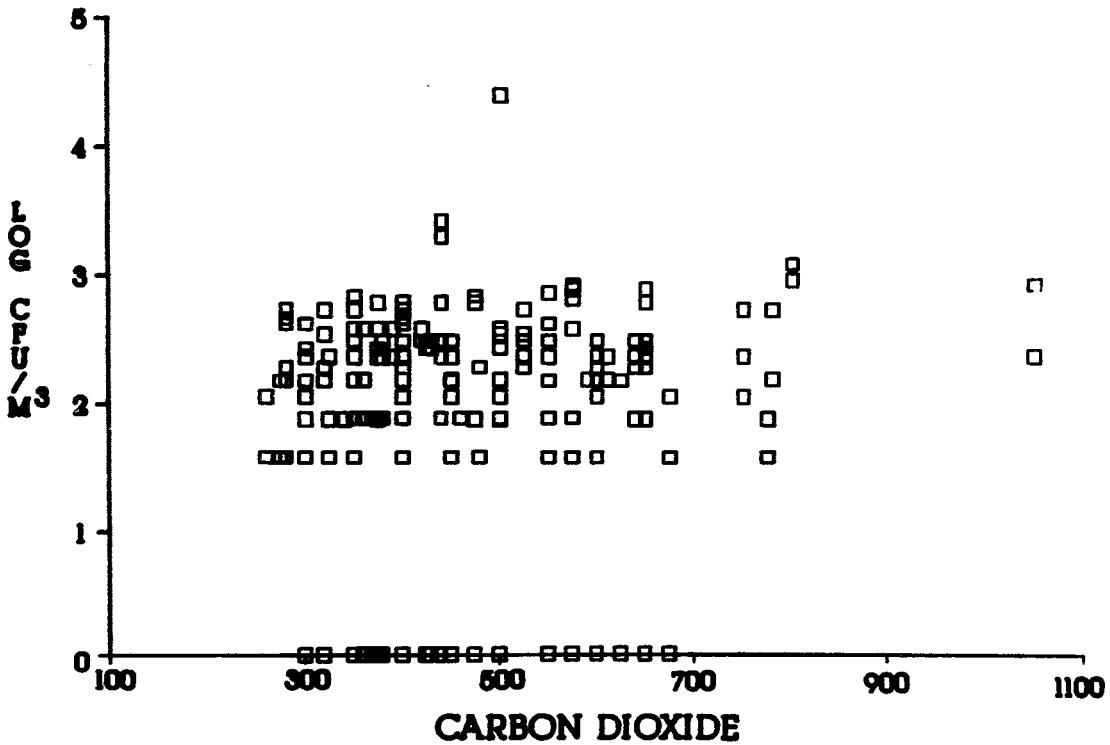

Figure 20. RELATIONSHIP BETWEEN 35° BACTERIA AND CO2 LEVELS FOR JULY SAMPLES

V. DISCUSSION

A. QUESTIONNAIRES

1. Distribution Problems

State Department questionnaire distribution was in the hands of a person who felt strongly that the building was causing severe health effects. This may also have been the case for the Equal Employment Opportunities Commission. On the other hand, the Bureau of Mines distributor was convinced that the building problems had been solved. We have no information on representatives distributing questionnaires for other agencies. The SD questionnaires were distributed only to a small fraction of the employees, all part of a single unit within the SD and all co-workers of the distributor. A wider distribution was achieved in the EEOC, questionnaires being distributed through the mailroom. It appears that questionnaires were distributed to essentially all employees of the BOM.

2. Completion Problems

As many as 30% of the distributed questionnaires were returned blank. The building has been overstudied and many occupants were convinced that additional studies were without value. Some believed all the building problems had been solved. Because of the way questionnaires were distributed, we were unable to ascertain specific locations from which blank questionnaires were returned. It is possible (and even probable) that people without building-related problems were more likely to return a blank questionnaire, thus biasing our data in favor of a high complaint rate. It is essential for future studies, especially in buildings with vocal, complaining occupants, either that random sampling be achieved, or response rates of near 100% [Burge, S. 1987].

Many occupants of the lower floors of the Columbia Plaza complex seemed unaware of which specific building they occupied. We sampled on floor 2 of the high-rise, but so far have been unable to separate out occupants of the high rise part of floor 2 where we sampled from those in the low and intermediate rises. We had offices labelled 200A (which is in the low rise) labelled as being in each of the three building sections.

3. Questionnaire Design Problems

Many people responded "no" to question 4 indicating satisfaction with their environment, then scored high on question 6, indicating dissatisfaction with environmental conditions. While hayfever or pollen allergies (question 7) is a discrete condition with well-defined symptoms, "other allergies" is not, making it impossible to know how many people actually have physician-diagnosed atopic disease, hypersensitivity pneumonitis, or asthma. The medical conditions table (question 8) was apparently not clear to a number of people. Some interpreted "no specific trend" to mean absence of the symptom. Others obviously understood it to mean symptoms not related to any specific time interval. A number of people would check all boxes except "after holidays," and "weekends only" wanting to make absolutely clear that their symptoms were related to work. Further indication that this question was difficult for a number of people is shown in answers to questions like "dry flaking skin" that include "all day" with relief "immediately after leaving work". The chances of this symptom pattern are very unlikely.

4. Does Questionnaire Data Indicate A Problem?

Fifty percent overall, and 42% of people responding from an agency where a complete sample was obtained, expressed dissatisfaction with the environment in Columbia Plaza. This maximum 58% satisfaction rate is far below the ASHRAE 80% standard [ASHRAE 1981]. Dissatisfaction rate was highest for those EEOC employees occupying the second floor (a floor where multiple flooding problems had occurred, some within weeks of our sampling). Lowest rate was for the 5th floor BOM occupants. The very high rate on floor 2 could be due to actual air quality problems, to the fact that so many problems had occurred in the past, to the presence of one or two very vocal complainants, or to improper questionnaire distribution and followup techniques. In addition, environmental factors on the second floor, including lack of windows, heat accumulation due to the lights being left on when the ventilation system is off, and poor physical appearance of the unit probably contributed to the high complaint rate.

People reporting hayfever and other allergies were more likely to express discomfort than other groups. These are diseases associated with environmental exposures as well as a tendency to amplified responses to irritants in the environment. The very consistent hay fever rate across floors and agencies is indicative of the objective nature of this question, while the "allergy" rate was more variable and probably includes people who believe they have allergies but have not been actually diagnosed by a physician. Especially on floor 13, we encountered people who complained of "allergies" but symptoms reported were not those normally associated with atopic disease.

Questionnaire data do not suggest a bioaerosol cause for building related complaints. HP, if present, is rare in the building. Symptoms most frequently reported are those generally associated with tight or sick building syndrome, not familiar bioaerosol induced illnesses. However, recent opinion in the indoor air quality community is tending toward assigning an important role for bioaerosols in TBS [Burge, S. et al. 1987]. Microbial growth produces an abundance of volatile organic compounds with unknown physical effects as well as a variety of toxins with serious acute and toxic health effects [Burge 1987].

Both floor and agency related differences were apparent with respect to both discomfort response and Dscores but are difficult to separate from other significant differences related to age and sex ratios. For example, Dscore differences were significant when BOM and EEOC were compared as a whole, but not when floors 5 and 2 were compared. BOM had older occupants that were more often males, both characteristics negatively correlated with Dscore.

B. BIOAEROSOLS

1. Are Bioaerosols Present In "Dangerous" Levels?

Bioaerosols that presented occupants with an unusual exposure situation were found in the building in both March and July. In other words, building occupants were exposed to bioaerosols that, in July, either exceeded levels for outdoors, or were composed of different taxa. The March bioaerosol consisted principally of thermophilic actinomycetes, organisms implicated in a number of cases of building related hypersensitivity pneumonitis. The July bioaerosol did not contain these organisms, but was dominated by Sporobolomyces, an organism that has been connected with farming related hypersensitivity pneumonitis. Note, however, that in spite of the presence of these aerosols, the main complaints in the building were not hypersensitivity pneumonitis but rather headaches, fatigue and irritant symptoms. It is also interesting to note that on no other occasion when volumetric air sampling was conducted in Columbia Plaza were ambient levels above 200 cfu/m^3 of any bioaerosol recovered.

The implications of these latest results are not clear with respect to past symptoms reported in the building. They do indicate that the building at least sporadically is contaminated with organisms that can cause disease, and therefore, building conditions may present some health risk to the occupants.

2. How Do Bioaerosol Recoveries Correlate With Questionnaire Data?

Thermophilic actinomycete recoveries during March were relatively consistent over all sites sampled, and were not lower on the 5th floor where complaints were lowest. Sporobolomyces was recovered on both 2 and 13, but only at sporadic sites and times, and was not consistently present in complaint areas and absent from complaint-free areas. At least for the two sampling occasions discussed here, no evidence can be presented linking bioaerosols with symptoms reported on questionnaires.

3. How Do Bioaerosol Recoveries Relate To Relative Humidity? Is The Ventilation System Providing Adequate Relative Humidity Control?

Relative humidity and fungus spore levels were directly correlated for July samples but not for March. Relative humidity in July tended to be consistently in excess of 60%, while that in March averaged between 34 and 40%. Relative humidity does still appear to constitute a problem in the building, and its control might go far to decrease the potential for sporadic microbial contamination. On the other hand, the high thermophilic actinomycete levels found in March were probably due to contamination of a specific reservoir, and control of relative humidity alone would not have solved this problem.

Earlier consultants studying Columbia Plaza recommended that the HVAC systems be modified to provide better humidity control, and, in fact, chillers were upgraded before we entered the building. However, either modifications were inadequate to consistently reduce relative humidity to the point where fungus growth is unlikely, or the new chillers are being operated at a temperature too high to provide adequate relative humidity control.

4. Is The Ventilation System Contaminated?

Sources of bioaerosols recovered during these studies have not been confirmed. The thermophilic actinomycetes were recovered from all sites in approximately equal levels, with levels declining over time. March sampling was begun early Monday, just after the main HVAC had been turned on. It is likely that the actinomycetes built up in the central system during the weekend shut down, and were forced throughout the building early Monday morning. Spores were gradually removed from the air by deposition and dilution throughout the week. A second possibility is contamination of peripheral fan coil units which provide auxiliary heat and internal circulation. This is less likely because a majority of units on all floors would have to have been contaminated to produce the uniform aerosol.

Sporobolomyces, on the other hand, was sporadically distributed throughout the building, and probably was disseminated from several local sources. The likely possibilities are the peripheral and vertical fan coil units which were poorly

maintained, filled with dirt which provides adequate nutrient material, and often contained standing water in drip pans. Data displayed in Table 8 confirms that vertical fan coil units were foci for microbial growth and provided reservoirs of fungus spores that were readily aerosolized with only slight disturbance.

C. OTHER FACTORS THAT MIGHT AFFECT COMPLAINT LEVELS

1. Physical Environment On The Floors

The physical environment was very different on the three study floors. Floor 5 had pleasant subdued lighting, carpeting in reasonable condition, good-sized, relatively private work spaces for each employee, and little if any clutter. Floor 13 was brightly lit with large windows, crowded, with little privacy for most employees, cluttered, and noisy. The carpeting was in poor condition, and had stretched and buckled on the floor. Floor 2 is below ground with no windows. The carpeting was in poor condition, and flood damage had not been completely repaired. Many office and hallway areas were cluttered, although the floor was not heavily occupied. On the other hand, the obvious mold contamination extending out from vertical fan coil unit vents was about equal on all three floors.

2. Stress

While measures of stress were not used in these studies, it is possible that employees of the State Department and the Equal Opportunities Commission are consistently under greater stress than those of the Bureau of Mines. Many of the symptoms recorded can increase in stressful circumstances, making it necessary to consider stress as a possible co-variable in data analyses of this type.

3. Attitudes and Occupations

Both men and smokers predominate on 5. While not clearcut, there is a tendency for both men and smokers to be more satisfied with their environment than females and nonsmokers.

An organized group of protesters on the 13th floor had convinced many occupants that the environment was severely detrimental to their health. Members of this group were very vocal about their concerns. On the fifth floor, management and health officers are convinced there is no problem, and in spite of the fact that several occupants on the fifth floor reported many symptoms, they are apparently not vocal, and there is little or no verbalization of dissatisfaction.

The second floor is occupied by the Equal Employment Opportunities Commission, including many lawyers experienced in grievance procedures. Given the

same environmental conditions, this group may be more likely to understand how to complain and be less hesitant to do so than less experienced people.

VI. CONCLUSIONS

A. The complaint rate in Columbia Plaza exceeds the ASHRAE standard of 80% acceptance.

B. Columbia Plaza is sporadically contaminated with both molds and thermophilic actinomycetes.

C. Lack of relative humidity control and lack of adequate building maintenance are primary factors in the biological contamination.

D. Health risks posed by the biological contamination are not clear, although two of the most abundant organisms recovered are known to be causative agents of hypersensitivity pneumonitis. Most reported symptoms have not been formally connected with exposure to bioaerosol.

VII. RECOMMENDATIONS

A. RECOMMENDED REMEDIAL ACTIONS

Based on our findings and experience gained in prior investigations, remedial actions that should be undertaken in Columbia Plaza are as follows:

1) The central air handling units should be maintained in excellent mechanical and sanitary condition and monitored for the presence of thermophilic actinomycetes during the heating season. Building air should be monitored for these organisms as well.

2) Relative humidity in the building should be maintained below 60% at all times, preferably below 50%. Relative humidity should be monitored in the building during the cooling season, as well as airborne fungus spores, with special emphasis on Sporobolomyces.

3) Vertical and peripheral fan coil units and associated ductwork should be cleaned (which probably would involve removing all interior sound lining) and filters should be changed on a schedule that does not allow excessive dust buildup. The current 6-month schedule is not adequate.

4) The second and 13th floors should be cleaned, and the space organized in such a way as to make the environment more pleasant for the occupants. Questionnaire data indicate that dissatisfaction with the environment may be the largest factor in the

high complaint rate on these two floors. It is possible that housekeeping, decorating, and obvious management concern for the occupants' complaints would solve a majority of problems in this building.

5) Most past consultants have recommended that the ventilation system be modified to provide more fresh air to the occupied space, and to more adequately mix the fresh air provided. We cannot comment on this recommendation based on our own data except to say that the CO_2 levels were not excessive, indicating adequate dilution air was being provided to satisfactorily dilute internally produced CO_2. It is probable, due to low occupancy rates on the 2nd and 5th floors, that CO_2 is a very inaccurate measure of ventilation rate and that other gas and vapor phase contaminants are accumulating and causing some complaints. This would be consistent with the pattern of complaints which is more indicative of tight building syndrome than building related disease.

6) It should be made clear to building management, that long-term failure to correct obvious problems (e.g. leaks, exhaust penetration) has exacerbated complaints and increased long term costs. Immediate attention to these conditions would probably have contributed to a non-adversarial environment (especially on the 2nd floor).

7) Where building maintenance is poor, as was obvious to all investigating teams, further investigation should not be attempted until maintenance deficiencies are corrected. It is not cost-effective to take shortcuts on maintenance, as should be obvious from this one case. These facts should be made clear to building management.

8) Sampling to determine the adequacy of the ventilation system was essential, and should have been one of the first steps following pre-assessment. In the case of Columbia Plaza, bioaerosol sampling was never indicated by complaints. The problems with the building were not clarified using bioaerosol sampling, but rather by the observations of occupants and trained observers (to whom the lack of maintenance was immediately obvious). The high levels of thermophilic actinomycetes uncovered by bioaerosol sampling were probably indicative of inadequate building maintenance, and were not connected with symptom patterns reported by occupants. While this one data set may be valuable in assessing potential health risks caused by poor maintenance in this building, such expensive assessment should not be necessary. Several of the previous consultants as well as our group could have predicted this risk based on visual examination of the ventilation system.

B. RECOMMENDED APPROACH TO BIOAEROSOL INVESTIGATIONS

Based solely on a review of reports of all microbial consultants that studied Columbia Plaza, and on reports of symptom occurrence, we would have concluded that the building was not generally contaminated with fungi (or actinomycetes) except for the filters and sound liners of internal circulation units. Our questionnaire data supported this conclusion, in that there appeared little evidence of documented microbial exposure symptoms. But, intensive air sampling supported the fact that the building air was periodically contaminated with organisms known to have caused disease in other environments. One cannot base recommendations for expensive renovations on guess-work, which is essentially what was done.

Two clues were provided by experienced consultants that indicated the possibility that the building could be microbially contaminated: the main air handling units were poorly maintained and contained standing water, and the relative humidity in the building (during the cooling season) was at least sporadically elevated. While not always associated with microbial contamination, one or the other or both of these factors are almost always present when buildings are found to be contaminated. Three questions arise: A) what constitutes adequate evidence that a building is microbially contaminated; B) what is the appropriate way to document contamination in equivocal cases; C) how does one establish risk in cases of (1) real or (2) probable contamination.

A. What constitutes adequate evidence that a building is microbially contaminated?

1) An epidemic of infectious disease, humidifier fever, or hypersensitivity pneumonitis that can be unequivocally shown to be building associated constitutes adequate evidence of microbial contamination, and should immediately lead to protection of occupants (in many cases building evacuation), search for the source of contamination, and remedial actions both to eliminate current contamination, and to prevent re-occurrence. Air sampling is generally neither necessary nor useful in these clear-cut cases. Air sampling is generally not possible for most infectious agents, and often reveals nothing in cases of hypersensitivity pneumonitis or humidifier fever, since the causative antigens are frequently carried on nonviable or morphologically indistinct particles and treatment does not depend on the nature of the organism. Sampling for airborne antigens may be useful in cases where building association is in doubt; however such sampling is not necessary where epidemiologic evidence makes building association clear. Source sampling is necessary, however, to pinpoint causes and focus remedial actions.

2) Obvious microbial growth provides irrefutable evidence of contamination. In general, such obvious contamination should be cleaned up and conditions causing the problem remedied. However, there is little evidence that microbial growth on surfaces is directly related to contamination of the air, and localized microbial contamination, unless in the ventilation system or other appliance where organisms or antigens are actively sprayed into the air, may contribute little risk of disease. The role of microbial growth in contributing to symptoms of tight building syndrome (via volatile metabolic products) remains to be investigated.

3) Flooding, standing water associated with ventilation systems, presence of either central or console humidifiers, and elevated relative humidity (consistently above 60% or sporadically above 70%) are serious risk factors for microbial contamination and should lead to further investigation in complaint situations. Standards should be formulated that address these risk factors. Further investigation should include epidemiological studies to establish that complaints are actually related to building occupancy, and some kind of microbial sampling (either source or air or both) to determine the extent of the problem.

4) Complaints that can be shown not to be related to building occupancy, and tight building syndrome complaints in buildings with none of the risk factors mentioned in 3 are extremely unlikely to be related to microbial contamination, and further investigation along these lines is probably not warranted. For complaints unrelated to building occupancy, perhaps the best solution is education of occupants. For example, we have encountered several cases where clusters of unrelated cancers in buildings have given rise to fears that the environment is unsafe. Verbal and/or written documentation that these diseases could not have been caused by building occupancy has been effective in calming near panic emotions, and reducing complaints (there will always be some who are determined to complain and who don't believe even objective evidence).

In cases of tight building syndrome where no microbial risk factors are present, examination of the ventilation system function and, especially, fresh air ventilation rates should almost always be the first step. Sampling for microbial aerosols is contra-indicated in these cases. Molds and bacteria are present in all environments, especially on surfaces. Documenting their presence in a situation where air quality is of concern will only serve to exacerbate complaints to no purpose.

B. What is the appropriate way to document contamination in equivocal cases?

In cases with significant risk (see above) where remedial actions are expensive, or where management and building occupants are in an adversarial situation, well-designed microbial investigation may be necessary. Such investigation should include the following:

1. Preassessment

a) Medical documentation of symptoms, if present, and medical opinion as to probable causes of symptoms should be obtained. In most cases, one cannot rely on family physicians for this kind of assessment. An occupational health physician, or allergist or pulmonologist trained in environmentally caused disease should be consulted.

b) Comfort factors that could be contributing to complaints should be eliminated. These include temperature, odors, light levels, patterns of smoking and aesthetic factors (neatness and overall environmental quality). The carbon monoxide problem in Columbia Plaza, while it may not have carried a severe health risk, was a constant irritant to the affected occupants, and raised the level of concern for the environment in general. Also, the very poor carpeting and general atmosphere of disorganization on both the 2nd and 13th floors probably contributed to the high level and long term complaints on these floors.

c) Complaint patterns should be mapped both in space and time so that sampling approaches can be formulated. For example, if symptoms occur only in the cooling season, heating season samples are, at best, only a control. In cases of year round symptoms, the possibility of seasonal causation should not be excluded, since severe seasonal symptoms can raise the level of environmental concern and lead to possible psychosomatic symptoms at other times of the year. Likewise, symptoms associated with multiple sites in a building may be the result of heightened environmental awareness (or possibly increased sensitivity) resulting from pollutant exposure at one site.

2. Environmental sampling

If the preassessment phase fails to uncover obvious problems, or if, after correction of problems uncovered by the preassessment phase, complaints continue, environmental sampling may be appropriate. An environmental sampling program must be designed to address probable causes of complaints, and must be sufficiently comprehensive to eliminate or firmly establish the probability of microbial contamination. Ideally, a time discriminating bioaerosol monitor should be used that can be placed simultaneously at multiple building sites, and record diurnal and

seasonal variation in bioaerosol levels. Such a monitor should assess viable organisms, spores, and antigens. Needless to say, such a monitor does not exist. The Burkard spore trap comes closest, and will continuously collect fungus spores over seven days. Samples are examined microscopically by a trained observer, and counts are reliable in the range of 300 to 1,000,000 per cubic meter of air. Time discrimination can be as short as 2 hours. Unfortunately, small, colorless fungus spores, and all bacteria (including actinomycetes) are not discernable on these samples. Also, very few people currently have adequate training to analyze these samples.

Given that the ideal monitor is not available, we recommend the following minimum protocol for bioaerosol sampling in buildings:

Equipment:

a) duplicate culture plate samplers of known efficiency (e.g. the Casella or Matson-Garvin or New Brunswick slit samplers; the Andersen "N-6" sampler, the Surface Air Systems [SAS] sampler, the Biotest RCS sampler;

b) at least one spore trap sampler of known efficiency (e.g. the Burkard personal spore trap or recording spore trap);

c) a powered psychrometer or other accurate instrument for measuring temperature and relative humidity;

d) a CO_2 monitor (optional, but useful in very rough estimations of ventilation status).

All equipment must be calibrated in the form to be used in the field (i.e. pump calibration is not sufficient for air samplers).

Sampling plan:

The entire array of likely viable microbes should be addressed. In general, this means using at least 2 culture media (one for fungi and one for bacteria) and at least 3 incubation temperatures (room temperature for mesophilic fungi and bacteria, 35-37 degrees for potentially infectious agents, and 56 degrees for thermophilic actinomycetes). Malt extract agar is the medium of choice for fungi since species of Aspergillus can be readily determined without subculture. Any standard, wide-spectrum bacterial medium can be used. Casein-soy peptone agar is one of the diagnostic media for thermophilic actinomycete identification and will support most environmental bacteria as well.

Sampling one cubic foot of air is usually sufficient to establish levels of most viable environmental microorganisms. One colony at 1 cubic foot represents 35 colonies per cubic meter of air. This is a low level by any criterion. If duplicate plates are used, and sufficient samples taken, concern over possible blank plates is unwarranted. The serious problems that attend overloading are much greater than errors introduced by blank plates in these situations. The Burkard personal spore trap should be run for at least 5 minutes unless sampling is done in an obviously contaminated situation to document levels (e.g. in farming situations, or within contaminated air handling units with agitation of contaminated elements). Undersampling with the Burkard trap makes analysis tedious and difficult.

Sufficient sites should be sampled to clearly establish site to site differences, if present. In the case of Columbia Plaza, where site to site differences were not marked, the four sites sampled per floor were essential. Where clear evidence exists of site to site variation in symptom patterns, all sites where symptoms occur should be sampled, along with matched sites without symptoms. This is often very difficult, since lack of symptoms may reflect lack of sensitivity of occupant rather than absence of pollutant. The outside air is a necessary and useful control, and outside air samples should be taken within two hours of indoor samples if they cannot be done simultaneously.

The possibility of diurnal and seasonal variation should be considered. If symptoms are restricted to a particular time of day or a particular time of year, sampling should be concentrated during that time, with control sampling at other times. It is usually the case that building investigations are done long after the original episodes of complaints, and are often conducted at different times of the year. If the initial series of samples is essentially negative (as was the case for fungi in Columbia Plaza), it is necessary to sample at other times of the year to accurately document whether the building is actually free of microbial contamination. Again, in the Columbia Plaza case, summer sampling revealed unusual mold contamination, and documented that cooling season conditions in the building were appropriate for mold contamination.

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