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WHAT ARE TYPICAL CONCENTRATIONS OF FUNGI, TOTAL VOLATILE ORGANIC COMPOUNDS, AND NITROGEN DIOXIDE IN AN OFFICE ENVIRONMENT?

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ABSTRACT

Air sampling was carried out for mesophilic fungi, total volatile organic compounds (TVOC), and nitrogen dioxide (NO_2) in buildings where occupants reported the occurrence of widespread annoyance and discomfort complaints on at least one floor or building zone. Our objective was to compare air contaminant concentrations found in these buildings with outdoor "reference" contaminant levels.

In most buildings the concentrations of fungi collected during quiescent sampling indoors were 10% to 25% of those found in the outdoor air. In a few buildings elevated levels of fungi in indoor air were detected in the immediate vicinity of active (wet) microbial amplification sites.

When furnishings and heating, ventilating, and air-conditioning (HVAC) system components are disturbed (aggressive sampling), concentrations of airborne fungi in the immediate vicinity generally become elevated relative to outdoor concentrations. However, concentrations vary widely and a uniform interpretation of results cannot be obtained by simple comparison of the indoor to outdoor concentration ratio.

The average concentration of TVOC indoors was about three times that present outdoors. However, wide variations in indoor/outdoor concentration ratios of TVOC occur in commercial office buildings as a function of contaminant source strengths and because of HVAC system operational variables. The ratio of indoor/outdoor TVOC varied from 4 to 16 under conditions of minimum outdoor air ventilation to less than 2 when large amounts of outdoor air were being used.

The minimal concentration of NO_2 found in the outdoor air around two of seven buildings studied in the New York City area exceeded 0.05 parts per million (ppm). In one building where the HVAC system outdoor air inlet was sporadically contaminated by vehicular combustion products, indoor levels of NO_2 reached peak concentrations of 0.6 to 0.7 ppm.

Because of numerous indoor and outdoor variables that affect concentrations of mesophilic fungi, TVOC, and NO_2, typical concentrations of these air contaminants cannot be specified. Interpretation of air sampling data is best made on a building-by-building basis after all variables affecting building and HVAC system performance are considered.

INTRODUCTION

Air sampling in 25 office buildings where occupants reported the widespread occurrence of annoyance and discomfort complaints on at least one floor or zone was carried out for one or more of the following contaminants: mesophilic fungi, TVOC, and NO_2. As a reference for deciding what is "typical," air sampling was also carried out in protected outdoor locations, generally on the roof, away from potential sources of these air contaminants. Our objective was to determine if the indoor concentrations of airborne fungi, TVOC, and NO_2 differed in some predictable way from those present in the outdoor air.

Microbiological Sampling

The sampling methods used to collect airborne fungi are described elsewhere (ACGIH 1987; Morey et al. 1986a, b). Viable fungi were collected onto malt extract agar using a sieve impactor (no sizing; respirable and nonrespirable particulate collected on same plate) operating at a flow rate of 6.4 cubic feet per minute (cfm) (180 liters per minute [L/min]). Incubation temperatures for fungi were 25°C.

Volatile Organic Compound Sampling

Most samples for TVOC were collected by using battery-powered portable pumps to draw air at measured flow rates through glass tubes containing 2,6-diphenyl-p-phenzlene oxide. In the laboratory, the sample is thermally desorbed directly into a gas chromatography/mass spectral analyzer. The spectra from the desorbed sample is evaluated via a computer data base interface with the unit to identify the individual components in the sample. The quantity of each compound present is determined. Analytical results, which include any necessary corrections for parallel blank and recovery determinations, were used in conjunction with sampling data (volume of air sampled) to calculate the concentrations of airborne TVOC represented by each sample, expressed in micrograms analyte per cubic meter of air (ug/m^3).

A few samples for TVOC were collected by using organic vapor monitor badges. The contaminant enters the monitor by diffusion and is adsorbed by an active adsorbent medium (charcoal) inside the badge. The amount of contaminant adsorbed is determined by exposure time and contaminant concentration present in the sampled environment. A measured volume of carbon disulfide is added to the monitor to desorb the collected organic vapors. A portion of the desorbing solvent containing the organic contaminants is withdrawn from the monitor and analyzed by gas chromatography. Quantities of each analyte present are determined by comparison of areas under the sample chromatogram peaks with areas under chromatogram peaks for standards (as mineral spirits) prepared in carbon disulfide.

Nitrogen Dioxide Sampling

Integrated long-term area samples were collected by drawing air at measured flow rates (50 to 200 milliliters per

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TABLE 1

Airborne Fungi in Seven Buildings Where Quiescent and Aggressive Sampling Was Carried Out

Building, Time of Year	Fungi in Outdoor Air (cfu/m³)	Ratio Indoor/Outdoor Fungal Concentrations			Environmental Conditions in Building
		Quiescent Sampling in Offices	Quiescent Sampling in HVAC System	Aggressive Sampling in Office or HVAC System	
A, January	36	0.21	—	5.5	Excessive moisture RH = 60 to 80% dewpoint 62 to 72 °F
B, October	200	0.08	0.08	10 to 100	Dry, moldy insulation on inside of air handling units
C, June	200	0.1 to 1.0	—	—	Floors 1 to 4; RH = 30-40%; dewpoint 43 to 48 °F
C, June	200	2.5 to 5	—	—	Basement; RH = 60 to 70%; dew point 62 °F to 70 °F
D, November	830	0.07	—	13.2	Ceiling tiles dry but damaged by previous floods; induction units poorly maintained
E, December	100	0.15	—	0.5	Induction units poorly maintained
E, September	75	0.13	—	0.5	Induction units poorly maintained
F, August	200	0.25	0.5	1.5	Excessive moisture on day before sampling; RH = 50% on date of sampling
G, May	85	0.16	—	2.0	Fan coil units poorly maintained

cfu/m³ means colony forming units per cubic meter of air.

minute) for at least four hours through a sampling tube containing a 400-milligram triethanolamine-impregnated molecular sieve. Laboratory analysis is accomplished by transferring each triethanolamine-impregnated molecular sieve section to a flask where the nitrogen dioxide is desorbed and hydrolyzed in an aqueous triethanolamine solution to yield nitrite ion. An aliquot is treated with hydrogen peroxide, sulfanilamide, and n-(1-naphthyl)-ethylenediamine dihydrochloride. The reacted nitrite ion is measured with a spectrophotometer in a 1-centimeter cell at 540 nanometers.

RESULTS AND DISCUSSION

Microorganisms

Results of air sampling for mesophilic fungi in seven buildings are presented in Table 1. Air sampling was carried out in offices during normal working hours, under normal environmental conditions, with HVAC systems operating in a manner typical for each building. This is referred to as quiescent sampling. Sampling was also carried out as a reference in the outdoor air and, in a few buildings, within HVAC system air-handling units themselves (also quiescent sampling; Table 1). In a majority of buildings, airborne fungi were also collected in the occupied space or in the HVAC system when furnishings and mechanical components (for example, induction units) were manipulated by gentle pounding or agitation. This mode of sampling is referred to as "aggressive."

Concentrations of fungi collected indoors are expressed in terms of the ratio of the average indoor level divided by that present outdoors. With the exception of the basement of Building C, the ratio of the indoor/outdoor concentration of mesophilic fungi was substantially less than unity. Thus, in most buildings the concentration of fungi collected indoors is only 10% to 25% of that found at the same time in the outdoor air.

When furnishings in the occupied spaces or components of the HVAC system such as induction units, internal insulation, or drain pans are mechanically disturbed (aggressive sampling) levels of airborne fungi in the immediate vicinity generally become elevated above unity (Table 1). However, concentrations vary widely and a uniform interpretation of results cannot be obtained by simple comparison of ratios in Table 1. For example, despite the elevated concentrations of fungi (mostly *Cladosporium*) released during aggressive sampling in Building B, few of these organisms reach the occupied space in this otherwise "healthy" building. On the other hand, in Building F, several occupants were affected by an illness in which fever and chills were characteristic symptoms and yet the indoor fungal concentrations during aggressive sampling were just slightly elevated relative to those outdoors.

Interpretation of air sampling data for fungi can best be achieved on a building-by-building basis where factors such as environmental conditions in occupied spaces, HVAC system variables, and types of microorganisms are considered. A brief consideration of sampling results for each building listed in Table 1 follows.

Building A. Occupants in a zone of this building had complained for several months about uncomfortable thermal environmental conditions. A malfunctioning humidifier in the air-handling unit serving this zone resulted in elevated moisture levels in indoor air (relative humidity 60% to 80%; dew point 62° to 72°F).

Air sampling in offices under aggressive conditions showed that fungi were present at levels about five times higher than outdoor concentrations. Indoor fungi were dominated by *Aspergillus*, *Penicillium*, *Cladosporium*, and *Aureobasidium*, whereas *Cladosporium* alone was the dominant outdoor genus. Sampling in Building A thus indicated that microbiological amplification was occurring indoors, a con-

TABLE 2

Concentrations of Total Volatile Organic Compounds in 15 Buildings

Location	Concentration of TVOC in ug/m³	Number Samples	Percent of Total Samples
Indoors	≥ 2000	6	6
Indoors	≥ 1000 to 1999	15	14
Indoors	≥ 500 to 999	25	23
Indoors	≥ 200 to 499	31	28
Indoors	≥ 100 to 199	19	17
Indoors	≥ 1 to 99	13	12
Outdoors	≥ 500 to 999	3	13
Outdoors	≥ 200 to 499	5	22
Outdoors	≥ 100 to 199	7	30
Outdoors	≥ 1 to 99	8	35

Average of 109 indoor samples = 660 ug/m³
Average of 23 outdoor samples = 232 ug/m³

clusion that could also have been surmised from the high moisture levels characteristic of the affected zone.

Building B. During routine HVAC system preventive maintenance, it was observed that the interior insulation in air-handling units at locations downstream of the cooling coil section was covered with a mildew-like layer. The dominant fungus in the contaminated insulation was *Cladosporium*. Quiescent sampling both in offices and in active air-handling units (3 in from insulation) indicated that concentrations of fungi were less than 10% of outdoor levels (Table 1). However, when similar sampling in air-handling units was carried out simultaneously with slight agitation of insulation, recoveries of airborne fungi increased by two or three orders of magnitude.

Clearly the internal insulation in air-handling units was an amplification site for the common environmental fungus *Cladosporium*. Since the insulation was dry at the time of sampling, low concentrations of fungi in offices under quiescent conditions were probably due to the absence of active fungal growth and sporulation.

Building C. Occupants in a four-story building became concerned about a strong musty smell that was noticeable especially on lower floors. The basement had recently been flooded and its walls were wet and covered with a fungal growth.

Quiescent sampling in the basement showed that concentrations of airborne fungi were higher than outdoor levels. Sampling on floors one through four, however, failed to demonstrate elevated fungal concentrations. In this building, quiescent air sampling for fungi was effective in demonstrating the presence of an amplification site only in its immediate vicinity. The conclusion that wet basement walls were amplification sites for microorganisms was obvious (visually) prior to the initiation of sampling.

Building D. Quiescent and aggressive air sampling were carried out in an office where floods earlier in the year had damaged several ceiling tiles. Levels of fungi in offices during quiescent sampling (mostly *Cladosporium* and *Penicillium*) were less than 10% of outdoor levels (mostly *Cladosporium*, *Epicoccum*, and *Aureobasidium*). When damaged but dry ceiling tiles and dry insulation inside induction units were disturbed, concentrations of fungi (mostly *Cladosporium*, *Penicillium*, and *Epicoccum*) in offices increased to more than

TABLE 3

Concentrations of Total Volatile Organic Compounds in Building E Under Different HVAC System Outdoor Air Ventilation Operational Modes

Time of Year and Outdoor Air Ventilation	Average Concentration of Total Volatile Organic Compounds*		Indoor/Outdoor Ratio
	Indoors	Outdoors	
June; Minimum Outdoor Air	1420	—	—
November; Minimum Outdoor Air	1270	310	4.1
December; Minimum Outdoor Air	445	93	4.8
September; Minimum Outdoor Air	268	16	16.0
September; Maximum Outdoor Air	71	48	1.48
October; Maximum	85	50	1.70

*Concentration in micrograms per cubic meter of air

10,000 colony-forming units per cubic meter of air (cfu/m³) or about 10 times the outdoor level. It was apparent from this study that aggressive, not quiescent, sampling was effective in demonstrating the presence of dry microbial reservoirs. Of course, it could be surmised without sampling that water-damaged ceiling tiles were likely microbial amplification sites.

Building E. Quiescent air sampling was carried out for three days in a high-rise building in December and then during the following September. Concentrations of fungi recovered indoors averaged 13% to 15% of outdoor levels.

Aggressive air sampling near induction units that were poorly maintained showed that recoveries averaged only about half of those present in outdoor air. Thus, air sampling in this building was unsuccessful in demonstrating any significant fungal amplification site. Subsequent studies in this building have shown that HVAC system components are amplification sites for bacteria, including *Flavobacterium* and streptomycetes.

Building F. Quiescent and aggressive air sampling were carried out in a small building four to five days after an episode of illness characterized by fever, chills, and breathing difficulties. During the outbreak, relative humidity indoors exceeded 60% and dew point temperatures were above 62°F. When sampling was carried out, moisture levels in the occupied spaces had declined considerably.

Even during aggressive sampling, levels of fungi indoors only slightly exceeded those present in the outdoor air. Air sampling, however, did reveal that *Chaetomium* was a predominant fungus indoors but not outdoors.

Building G. Quiescent air sampling in an office with reported sick building syndrome complaints consistently showed that indoor recoveries were only about 16% of those found in outdoor air. *Cladosporium* dominated indoor and outdoor fungi. When poorly maintained fan coil units were disturbed, levels of fungi indoors increased to about two times those outdoors. *Aspergillus* dominated the fungal recoveries indoors during aggressive sampling.

VOLATILE ORGANIC COMPOUNDS

Air sampling for TVOC was carried out in 15 office buildings using 2,6-diphenyl-p-phenzlene oxide sorbent and gas

TABLE 4

Nitrogen Dioxide Concentrations in Seven Buildings in the New York City Area

Building	Nitrogen Dioxide Concentrations*		
	Protected Outdoor Air	Indoor Air	HVAC System Outdoor Air Inlet
Bldg. E	< 0.07	< 0.06 to 0.10	—
Bldg. E	—	0.2 to 0.3	—
Bldg. F	0.04	0.20	0.08
Bldg. G	0.05	0.09 to 0.10	—
Bldg. H	0.10	< 0.07 to 0.09	—
Bldg. I	0.10 to 0.11	0.03 to 0.16	—
Bldg. J	< 0.02	< 0.02 to 0.20	—
Bldg. K	< 0.02 to 0.05	< 0.03 to 0.60	< 0.04 to 0.60
Bldg. K	0.03 to 0.08	< 0.04 to 0.70	0.03 to 2.0

< means less than
*Concentrations in parts per million

chromatography-mass spectrometry analysis (Table 2). The average concentration of TVOC indoors was 660 ug/m³ while that outdoors was 232 ug/m³ (indoor/outdoor ratio = 2.84).

Approximately 20% of the 2,6-diphenyl-p-phenzlene oxide TVOC samples collected in offices equaled or exceeded a concentration of 1000 ug/m³. Six percent of the samples exceeded or equaled 2000 ug/m³. Concentrations of TVOC in outdoor air never exceeded 1000 ug/m³. Thirty-five percent of the outdoor air samples had TVOC concentrations less than or equal to 100 ug/m³. Only 12% of indoor samples were characterized by TVOC concentrations less than or equal to 100 ug/m³.

The authors had the opportunity to measure TVOC in one New York City high-rise office building (Building E) on four occasions when the HVAC system was using minimum outdoor air and on two additional occasions when maximum outdoor air ventilation (economizer cycle) was being used. The concentration of TVOC indoors was significantly elevated above outdoor levels under minimum outdoor air ventilation conditions (Table 3). The indoor/outdoor ratio of TVOCs in Building E under minimal outdoor air ventilation conditions ranged from 4 to 16. By contrast, under maximum outdoor air ventilation conditions, the indoor/outdoor ratio was just slightly greater than unity (1.4 to 1.7).

In one building (Building H) during a three-week period, TVOCs were measured by passive charcoal monitor. The offices of one tenant were contaminated by odors from the printing press operations of another tenant. Offices of the former tenant were characterized by occupant complaints of eye, nose, and throat irritation. Average concentrations of TVOC (as mineral spirits) indoors (time-weighted average for three weeks) was 22,500 ug/m³. Concentrations outdoors but within 6 ft of the building envelope averaged 1450 ug/m³. At a site remote from the building the TVOC concentration was less than 200 ug/m³ (the limit of detection of the sampling technique used).

NITROGEN DIOXIDE

Air sampling for NO_2 and other products of combustion were carried out in seven buildings in the New York City area (Table 4). Landlords or tenants in these buildings were concerned about the possible entry of combustion gases into offices from parking garages, loading docks, or poorly located HVAC system outdoor air inlets. Sampling for NO_2 in all buildings was carried out in the outdoor air, generally on the roof, as far away as possible from vehicular traffic or exhaust stacks that may contain combustion gases. In one building (Building K), extensive sampling was also carried out in the outdoor air inlet of the air-handling unit providing conditioned air to occupied spaces.

In two of the seven buildings, the lowest concentration of NO_2 in outdoor air (Buildings H and I) was greater than 0.05 ppm. Indoor concentrations of NO_2 generally exceeded outdoor levels, a result ascribed to contamination of the HVAC system outdoor air intake with combustion gases.

In one building (Building K) where sampling was carried out round-the-clock for six days, the authors had the opportunity to compare NO_2 concentrations in the indoor air with those outdoors on the roof and in the outdoor air inlet of the HVAC system. The outdoor air inlet for the HVAC system was located at grade level near a loading dock. Approximately 40% of the occupants in one office reported periodic complaints of headache, disorientation, nausea, burning eyes, and nosebleeds. Complaints of gasoline or diesel odors were also reported at the same time. Because of sporadic disruption of productivity, management had these offices vacated pending a resolution of the problem.

Concentrations of NO_2 in outdoor air in a protected location on the roof of Building K never exceeded 0.08 ppm (Table 4). In the affected office, NO_2 concentrations also did not exceed 0.08 ppm except on two occasions when levels rose as high as 0.6 to 0.7 ppm. On one of these occasions the concentration of NO_2 in the outdoor air inlet of the air-handling unit approached 2.0 ppm. On the other occasion it was assumed that a high concentration of NO_2 in the HVAC system outdoor air inlet preceded sampling in the occupied spaces. This building-associated problem was caused by poor HVAC system design, namely locating the outdoor air intake at grade level near a loading dock that would be periodically contaminated by combustion gases.

CONCLUSIONS

Microbiological Sampling

With the exception of only one building (Building C, Table 1), concentrations of fungi collected during quiescent sampling in the office environment were 10% to 25% of those in the outdoor air. Mechanisms such as HVAC system filtration and sedimentation of large spores are likely preventing the entry of most fungi into the indoor air. Elevated levels of fungi in indoor air during quiescent sampling are likely to be detected only in the immediate vicinity of active (wet) microbial amplifiers.

In some buildings with obvious but inactive amplifiers (Table 1, Building B), indoor fungal levels during quiescent sampling were much less than those in the outdoor air. A thorough visual examination of the building, including its HVAC system, is required to detect microbial reservoirs and amplification sites. Aggressive sampling in the immediate vicinity of the reservoir or amplifier may, however, be useful to confirm the visual impression that a microbial amplification site exists.

Aggressive sampling showed that elevated fungal levels (5 to 100 times that present in outdoor air) existed in three buildings (Buildings A, B, and D, Table 1). There was no indication, however, that complaints suggestive of hypersensitivity lung illness were characteristic of these buildings. In one building (Table 1, Building F) where occupants offered

complaints suggestive of hypersensitivity lung illness, aggressive sampling revealed only slightly elevated levels of fungi indoors. These data suggest that interpretation of air sampling data for microorganisms should be made with caution. Recoveries of viable particulate are affected by numerous variables including the condition of the amplifier (for example, wet or dry) and the time interval between the onset of the water problem and the onset of sampling. The possibility that occupant problems are related to agents other than viable fungi should not be overlooked (Morey 1988).

Air sampling for fungi should ideally be carried out only after a preassessment phase in which visual inspection of the building is carried out to identify microbial reservoirs and amplification sites (ACGIH 1987). It is generally much easier to carry out remedial actions than to prove that a microbial agent is causing occupant building-related illness.

Many variables affected microbial concentrations in indoor air. The perception of what is "typical" depends on the availability of water and nutrients, the number and kinds of fungi present outdoors and indoors, the operational status of the HVAC system, and the types of activities occurring in the occupied spaces. All these variables most be considered in deciding if indoor microbiological parameters are typical or normal. It should always be kept in mind that air sampling for microorganisms in itself cannot be used to predict potential adverse health responses in the office environment (ACGIH 1987; Morey 1988).

Volatile Organic Compound Sampling

The average concentration of TVOC (2,6-diphenyl-p-phenzlene oxide data only) indoors was elevated above outdoor levels in most of the offices studied. Wallace (1987) has shown that indoor/outdoor ratios for TVOC in residential environments significantly exceed unity.

In Building E we measured TVOC levels under both minimal and maximum outdoor air ventilation conditions. Under minimal outdoor air ventilation, the ratio of indoor to outdoor air TVOC concentrations was significantly above unity. Under economizer conditions, however, indoor levels were just slightly elevated above outdoor levels. These data from Building E suggest that wide variations in TVOC concentrations can be expected dependent upon the amount of outdoor air being utilized in conditioned air. Therefore, predictions on what is typical in terms of indoor TVOC concentrations and indoor/outdoor ratios are highly dependent on office building HVAC operational variables.

Molhave (1985) has speculated that a threshold for sensory perception to TVOC in indoor environments occurs at levels equal to or exceeding 1000 ug/m^3. Among the 109 air samples collected in office environments, 20% were characterized by TVOC concentrations equal to or exceeding 1000 ug/m^3, and 6% had concentrations equal to or exceeding 2000 ug/m^3.

Nitrogen Dioxide Sampling

Reference to outdoor air in protected locations generally provides guidance as to what is typical for a given geographical area in terms of concentrations of indoor combustion gases. In two of the seven buildings in Table 4, the minimal concentration of NO_2 outdoors was consistently greater than 0.05 ppm, which is, therefore, above the acceptable level of NO_2 recommended by ASHRAE Standard 62-1981R (ASHRAE 1981). In these buildings, the NO_2 levels indoors were similar to or just slightly elevated relative to outdoor concentrations.

In several buildings, however, the maximum concentration of NO_2 indoors (Buildings F, J, and K) greatly exceeded the outdoor level. We were fortunate in Building K to simultaneously correlate high indoor levels of NO_2 with even higher levels of this gas in the HVAC system outdoor air inlet. The collective data of this study can be interpreted as suggesting that when indoor levels of NO_2 greatly exceed (perhaps two to four times) the concentrations in protected outdoor areas, the air indoors is no longer "typical." Certainly when indoor levels of NO_2 exceed 0.5 ppm, even on a sporadic basis, widespread occupant problems can be expected.

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DISCUSSION

Jeffrey C. Olcott, Envirogenics Inc., Pennington, NJ: Of the studies you have described, how many were corroborated by clinical findings giving a diagnosis of hypersensitivity pneumonitis?

P.R. Morey, Clayton Environmental Consultants, Wayne, PA: None. However, in several of the studies involving buildings with fungal problems, private physicians had expressed the opinion that one or more occupants had symptoms suggestive of hypersensitivity lung illness.

Carl N. Lawson, LRW Engineers, Tampa, FL: On the building you checked, did any duct liners have a vinyl coating and, if so, was there any fungus growth?

Morey: None of the air-handling units had, to my knowledge, a vinyl liner covering internal insulation. However, in several instances, internal liners were sealed, apparently with an epoxy compound. Fungal and bacterial colonization of internal insulation in air-handling units downstream of cooling coils and in major air supply ducts was always most intense where the insulation exposed to the airstream was very porous. In one instance, the porous insulation (already heavily contaminated with *Penicillium*) was sealed with a polyvinyl acetate compound. Within two to three months, this sealant (polyvinyl acetate) became a substrate that supported a luxuriant fungal growth.