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Abstract

To test proposed methods for reducing SBS symptoms and to learn about the causes of these symptoms, a double-blind controlled intervention study was designed and implemented. This study utilized two different interventions designed to reduce occupants' exposures to airborne particles: (1) high efficiency filters in the building's HVAC systems; and (2) thorough cleaning of carpeted floors and fabric-covered chairs with an unusually powerful vacuum cleaner. The study population was the workers on the second and fourth floors of a large office building with mechanical ventilation, air conditioning, and sealed windows. Interventions were implemented on one floor while the occupants on the other floor served as a control group. For the enhanced-filtration intervention, a multiple crossover design was used (a crossover is a repeat of the experiment with the former experimental group as the control group and vice versa). Demographic and health symptom data were collected via an initial questionnaire on the first study week and health symptom data were obtained each week, for eight additional weeks, via weekly questionnaires. A large number of indoor environmental parameters were measured during the study including air temperatures and humidities, carbon dioxide concentrations, particle concentrations, concentrations of several airborne bioaerosols, and concentrations of several microbiologic compounds within the dust sampled from floors and chairs.

This report describes the study methods and summarizes the results of selected environmental measurements. The environmental conditions measured during this study were typical of the conditions commonly encountered inside office buildings. Air temperatures were sometimes outside of the boundaries of the ASHRAE thermal comfort zone. The spatial and temporal variations in air temperature ranged up to a few degrees Celsius-- large enough to suggest that it

may be important to account for variations in temperature in the evaluations of the interventions. Relative humidities were maintained within a narrow and widely accepted range (42% to 58%). Carbon dioxide concentrations were always below the 1000 parts per million guideline concentration recommended by ASHRAE but occasionally above the lowest suggested guideline value of 800 parts per million. Carbon dioxide concentrations tended to be higher on the second floor. The effective time-average steady ventilation rates (ESVRs) were approximately equal to or above the recommended minimum rates in the ASHRAE ventilation standard. For the nine-week study period, the average ESVRs were relatively constant (e.g., ± 15%), thus, temporal variation in ventilation rates were not likely to be a major confounding factor distorting the apparent effects of the interventions on SBS symptoms. The use of high efficiency air filters greatly decreased the indoor concentrations of submicron particles. Indoor concentrations of 0.3 μm to 0.5 μm size particles were, on average, a factor of 20 lower when the high efficiency filters were used compared to the concentrations with the standard air filters.

Because the processing and analyses of the questionnaire data are still underway, the influence of the interventions on symptoms is not yet known.

Background

Office workers frequently report a variety of acute health symptoms that are associated with occupancy in their office building. The symptoms include irritation of eyes, nose, throat, and skin, symptoms of the central nervous system (headache, fatigue, difficulty concentrating), and lower respiratory symptoms (wheeze and difficulty breathing). Buildings in which the prevalence or severity of symptoms is unusually high, prompting investigations and remedial activity, are often referred to as sick buildings; thus, these symptoms are often called sick building syndrome (SBS) symptoms. Investigations from the United States and Europe, in office buildings selected for study without a consideration of sick-building status, indicate that a significant proportion of office workers in nearly all office buildings experience these building-related symptoms (e.g., Fisk et al. 1993; Nelson et al. 1995, Sundell 1994). The prevalences of symptoms vary widely among buildings, indicating that some building-related factors influence these symptoms. The average proportion of workers that frequently experience a symptom that improves when they leave the building varies from a few percent (e.g., for wheeze) to approximately 20 or 30% for some of the irritation symptoms and headache.

SBS symptoms are considered to be non-specific symptoms because they do not indicate a specific known disease. Suspected causes of SBS symptoms include a variety of indoor pollutant exposures, e.g., chemical or microbiological irritants, chemicals that affect the central nervous system, allergens, and physical skin irritants such as fibers (e.g., Mendell 1993, Sundell 1994, Menzies and Bourbeau 1997). Other factors that have been statistically associated with SBS symptoms in one or more studies include the following: air temperature, humidity, building ventilation type, building ventilation rate, and various job factors, especially job stress (e.g., Mendell 1993, Sundell 1994, Menzies and Bourbeau 1997). Currently available information suggests that multiple factors acting simultaneously contribute to these symptoms.

SBS symptoms adversely affect the health and well being of many office workers. In addition, efforts to reduce SBS symptoms may lead to increased building energy use. SBS symptoms are commonly associated with modern energy-efficient building design. Attempts to reduce or prevent SBS symptoms often prompt designers and operators of buildings to increase ventilation rates or to avoid energy-efficient HVAC designs, leading to increased energy use. For example, some building operators operate building ventilation systems with 100% outside air, regardless of the energy consequences, in an attempt to reduce symptoms among workers in their building. SBS problems are a major consideration in ASHRAE's selection of minimum ventilation rates for buildings. In turn, these minimum ventilation rates influence building energy use.

SBS also imposes an economic penalty on society. When problems are severe and investigations of buildings are required, financial expenditures are necessary to support the investigations and considerable effort is typically expended by building management staff, by health and safety personnel and by building engineers. Responses to SBS have included costly changes in buildings, such as replacement of carpeting or removal of wall coverings to remove molds, and changes in building ventilation systems. Some cases of SBS have led to costly litigation. Some employers have moved their staff to a different building, incurring large moving costs. SBS symptoms can be a distraction from work and can lead to absence from work (Preller et al. 1990) and visits to doctors. Fisk and Rosenfeld (1997) have estimated that the annual productivity losses attributable to SBS symptoms experienced by U.S. office workers are on the order of $50 billion.

Many of the investigations of SBS have been case studies of individual buildings. These case studies have yielded valuable suggestions of causes, but little scientifically valid information. Also, during the past decade, a number of cross-sectional epidemiological studies have been undertaken to study SBS. In these cross sectional studies, populations of workers have been selected from a set of multiple buildings and the symptoms, building characteristics, job characteristics, and indoor environmental quality characterized for each population. Multivariate statistical models were then used to test for statistical associations between symptoms and suspected risk factors. These cross sectional studies, including our California Healthy Building Study (Fisk et al. 1993, Mendell et al. 1996), have substantially advanced the state of knowledge with respect to SBS symptoms. A weakness of cross-sectional studies is that they can not distinguish between actual causes of symptoms and confounding factors. The different populations of workers in these studies have many different potential risk factors, such as different ventilation rates, different pollutant exposures, and different psychosocial and job environments. Therefore, these studies are not ideally suited for assessing the influence of individual factors on symptoms.

To obtain more definitive information on the causes and solutions for SBS symptoms, intervention (i.e., experimental) studies are starting to be used. Intervention studies are controlled experiments in which a single variable is changed in order to test the hypothesis that a change in that variable will cause a measurable change in an outcome. In this area of study, the outcome of interest is the prevalence or severity of SBS symptoms. Intervention studies are strengthened through the use of similar experimental and control groups and by maintaining the occupants and the researchers in contact with occupants blind with respect to the precise times when the intervention variables are changed. This report describes the progress to date in

completion of an intervention study performed as a collaboration of the Indoor Environment Department at Lawrence Berkeley National Laboratory and the National Institute for Occupational Safety and Health.

Research Objectives

There were two primary objectives of this research: (a) to determine if two energy-efficient interventions designed to reduce office workers' exposures to particles resulted in a reduction in SBS symptoms; and (b) to develop and demonstrate an improved research methodology for investigations of the causes and solutions for SBS symptoms. The first intervention consisted of using, in the building's HVAC system, air filters that have a much higher particle removal efficiency than commonly used filters. We used filters with a rated efficiency of 95% for 0.3 μm size particles. The second intervention was to perform thorough cleaning of carpets and chairs using a unique, very powerful vacuum cleaner. The presumption underlying this second intervention was that improved cleaning reduced workers exposures to resuspended particles, including bioaerosols. In addition to testing these proposed intervention methods, the study was intended to advance our knowledge regarding the contribution of airborne particles to SBS symptoms.

The research was also designed to satisfy a number of secondary objectives including the following: (1) advancing our understanding of the influence of efficient air filters on indoor particle exposures and, in general, advancing the state of knowledge about indoor-outdoor particle relationships in commercial buildings, (2) quantifying the effects of the new vacuuming procedure on surface dust quantities and on the quantity of microbiological agents on surfaces; (3) evaluation of a new practical tracer-gas procedure for monitoring of ventilation in commercial buildings, (4) development and evaluation of new procedures for collecting dust samples from chairs and floors, (5) assessments and intercomparisons of new measurement procedures for microbiological agents and toxins in air and in surface dust; and (6) intercomparison of two symptom questionnaires. Also, this study was designed to have the potential to provide information on the relationship of symptoms to ventilation rate and indoor temperature, if sufficient temporal and spatial variation occurred in these parameters.

Building Description

The two study groups were the workers on the second and fourth floors of a large office building with mechanical ventilation, air conditioning, and sealed windows. The floor area and average occupancy on the second floor were 4130 m^2 (44500 ft^2) and 165 persons. The floor area and average occupancy on the fourth floor were 4840 m^2 (52100 ft^2) and 280 persons. Each floor of the building had an independent set of ventilation systems, thus, there was no mechanical recirculation of air between floors. With this arrangement, an intervention on one floor should have had no discernible effect on the environment in another floor.

Each floor was ventilated and conditioned by a set of four identical air handling units (AHUs). Two AHUs were located in each of the two mechanical rooms located at opposite corners of the floor. For each air handler, a supply fan drew outside air through louvers and dampers in the exterior walls. The outside air mixed with recirculated indoor air drawn from the mechanical room and the mixture passed through a bank of eight air filters, each with nominal cross-sectional dimensions of 0.6 m by 0.6 m (24 inch by 24 inch). The filtered air passed through the supply fan, through coils used for cooling, and then into the supply air duct system located in the ceiling plenum above the occupied space. The ventilation systems used variable-air volume (VAV) controls in the supply air distribution system to modulate the rate of air supply to different sections of the building as needed to maintain the desired indoor temperature. Thus, the total air supply rate varied with changes in thermal loads. No air filters were present in the VAV units used during the summer cooling season. The supply air was delivered to the space through diffusers installed in the suspended ceiling that separated the occupied space from the ceiling plenum. Return air was drawn through grilles in the suspended ceiling and flowed through the ceiling plenum to the mechanical rooms. When thermal loads were particularly low, a portion of the supply air was vented to the mechanical room, bypassing the supply air ductwork. This procedure limited the maximum air pressures in the supply air ductwork and in the VAV control units. Air exited the floors to the outside through bathroom exhaust fans and, upon demand, through a relief fan located in each mechanical room. The rated maximum supply air flow from the set of four air handlers that serve each floor (Persily et al. 1994) was 18.4 $m^3 s^{-1}$ (39,000 cfm). With the floor areas provided above and the ceiling height (including the plenums) of 3.5 m (11.5 ft), the maximum rates of supply flow normalized by the indoor volume were 4.6 h^{-1} on Floor 2 and 3.9 h^{-1} on Floor 4.

Each AHU had an automatic control system, called an economizer, that increased the rates of outside air drawn into the unit above a minimum value when the outside air temperature was below approximately room temperature. (The purpose of economizers is to save energy.) During the study, the outside air temperatures were high and the outside air dampers were nearly always in the minimum open position during building occupancy. (Damper position was confirmed using sensors on the actuators that control outside air damper position).

The exterior walls of the building were steel and glass. Also, the building had a large enclosed atrium at its core, separated from the office spaces primarily by glass. Except for the bathrooms and elevator lobbies, the floors were fully carpeted. The furnishings included extensive fabric-covered partitions, chairs that were mostly fabric covered, desks, file cabinets, and normal office equipment including many desk-top computers.

Research Methods

Overall Study Design

Our intent for this study was to utilize the strongest study design possible within financial, time, and other constraints. A strong study of SBS symptoms should test one or more plausible hypotheses with a physiological basis, minimize the potential for bias and confounding, be large enough for statistically significant findings, and utilize high quality measurement procedures.

The features of this study that met these criteria included the focus on a reduction in particle exposures, which has a clear physiological potential to reduce symptoms. Also, prior SBS research points to particles, especially bioaerosols, as a potential cause of symptoms (Mendell 1993, Fisk et al. 1992). An intervention (experimental) approach with a within-subject comparison of symptoms (i.e., primary results will be based on the changes in symptoms within subjects), was selected to reduce the potential for confounding by personal, job, building, or environmental factors other than those environmental factors intentionally manipulated. The two interventions were designed to have a large, but still practically achievable, effect on airborne particles and surface cleanliness, respectively. A control group was used to assess and account for temporal changes in symptoms unrelated to the interventions. For the space-cleaning intervention, occupants of a floor without special space cleaning were the control group. For the enhanced-filtration intervention, a crossover design (experimental group becomes control group and vice versa) with multiple crossovers was used to further determine if measured changes in symptoms were a consequence of the intervention and not coincidental. The multiple crossover also increased statistical power. The experimental and control populations, each containing about 200 individuals, were as large as practical and considered adequate based on a pilot study and statistical calculations. The study was double blind in that both the occupants of the building and researchers in contact with the occupants were unaware of timing of the interventions in particular study spaces. With respect to measurements, within financial constraints we used the best methods possible (described below) for environmental measurements. Finally, we developed and used a new symptom questionnaire that collected information on symptom intensity during the current day. This questionnaire should have provided a more accurate measurement of symptoms than the more common questionnaires that require subjects to recall their symptom prevalences during an extended period, such as a month or year.

The study took place during summer (July through early September 1996) to minimize potential influences of changing season or weather on building operation or on indoor environmental conditions. The two floors selected for the study had a very similar office layout and furnishings, primarily small workstations inside cubicles made from fabric-covered partitions. The type of work performed was also very similar on both floors (i.e., information processing).

Table 1 illustrates the overall experimental sequence. To maintain the study blind until additional data analyses are completed, we designate the two study floors as Floor A and Floor B in this table. No interventions were implemented in weeks 1 and 2; however, baseline data were collected on health symptoms, ventilation, and indoor environmental quality (IEQ). Weeks 3 through 6 constituted the filtration interventions with crossovers. During week 7, both spaces were in the normal (baseline) condition. The floors and chairs of Floor A received the special thorough cleaning during the weekend before week 8, which had an effect presumed to persist through week 8 and possibly through week 9.

Table 1. Experimental sequence.

Week	Corresponding Dates	Floor A Condition	Floor B Condition	Measurements
1	July 18-July 19, 1996	baseline, normal filters	baseline, normal filters	symptoms, ventilation, IEQ
2	July 25-July 26, 1996	baseline, normal filters	baseline, normal filters	symptoms, ventilation, IEQ
3	August 1 - August 2, 1996	baseline, normal filters	high efficiency filters	symptoms, ventilation, IEQ
4	August 8 - August 9, 1996	high efficiency filters	baseline, normal filters	symptoms, ventilation, IEQ
5	August 15 - August 16, 1996	baseline, normal filters	high efficiency filters	symptoms, ventilation, IEQ
6	August 22 - August 23, 1996	high efficiency filters	baseline, normal filters	symptoms, ventilation, IEQ
7	August 29 - August 30, 1996	baseline, normal filters	baseline, normal filters	symptoms, ventilation, IEQ
8	September 5 - September 6, 1996	thoroughly cleaned floors and chairs, normal filters	baseline, normal filters	symptoms, ventilation, IEQ
9	September 12 - September 13, 1996	thoroughly cleaned floors and chairs, normal filters	baseline, normal filters	symptoms, ventilation, IEQ

Interventions

The filtration intervention was implemented by switching between the normal air filters in the HVAC systems and high efficiency filters. New normal filters were installed on both study floors at the start of the study. These filters have an initial ASHRAE efficiency rating (ASHRAE 1992) of 22% and a rating of 27% after extended use. No data were available on the efficiency versus particle size for these specific filters, although filters with a similar ASHRAE rating typically have efficiencies of approximately 3%, 15%, 40%, and 80% for particles with aerodynamic diameters of 0.3 μm, 0.85 μm, 1.5 μm, and 3 μm, respectively (ASHRAE 1992b). The high efficiency filters used in this study have a minimum efficiency of 95% for particles with a diameter of 0.3 μm. While the normal filters have no gaskets or seals to limit the bypass of air around them, the high efficiency filters have flexible rubber seals. The published airflow resistance (i.e., pressure drop) of the normal and high efficiency filters was nearly identical for the rates of airflow in the AHUs. Switching between the normal and high efficiency filters caused no discernible change in the supply air flow rate based on multipoint measurements of supply air velocity. The changeover between normal and high efficiency filters took place after normal working hours inside mechanical rooms that were not accessible to the office workers. Thus, the occupants had no indication of the type of filters utilized on a particular week.

For the surface cleaning intervention, we initially considered various methods of wet cleaning. However, wet cleaning was rejected for two reasons: (1) it removes stains and leaves a damp carpet, making the intervention detectable to building occupants; and (2) we feared that the moisture that remains in carpets after wet cleaning could lead to a temporary increase in growth of microorganisms within the carpet. Therefore, we utilized a thorough dry vacuum cleaning of floors and fabric-covered chairs for the surface cleaning intervention. For this purpose, a special

canister-type vacuum cleaner system was designed and built. This vacuum cleaner had an unusually high flow and suction, due to the simultaneous use of two powerful vacuum motors (each motor required a separate 20 ampere, 120V electrical circuit). The component in contact with the floor was a nozzle without a beater bar or brush connected to the vacuum by a 5 cm (2 in) diameter flexible hose. The vacuum's filter system included a settling chamber for large particles, followed by a low efficiency filter, followed by a HEPA filter. (HEPA filters are designed to have a minimum efficiency of 99.97 % for 0.3 μm particles.) Vacuuming, performed by the company that fabricated the special vacuum cleaner, occurred late during the Friday and Saturday nights preceding week 8, when the building occupants were not present. A member of the research team monitored the cleaning process. To help maintain the blinding of the occupants, after the floor and chairs were vacuumed this person also distributed small fragments of paper on the floor and chairs to lessen the "cleaned" appearance of the floor (Paper fragments were not distributed on the control floor but were naturally present on the floors.)

Environmental Measurements

A large number of indoor environmental parameters were measured during the Healthy Building Intervention Study. Some parameters were measured only on Thursdays and Fridays, the days of the week on which occupants were asked to complete the health symptom questionnaires. The results of environmental measurements are organized by the study week number. Table 1 relates the study week numbers to corresponding dates for Thursday and Friday.

Table 2 lists measured parameters, the number of measurement locations, and the measurement frequencies. Measurement methods and quality control measures are listed in Table 3.

A few of the measured parameters require explanation. Endotoxins are lipopolysaccharide molecules found in the outer membrane of Gram-negative bacteria. Epidemiological data indicate that endotoxin is a cause of airway inflammation. In experimental studies with endotoxin, health effects have included fever, headache, cough, diffuse aches, nausea, malaise, shortness of breath, and acute air flow obstruction. Some sick-building studies (Teeuw 1994; Teeuw 1992; Gyntelberg et al. 1994) provide evidence that endotoxin or Gram-negative bacteria may be associated with SBS symptoms.

Two chemical markers for fungi, which are also suspected to be a cause of SBS symptoms, were also measured. Ergosterol is a component of fungi and is being explored as an indicator of total fungal biomass. β-1,3 glucan is a component of the cell walls of fungi and is a source of inflammation. Research by Rylander et al. (1992) indicates that β-1,3 glucan may associated with SBS symptoms.

Table 2. Measured environmental parameters, measurement locations, times, and frequencies.

Parameter	# of Locations or Samples per Floor	Measurement Locations	Outside Air Measurement Y/N	Measurement Times	Recording Frequency
Airborne particles	2	Occupied space between ~ 1.8 m above floor	Y	Thursday and Friday workday	Usually 1-3 minute
Air temperature	9	Occupied space between 1 and 1.8 m above floor	Y	Continuous	1.2 hour
Air relative humidity	2	Occupied space between 1 and 1.8 m above floor	N	Continuous	1.2 hour
Carbon dioxide	2	Mechanical rooms (return air path)	Y but instrument failed	Continuous	5 minute
Outside air damper position	2	Mechanical rooms	Not applicable	Continuous	16 minute
Effective steady ventilation rate	5 - 6	Occupied space ~ 1.5 m above floor and mechanical rooms return air	N	Thursday-Friday workday average	Thursday-Friday workday average
Airborne endotoxin	8	Occupied space ~ 1.2 m above floor	Y	Thursday of weeks 3,4,7,8 MWF of week 1	8-hour average
Airborne β-1,3 glucan	3	Occupied space ~ 1.2 m above floor	Y	Thursday of weeks 3,4,7,8 W of week 1	8-hour average
Airborne ergosterol	4	Occupied space ~ 1.2 m above floor	Y	M-F of week 1	50-hour average
Floor & chair dust endotoxin	2 (floors) 2 (chairs)	Occupied space	N	Friday after work or Saturday of weeks 1, 6, 8	Not applicable
Floor & chair dust β- 1,3 glucan	2 (floors) 2 (chairs)	Occupied space	N	Friday after work or Saturday of weeks 1, 6, 8	Not applicable
Floor & chair dust ergosterol	2 (floors) 2 (chairs)	Occupied space	N	Friday after work or Saturday of weeks 1, 6, 8	Not applicable
Floor & chair dust bacteria	2 (floors) 2 (chairs)	Occupied space	N	Friday after work or Saturday of weeks 1, 6, 8	Not applicable
Floor & chair dust fungi	2 (floors) 2 (chairs)	Occupied space	N	Friday after work or Saturday of weeks 1, 6, 8	Not applicable
Chair dust house dust mite antigen	2 (chairs)	Occupied space	N	Friday after work or Saturday of weeks 1, 6, 8	Not applicable

Table 3. Sampling and measurement methods for environmental measurements.

Parameter Measured	Measurement Method	Estimated Accuracy	Quality Control Measures
Particle concentration (0.3-0.5 μm, 0.5-0.7μm, 0.7-1.0μm, 1.0-2.0μm, >2.0μm)	Laser optical particle counter, Met One Model 237B	Instruments agree within ~ 20%; 50% counting efficiency @ 0.3 μm; < 10% coincidence loss @ 140 part./ml	Pre- and post study factory calibration and instrument intercomparison
Air temperature	Solid state sensor & data logger, Onset Instruments, HOBO Temp, -5 to +37 ^{0}C range	±1 degree Fahrenheit (±0.5 degree Celsius)	Calibration vs. NIST traceable platinum resistance thermometer
Air relative humidity	Thin film polymer sensor & data logger, Onset Instruments, HOBO-RH	± 5% RH	Factory calibration check with salt solution method
Carbon dioxide	Infrared spectroscopy, California Analytical Instruments ZPF-9, 0-3000 ppm range	± 10% of measured value	Pre- and post study multipoint calibration
Periods when outside air damper is in minimum open position	Magnetic reed switch, battery, and data logger	Not applicable	Check via manual operation of damper
Equivalent steady ventilation rate	New tracer gas method (Fisk et al 1993; Faulkner and Fisk 1998)	± 15% of measured value (precision is ± 5%)	Weekly calibration of tracer gas analyzer, simultaneous measurements with two tracer gases
Air endotoxin	Filter samples at 3 L min^{-1} using pumps with flow controller collected on 37 mm diameter 1.6 μm glass fiber filters, kinetic limulus assay with resistant-parallel-line estimation (Milton et al. 1992)	Extraction efficiency of two methods have mean difference of 2.1%; Assay 95% CI ~ ± 0.28 log (measured endotoxin units)	Samples assayed simultaneously with control standard; control standards quantified for each lot; corrections for assay interferences
Floor-dust, and chair-dust endotoxin	Filter sample, kinetic limulus assay with resistant-parallel-line estimation (Milton et al. 1992)	95% CI for extraction is 1.02-1.28; Assay CV is 23% for field samples; Assay CV for control standards is 3.9% (within assay) and 7.5% between assays	Samples assayed simultaneously with control standard; control standards quantified for each lot; corrections for assay interferences

Table 3 continued.

Parameter Measured	Measurement Method	Estimated Accuracy	Quality Control Measures
Air, floor-dust, and chair-dust β- 1,3 glucan	Filter sample; kinetic limulus assay, spectrophotometric, using glucan-specific lysate; air samples collected at 3 L min^{-1} using pumps with flow controller on 37 mm diameter, 0.4 μm polycarbonate filters	Limit of detection ~0.6 ng m^{-3} with 1.4 m^3 sample volume and field blanks of 0.3 ± 0.2 ng/filter	Positive and negative control analyzed with each assay; analysis of filter blanks
Air, floor-dust, and chair-dust ergosterol	Filter sample; gas chromatography / mass spectrometry using ion trap instrument; air samples collected at 4 L min^{-1} on 37 mm diameter, 0.4 μm polycarbonate filter	Limit of detection = 50 μg per liter air, 3 ng per gram dust	GC-MS calibration; identification of ergosterol in MS verified by uptake of daughter spectra
Floor & chair dust bacteria (Gram-neg. total, rods, and cocci, Gram-pos. total, rods, cocci)	Filter sample, culture media is tryptic soy agar an other media, visual counting and identification using gram stain	Not available	Performance of media assessed with control organisms; diluents, reagents, and disposable materials checked for sterility
Floor & chair dust fungi (total and by genus/species)	Filter sample; culture media is inhibitory mold agar with antibiotics and yeast malt extract; visual counting and identification	Not available	Performance of media assessed with control organisms; diluents, reagents, and disposable materials checked for sterility
Chair dust, house dust mite antigen	Filter sample, polyclonal enzyme immunoassay for total dust mite antigen	Limit of detection is 16 ng per gm dust; intra-assay CV is 3.2%; inter-assay CV is 11.5%; sample extraction CV is 12%	Positive and negative controls for every assay; quality control checks for reagents

New methods and hardware were developed to collect dust samples from floors and chairs for subsequent microbiological analyses. These dust samples were collected on 37 mm diameter filters installed in filter cassettes. For endotoxin analyses, glass fiber filters were used. For other analyses, samples were collected on polycarbonate filters with 0.8 μm pores. After sample collection, the filters were capped and transported to various laboratories for analyses.

The apparatus developed to collect floor dust samples is illustrated in Figure 1. The components are as follows: (1) a rectangular aluminum plate (30.5 x 30.5 x 1.3 cm) called a sled that is maintained parallel to and above the surface of the carpet; (2) rectangular strips of teflon (30.5 x 3.2 x 0.5 cm), called runners, that rest on the carpet and hold the sled above the carpet; (3) a handle (not shown) used to pull the sled over the surface of the carpet; (4) three stainless steel sample tubes (outer and inner diameters of 6.4 mm and 3.9 mm) that extend through the sled perpendicular to its surface with one end extending below the surface of the carpet 1.0 mm below the base of the runners, (5) filters installed in filter cassettes connected to the top end of each sample tube; (6) a battery powered, flow-controlled sample pump mounted on top of the

sled that draws air into the sample tubes and through the filter; and (7) flexible tubing that connects the pump to the outlet sides of the filter cassettes. The apparatus acts as a miniature vacuum cleaner with a controlled flow rate of approximately 25 L min^{-1}. Dust is drawn from the carpet and into the filter cassettes where it is collected on the filters. The flow rate through each filter is nearly identical and equal to one-third of the total sample flow rate. The pump maintains a constant flow rate as the filters load with dust and the sled maintains the tips of the sample tubes at a fixed height relative to the surface of the carpet.

To collect floor dust samples, new filters and filter cassettes were installed, the pump was turned on, and the sampling apparatus was pulled over the carpet surface at a normal walking pace for ten minutes. With 10 minutes of sampling, the total sample path was approximately 240 m. To obtain a sample representative of the entire floor (excluding the areas of the floor located beneath furniture), the sample path extended throughout the occupied space and included the interiors of offices and cubicles as well as the aisles. This sampling system performed very satisfactorily. The mass of dust collected on each filter was usually 200 to 500 mg. The average relative standard deviation in the masses of dust collected within a sample period was 17% (n=6 per period from two sequential periods of sample collection on three filters). The sample flow rate remained constant throughout the 10 minute period of sampling. The only problem encountered was the occasional plugging of a sample tube by a large particle, making it necessary to collect another set of samples.

A similar procedure, based on a battery-powered sample pump and filter cassettes with 37 mm filters, was developed for sampling from fabric-covered chairs. The sample flow rate was approximately 20 L min^{-1}. Because the surface of chairs was not flat, the sample tube was held by hand and used to manually vacuum a portion of the surface of 10 to 20 chairs selected from throughout the study space. The chair sampling apparatus is illustrated in Figure 2. Only one filter sample was collected at a time. The nozzle that contacted the chair surface was 15.9 mm in internal diameter, much larger than the opening to the sample tubes used to sample dust from floors. A plastic sampling template with 20 holes (5.1 cm in diameter), five holes per quadrant, was placed on the seat of the chair to guide the sampling. To collect a sample, the first chair was selected, the plastic template was placed on the seat of the chair, and the portion of the chair's surface accessible through a set of four holes in the template, one hole per quadrant, was vacuumed. Each hole was vacuumed for three seconds (timed by counting). The template was moved to each remaining chair and the process was repeated. After all chairs had been vacuumed, the filter cassette was removed and capped. To obtain the next sample with a new filter, the entire process was repeated using a different set of holes in the sample template. For our application, a set of five dust samples was collected from each set of chairs (hence the five holes in each quadrant of the sample template). With this procedure, the mass of dust collected per filter was a few hundred milligrams. The sample flow rate remained constant except in rare instances when a large particle plugged the inlet to the filter. The average relative standard deviation in the mass of dust collected during a sample period (N=5 per period) was 32%.

The new tracer gas procedure used to measure equivalent steady outside air ventilation rates (ESVRs) is described in detail elsewhere (Fisk et al. 1993, Faulkner et al. 1998). For the measurements, an indoor pollutant source was simulated with approximately 100 passive sources of a perfluorocarbon tracer gas spaced uniformly per unit floor area. The sources continuously

released tracer at a known rate. During the workday periods, air samples from five to six seated breathing-level locations per floor were collected in gas storage bags. The concentrations of tracer gas in the bag samples were subsequently determined using a calibrated gas chromatograph with electron capture detector. The ESVRs were based on the tracer concentrations in the sample storage bags and on the indoor tracer emission rates. The ESVRs are the steady rates of outside air supply that, with thorough mixing of the indoor air, would yield the measured tracer gas concentrations.

Health Symptom Questionnaire

On Wednesday evening or Thursday of each study week, questionnaires were distributed and occupants were asked to complete the questionnaire on Thursday or Friday afternoon. The weekly questionnaire asked occupants to indicate the severity of different health symptoms during the current day on a scale of "none at all today" to "very severe today". In other sections of the weekly questionnaire, occupants rated the environment at work (e.g., "not at all too warm" to "much too warm") and answered questions regarding their mental state (e.g., mental confusion, mental fatigue, stress). The questionnaire used on the first week included an informed consent form and collected additional information including demographic and job information. In addition to the questions on health symptom severity, the first week questionnaire also contained questions about the prevalence of various symptoms during the previous four weeks. The completed questionnaires had only an identification number, thus, only the researchers could link completed questionnaires to individual persons. Copies of the questionnaires are provided in Appendix 1.

Results

Table 4 lists summary parameters for the workday period of Thursday and Friday of each week (the days of questionnaire completion), calculated from the environmental measurements of temperature, humidity, carbon dioxide concentration, and ventilation rate. These calculated parameters will be used in the statistical modeling to evaluate the outcome of the interventions and to investigate the relationship of symptoms to ventilation rate, carbon dioxide concentrations, and indoor temperature. The parameters were calculated for four sections of each floor (called spaces, depicted in Figure 3), except the carbon dioxide data apply for pairs of spaces and humidity data are available from only two spaces per floor. Because the occupants, who completed questionnaires, also identified the spaces that they work in, cross sectional analyses may provide information on the association of symptoms with some of these parameters. Table 4 does not contain the results of microbiological measurements because these data are still being analyzed.

Table 4. Summary of environmental data for 7:00 a.m. to 5:00 p.m. of Thursday and Friday of each study week, excluding particle and microbiological data.

week	Space	Avg. Temp. (C)	Hr. > 26 C	Hr. < 23 C	Deg-hr. for T > 21C	Deg-hr. for T > 23C	Deg-hr. for T > 25C	Avg. RH (%)	Avg. CO_2 (ppm)	Hr. CO_2 > 700 ppm	Hr. CO_2 > 800 ppm	Effective Steady Ventilation Rate (m3/s)	Effective Steady Ventilation Rate (cfm)
1	21	25.3	0.00	0.00	43	23	4	45	694	4.8	1.1	1.93	4084
1	22	24.4	0.00	0.00	34	14	0	----	694	4.8	1.1	1.94	4111
1	23	23.5	0.00	3.64	25	6	1	----	671	4.1	0.0	2.10	4455
1	24	24.1	0.00	2.78	31	12	1	50	671	4.1	0.0	1.83	3877
1	41	24.4	0.00	0.22	34	14	0	----	589	0.0	0.0	3.78	8004
1	42	24.2	0.00	0.00	32	12	0	54	589	0.0	0.0	3.76	7960
1	43	24.1	0.33	0.25	31	11	2	----	679	4.6	0.0	3.49	7385
1	44	23.8	0.00	0.75	28	8	0	54	679	4.6	0.0	3.15	6664
1	out	30.6	10.00	0.00	96	76	56	----	----	----	----	----	----
2	21	25.0	0.00	0.00	40	20	2	44	710	6.5	1.8	1.79	3793
2	22	24.2	0.00	0.00	32	12	0	----	710	6.5	1.8	1.77	3758
2	23	22.6	0.00	8.83	16	0	0	----	709	7.0	1.0	2.10	4455
2	24	23.2	0.00	4.42	23	6	0	51	709	7.0	1.0	1.75	3713
2	41	24.1	0.00	0.31	31	11	0	----	594	0.0	0.0	3.43	7273
2	42	24.0	0.00	0.58	30	10	0	53	594	0.0	0.0	3.89	8234
2	43	23.1	0.00	2.96	21	2	0	----	693	5.8	0.0	3.35	7093
2	44	23.0	0.00	5.04	20	1	0	52	693	5.8	0.0	2.94	6230
2	out	24.8	3.50	2.83	38	21	9	----	----	----	----	----	----
3	21	24.9	0.00	0.00	39	19	2	45	627	1.9	0.0	1.79	3793
3	22	24.1	0.00	0.00	31	11	0	----	627	1.9	0.0	1.75	3713
3	23	22.2	0.00	10.00	12	0	0	----	716	7.0	1.9	2.07	4391
3	24	23.5	0.00	4.06	25	9	0	50	716	7.0	1.9	1.72	3646
3	41	23.8	0.00	0.92	28	9	0	----	603	0.0	0.0	3.78	8004
3	42	23.5	0.00	1.04	26	6	0	58	603	0.0	0.0	----	----
3	43	23.2	0.00	2.00	23	3	0	----	678	5.6	0.0	3.02	6396
3	44	23.0	0.00	3.79	20	1	0	54	678	5.6	0.0	2.93	6203
3	out	24.6	2.42	2.67	36	20	7	----	----	----	----	----	----
4	21	24.6	0.00	0.00	37	17	0	47	738	6.9	4.4	1.87	3965
4	22	23.9	0.00	0.21	29	9	0	----	738	6.9	4.4	1.82	3853
4	23	22.5	0.00	9.83	15	0	0	----	731	7.1	3.1	2.19	4641
4	24	23.3	0.00	4.33	23	6	0	52	731	7.1	3.1	1.90	4030
4	41	23.5	0.00	2.22	26	6	0	----	640	0.6	0.0	3.52	7462
4	42	23.6	0.00	0.83	26	7	0	57	640	0.6	0.0	3.76	7960
4	43	23.3	0.00	1.42	24	4	0	----	689	6.1	0.0	2.99	6340
4	44	22.9	0.00	5.13	19	1	0	53	689	6.1	0.0	2.91	6176
4	out	26.7	5.67	1.08	57	38	22	----	----	----	----	----	----
5	21	25.6	1.17	0.00	46	26	6	44	663	5.0	0.3	1.95	4139
5	22	25.2	0.75	0.00	42	22	3	----	663	5.0	0.3	1.93	4084
5	23	22.6	0.00	9.22	16	0	0	----	702	6.5	1.3	2.01	4254
5	24	23.5	0.00	3.78	26	8	0	50	702	6.5	1.3	1.72	3646
5	41	24.4	0.00	0.50	34	14	0	----	625	0.6	0.0	3.49	7385
5	42	25.6	3.71	0.00	47	27	7	51	625	0.6	0.0	3.98	8428
5	43	23.5	0.00	0.75	25	5	0	----	673	4.8	0.0	3.02	6396
5	44	23.0	0.00	4.33	20	1	0	55	673	4.8	0.0	3.01	6368
5	out	27.3	5.83	0.75	62	43	26	----	----	----	----	----	----

Table 4. continued.

week	Space	Avg. Temp. (C)	Hr. > 26 C	Hr. < 23 C	Deg-hr. for T > 21C	Deg-hr. for T > 23C	Deg-hr. for T > 25C	Avg. RH (%)	Avg. CO_2 (ppm)	Hr. CO_2 > 700 ppm	Hr. CO_2 > 800 ppm	Effective Steady Ventilation Rate (m3/s)	Effective Steady Ventilation Rate (cfm)
6	21	24.9	0.00	0.00	39	19	2	43	723	6.7	3.4	2.07	4391
6	22	23.8	0.00	0.00	28	8	0	----	723	6.7	3.4	1.47	3109
6	23	22.8	0.00	7.00	18	1	0	----	681	6.3	0.6	2.63	5569
6	24	23.6	0.00	3.83	26	9	0	49	681	6.3	0.6	2.13	4504
6	41	23.9	0.00	1.72	30	11	0	----	637	1.4	0.0	2.91	6176
6	42	24.4	1.17	1.29	35	16	3	51	637	1.4	0.0	3.60	7621
6	43	23.4	0.00	1.17	24	4	0	----	664	3.5	0.0	3.05	6454
6	44	23.0	0.00	4.17	20	1	0	55	664	3.5	0.0	3.30	6989
6	out	28.4	7.67	0.00	74	54	34	----	----	----	----	----	----
7	21	24.3	0.00	0.00	34	14	0	42	691	5.0	1.9	1.81	3829
7	22	23.6	0.00	0.29	26	6	0	----	691	5.0	1.9	1.80	3805
7	23	22.6	0.00	9.61	16	0	0	----	669	3.9	1.2	2.36	5001
7	24	23.5	0.00	3.89	25	8	0	49	669	3.9	1.2	1.88	3978
7	41	24.1	0.00	0.47	32	12	0	----	623	0.6	0.0	3.64	7703
7	42	25.2	0.00	0.00	43	23	4	52	623	0.6	0.0	3.31	7023
7	43	23.5	0.00	1.29	25	6	0	----	657	2.9	0.0	3.25	6888
7	44	23.3	0.00	1.58	23	3	0	56	657	2.9	0.0	2.99	6340
7	out	25.6	4.67	2.67	46	29	16	----	----	----	----	----	----
8	21	24.8	1.00	0.00	39	19	2	42	700	5.7	2.2	2.04	4329
8	22	24.3	0.00	0.17	33	13	1	----	700	5.7	2.2	2.09	4439
8	23	23.8	0.00	3.00	28	11	1	----	695	5.8	2.3	2.42	5126
8	24	24.2	0.50	1.67	33	14	2	46	695	5.8	2.3	1.88	3978
8	41	24.5	1.36	0.58	35	15	3	----	725	4.6	3.4	2.68	5686
8	42	24.5	1.33	0.25	35	15	3	54	725	4.6	3.4	2.68	5686
8	43	23.8	0.00	0.79	28	8	0	----	736	7.2	3.1	3.22	6823
8	44	23.6	0.00	2.50	26	6	1	55	736	7.2	3.1	3.01	6368
8	out	26.7	5.83	1.83	57	38	23	----	----	----	----	----	----
9	21	23.9	0.00	0.17	29	9	0	42	675	3.6	2.0	1.82	3853
9	22	23.7	0.00	0.17	27	7	0	----	675	3.6	2.0	----	----
9	23	22.4	0.00	9.61	14	0	0	----	651	4.2	0.0	2.37	5021
9	24	23.2	0.00	4.22	22	6	0	46	651	4.2	0.0	1.90	4030
9	41	23.7	0.00	2.22	27	8	0	----	655	3.7	0.3	2.84	6020
9	42	24.1	0.00	0.92	31	11	0	43	655	3.7	0.3	3.05	6454
9	43	23.5	0.00	1.50	25	5	0	----	708	6.9	2.3	----	----
9	44	23.2	0.00	1.96	22	3	0	45	708	6.9	2.3	2.58	5469
9	out	----	----	----	----	----	----	----	----	----	----	----	----

Notes: Spaces 21-24 are four sections of Floor 2. Spaces 41-44 are four sections of Floor 4.
CO_2 data apply for sets of two contiguous spaces; the same data are listed for each space
out = outdoors
The ESVR is the steady rate of outside air supply to the entire floor that, with perfect mixing of the indoor air, would result in the measured tracer gas concentration.

Indoor Air Temperatures and humidities:

Figure 4 shows the average measured air temperatures for Thursday and Friday; 7:00 a.m. - 5:00 p.m. of each week. These average temperatures were within the normal range for office buildings but vary significantly with location and week. Since temperature differences on the order of 1 °C have been associated with changes in SBS symptoms (e.g., Jaakkola et al. 1991; Sundell et al. 1994; Menzies et al. 1993), these results indicate that it may be important to account for variations in temperature in the evaluations of the interventions. Figures 5 and 6 depict the number of hours during each Thursday and Friday workday period for which temperatures were above and below the temperature boundaries, approximately 23 °C to 26 °C, of the ASHRAE thermal comfort zone for summer (ASHRAE 1992c). Temperatures below the lower boundary, 23 °C, were quite common in this building.

Average relative humidities are plotted in Figure 7. The range of values was narrow, 42% to 58%. We are unaware of any evidence that SBS symptoms are affected by variations in relative humidity within this range.

Indoor Carbon Dioxide Concentrations:

At the concentrations normally encountered inside buildings, carbon dioxide is not considered harmful. The indoor carbon dioxide concentration is, however, sometimes used as a surrogate for the indoor concentrations of other normal human bioeffluents, such as body odors, that influence the perceived acceptability of air. There are no legal standards that define maximum acceptable indoor carbon dioxide concentrations in office environments, although some organizations, such as the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE 1989) suggest that concentrations be maintained below 1000 parts per million. Also, in a proposed (but not yet adopted) indoor air quality standard by the U.S. Occupational Safety and Health Administration, the maximum acceptable carbon dioxide concentration is 800 parts per million -- the lowest recommended guideline or standard for carbon dioxide.

The measured carbon dioxide concentrations never exceeded 1000 parts per million. The average work-time concentrations (Thursdays and Fridays) are provided in Figure 8. Figures 9 and 10 shows the average number of hours per workday during which measured concentrations exceeded 700 ppm and 800 ppm, respectively. Concentrations on the second floor often exceeded 800 parts per million a few hours per day.

One caution about the measurements of carbon dioxide concentrations is necessary. Carbon dioxide measurements were within the mechanical rooms that contain the ventilation equipment[1]. Because the air handling units vented a portion of the supply air into the mechanical room during periods with low thermal loads, the average carbon dioxide concentrations in the occupied spaces

[1] Carbon dioxide measurements were made in mechanical rooms because these rooms contained air drawn from throughout the occupied space, thus, mechanical room concentrations approximate the spatial average concentration in the occupied space. Also, based on our prior experience CO_2 measurements in occupied spaces can be unreliable because occupants may exhale high CO_2 air directly at the sample tube for the CO_2 analyzer.

during some periods likely exceeded the measured concentrations in the mechanical rooms by a modest amount.

Outside air ventilation rates:

The measured values of effective steady ventilation rate (ESVR)[2] are plotted in Figure 11. The ESVR can be compared to the minimum recommended ventilation rate in the ASHRAE ventilation standard which is 10 L s^{-1} per occupant for offices. For reference, figure 11 also shows the minimum required ventilation rates for each floor based on the ASHRAE Ventilation Standard (ASHRAE 1989) and on the average number of occupants present during the study (165 occupants on the second floor and 280 occupants on the fourth floor). The measured values of ESVR exceeded the minimum recommended ventilation rates except for two measured values that were slightly below, but within measurement error, of the minimum recommendation.

For the nine-week study period, the average ESVRs were relatively constant (e.g., ± 15%), thus, temporal variations in ventilation rates were not likely to be a major confounding factor distorting the apparent effects of the interventions on SBS symptoms.

Particle concentrations:

The particles present in indoor air include particles that enter from outdoors and particles from sources within buildings. This intervention study was designed to determine if the number or severity of health symptoms commonly experienced by building occupants could be reduced by decreasing indoor exposures to airborne particles. We have not completed the complex data analyses necessary to address this question; however, we know that one of the interventions employed during the study resulted in large decreases in indoor particle concentrations, particularly for submicron particles. Because of large temporal variations in outdoor particle concentrations, the effects of high efficiency filtration are more readily evident when considering the ratio of indoor to outdoor particle concentration. Figures 12 and 13 depicts average measured ratios of indoor-to-outdoor particle concentration for periods with normal filters and high efficiency filters installed in the ventilation systems. When the normal air filters were used in the building ventilation systems, indoor concentrations of submicron particles were 15% to 45% of outdoor concentrations. When the high efficiency air filters were used in the building ventilation systems, indoor concentrations of submicron particles were only 1% to 7% of outdoor concentrations. Indoor concentrations of 0.3 μm to 0.5 μm size particles were, on average, a factor of 20 lower when the high efficiency filters are used. For particles with a size between 0.5 μm and 0.7 μm, the corresponding factor was 7. For the largest particles, > 2 μm in size, the indoor-to-outdoor concentration ratio was only about 0.07 lower with high efficiency filtration because the normal filters already have a fairly high efficiency for these large particles.

[2] The ESVR is the steady rate of outside air supply to the entire floor that, with perfect mixing of the indoor air, would result in the measured tracer gas concentration at the location.

Plots of particle concentration versus time (not shown), showed occasional spikes in indoor concentrations of submicron particles without simultaneous spikes in outdoor concentrations. These data suggest that there were occasional short-term but strong indoor releases of submicron particles from unknown sources. For the largest particles, > 2 μm in size, during two Thursday-Friday periods, the time average indoor particle concentration were more than 90% of the outdoor concentration despite the substantial rate of removal of these particles by the filters and by deposition on surfaces. These data suggest strong and persistent releases of large particles indoors from unknown sources.

Because a separate paper is being prepared on the indoor particle data and on the comparison of measured and modeled indoor particle concentrations, further discussions of the particle data are not included in this report.

Summary:

To learn about the causes of SBS symptoms and to test proposed methods for reducing these symptoms, a unique double-blind controlled intervention study was designed and implemented. This study utilized two different interventions designed to reduce occupants' exposures to airborne particles: (1) high efficiency filters in the building's HVAC systems; and (2) thorough cleaning of carpeted floors and fabric-covered chairs with an unusually powerful vacuum cleaner. Substantial analyses of the environmental data collected during this study have been completed. Because the processing and analyses of the questionnaire data are still underway, the influence of the interventions on symptoms is not yet known.

This progress report describes the study objectives and methods and presents a summary of selected environmental data. The calculated environmental parameters are being used in the statistical modeling to evaluate the outcome of the interventions and to investigate the relationship of symptoms to ventilation rate, carbon dioxide concentrations, and indoor temperature.

As in many office buildings, air temperatures were sometimes outside of the boundaries of the ASHRAE thermal comfort zone. The spatial and temporal variations in air temperature ranged up to a few degrees Celsius in magnitude. Since temperature differences on the order of 1 °C have been associated with changes in SBS symptoms, these results indicate that it may be important to account for variations in temperature in the evaluations of the interventions.

Relative humidities were maintained within a narrow and widely accepted range (42% to 58%). We are unaware of any evidence that SBS symptoms are affected by variations in relative humidity within this range.

Carbon dioxide concentrations were always below the 1000 parts per million guideline concentration recommended by ASHRAE and occasionally above the lowest suggested guideline value of 800 parts per million. Carbon dioxide concentrations tended to be higher on the second floor.

The effective time-average ventilation rates (ESVRs) were approximately equal to or above the recommended minimum rates in the ASHRAE ventilation standard. For the nine-week study period, the average ESVRs were relatively constant (e.g., ± 15%), thus, temporal variations in ventilation rates are not likely to be a major confounding factor distorting the apparent effects of the interventions on SBS symptoms.

The use of high efficiency air filters greatly decreased the indoor concentrations of submicron particles. The data indicate that indoor concentrations of 0.3 μm to 0.5 μm size particles were, on average, a factor of 20 lower when the standard high efficiency filters were used. For particles with a size between 0.5 μm and 0.7 μm, the corresponding factor was 7. Occasional spikes in indoor concentrations of submicron particles without simultaneous spikes in outdoor concentrations suggest that there were occasional short-term but strong indoor releases of submicron particles from unknown sources. For the largest particles, > 2 μm in size, the data suggest strong and persistent releases of particles indoors from unknown sources.

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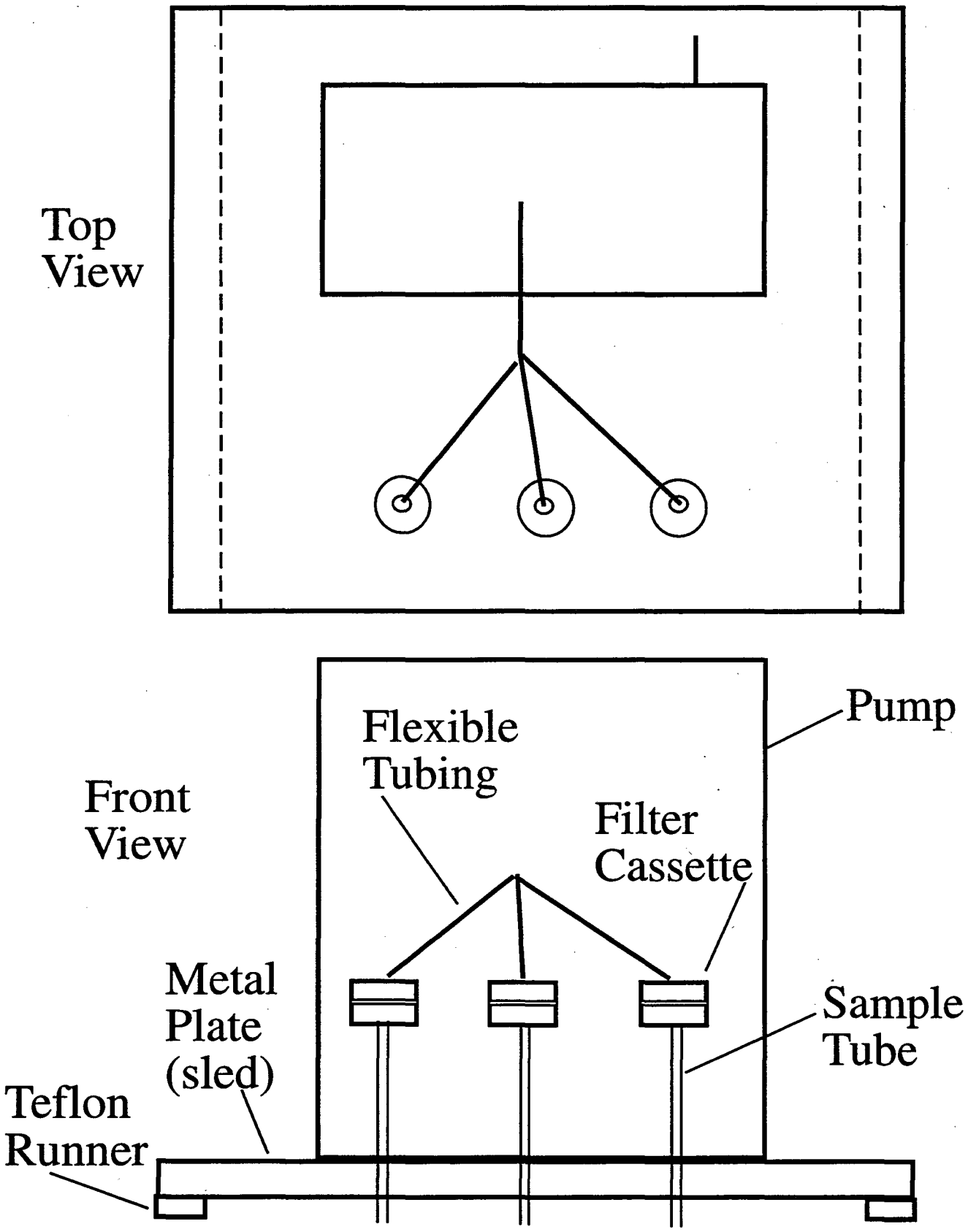


Figure 1. Schematic diagram of apparatus for floor dust sampling.

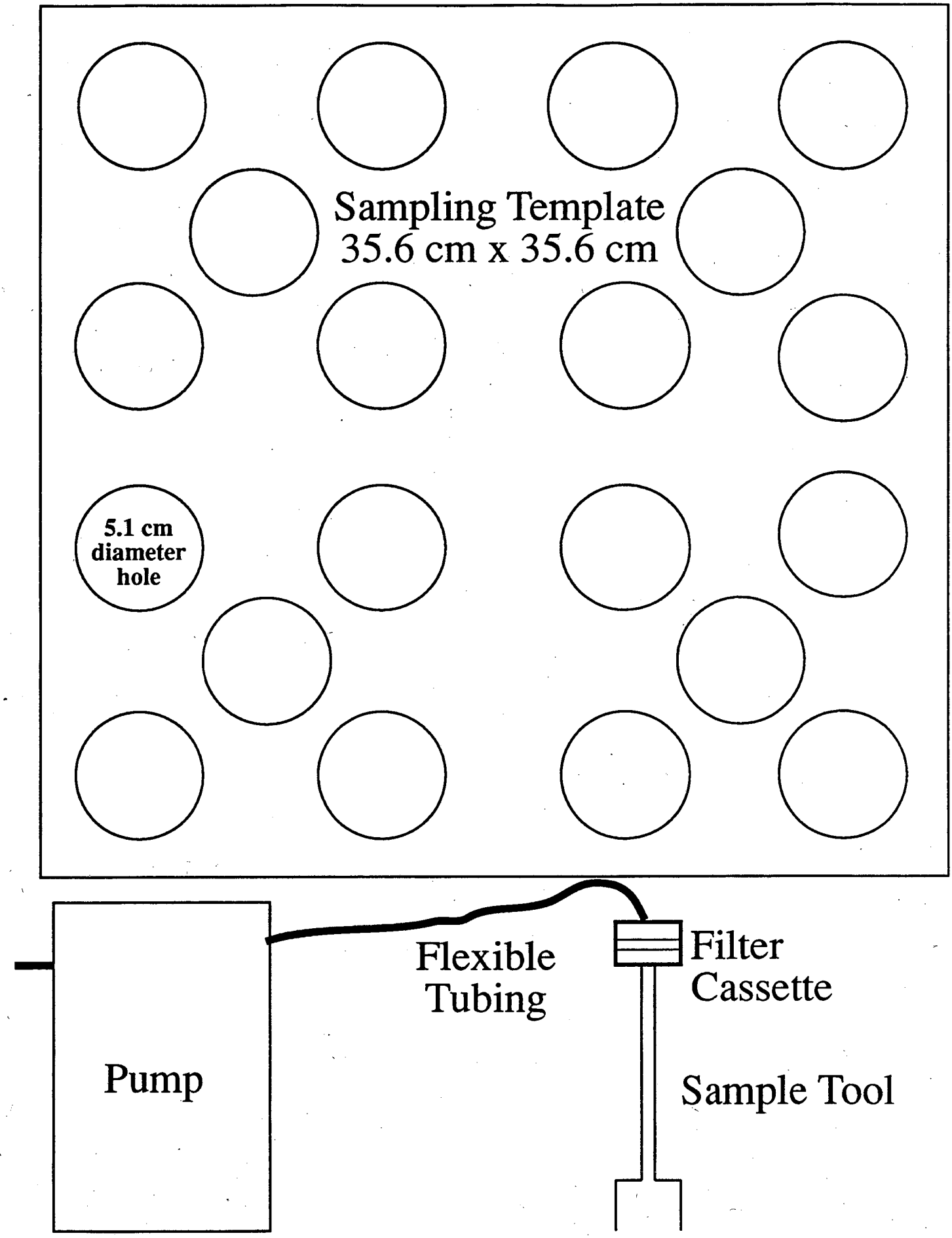
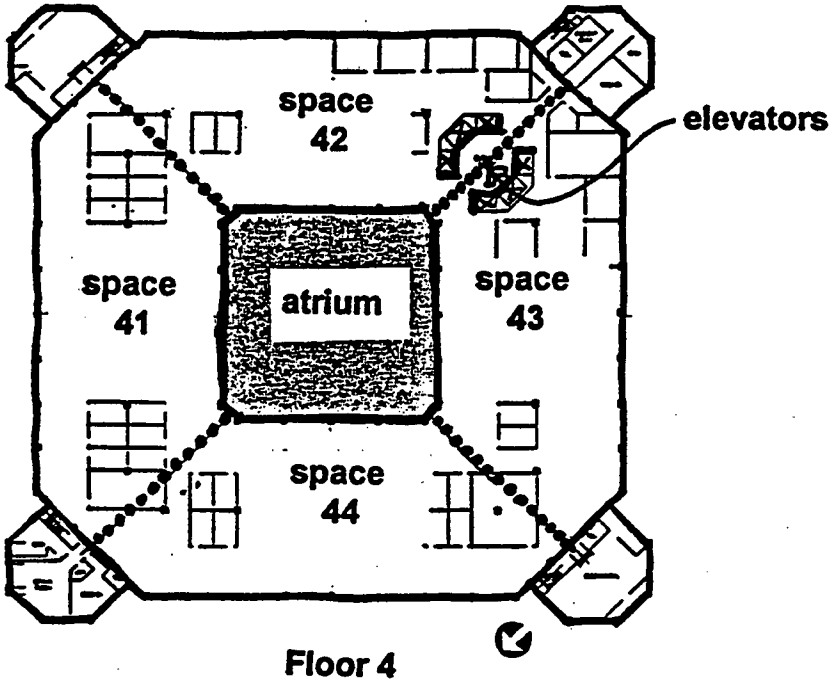


Figure 2. Schematic diagram of apparatus for chair dust sampling.



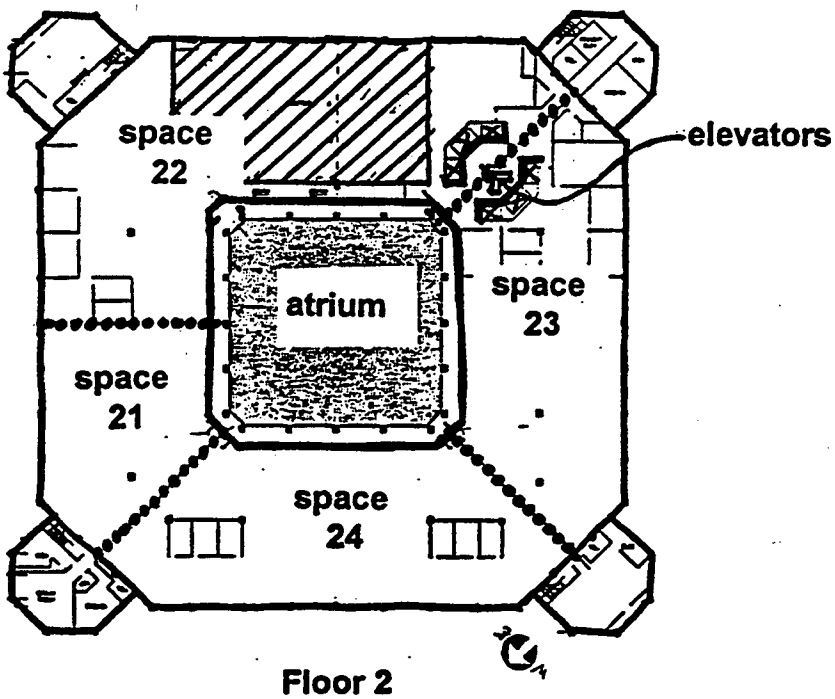


Figure 3. Locations of spaces within Floors 2 and 4.

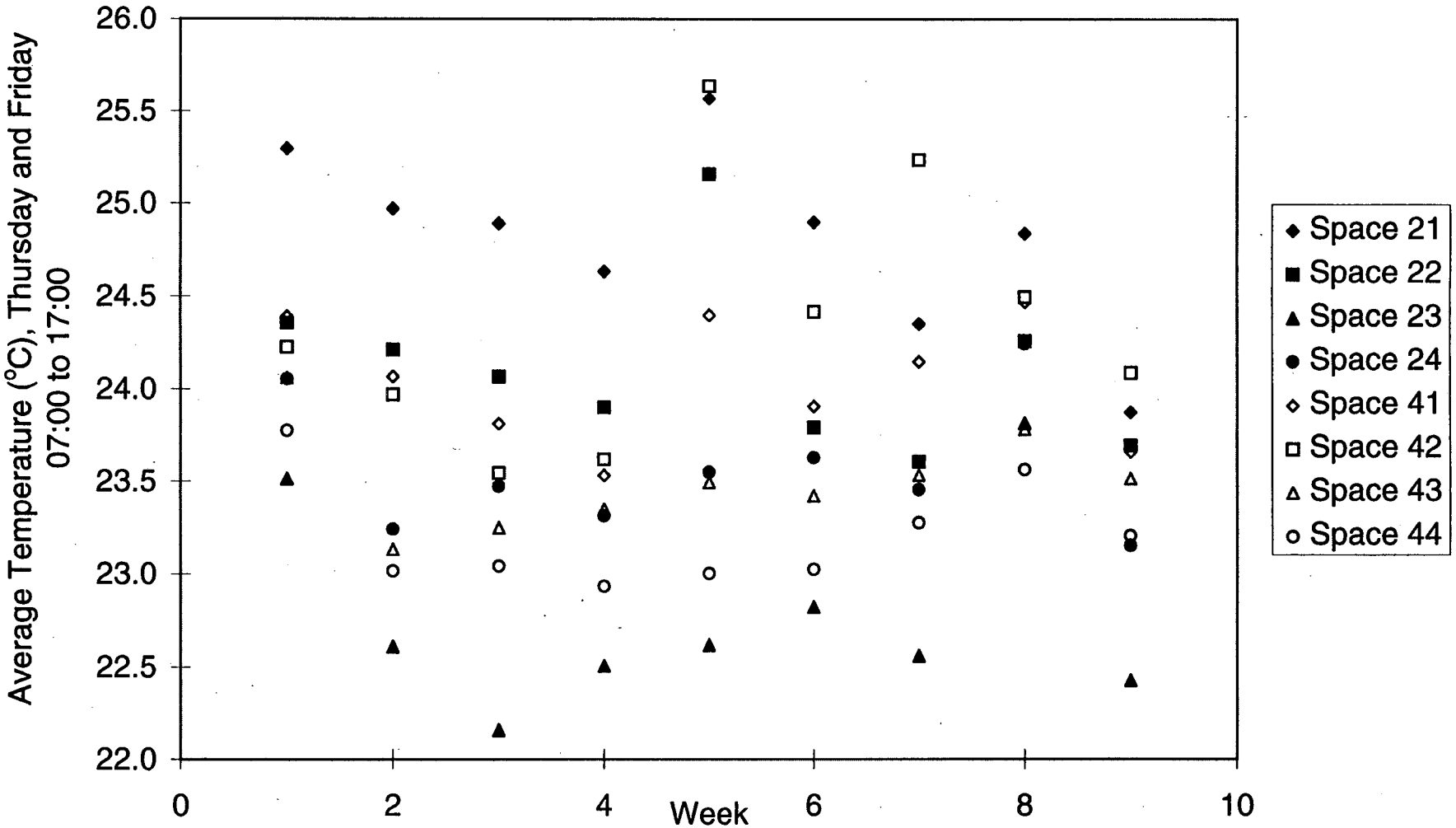


Figure 4. Average temperature.

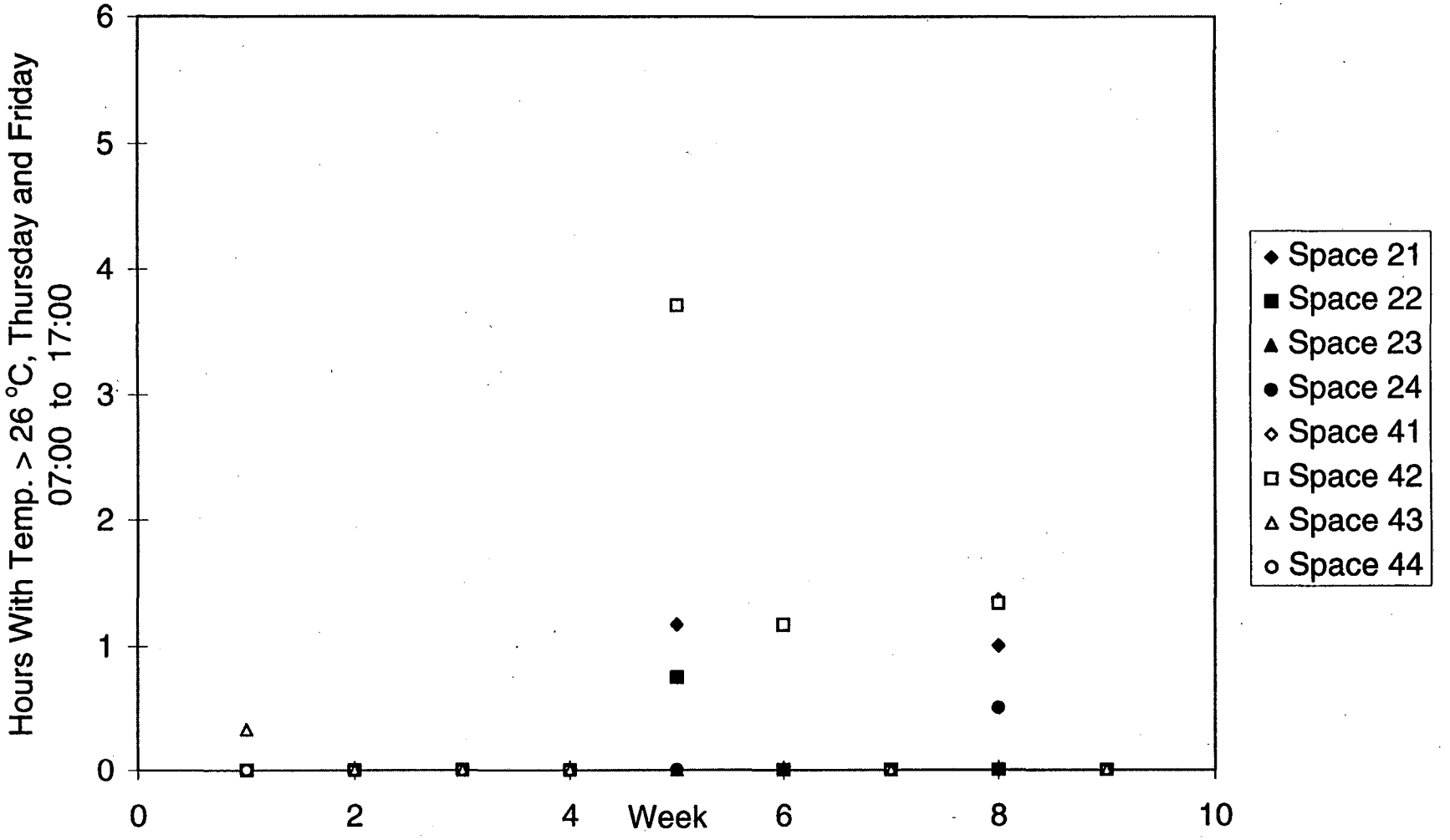


Figure 5. Average hours per day with air temperature > 26 °C.

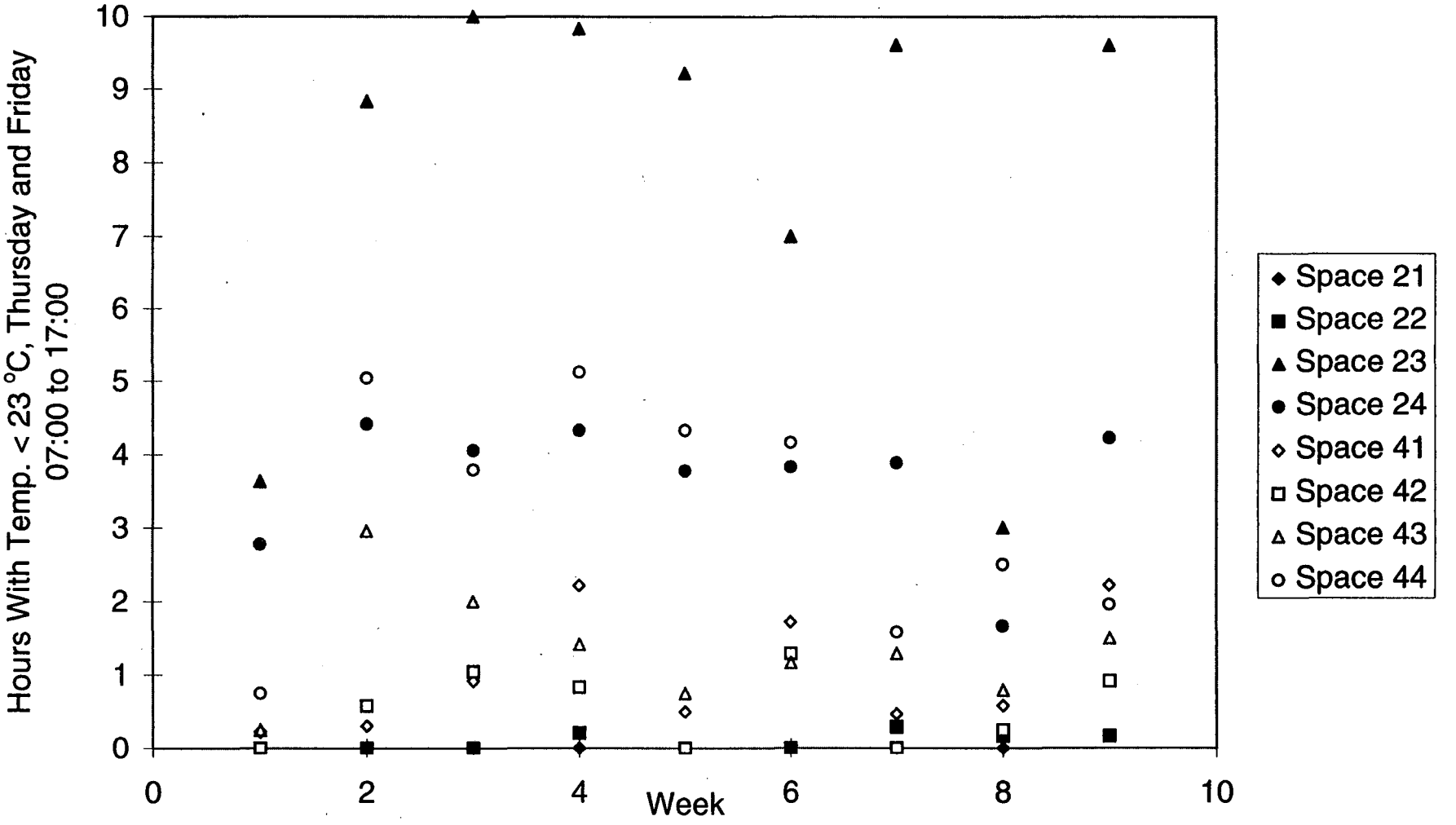


Figure 6. Average hours per day with air temperature < 23 °C.

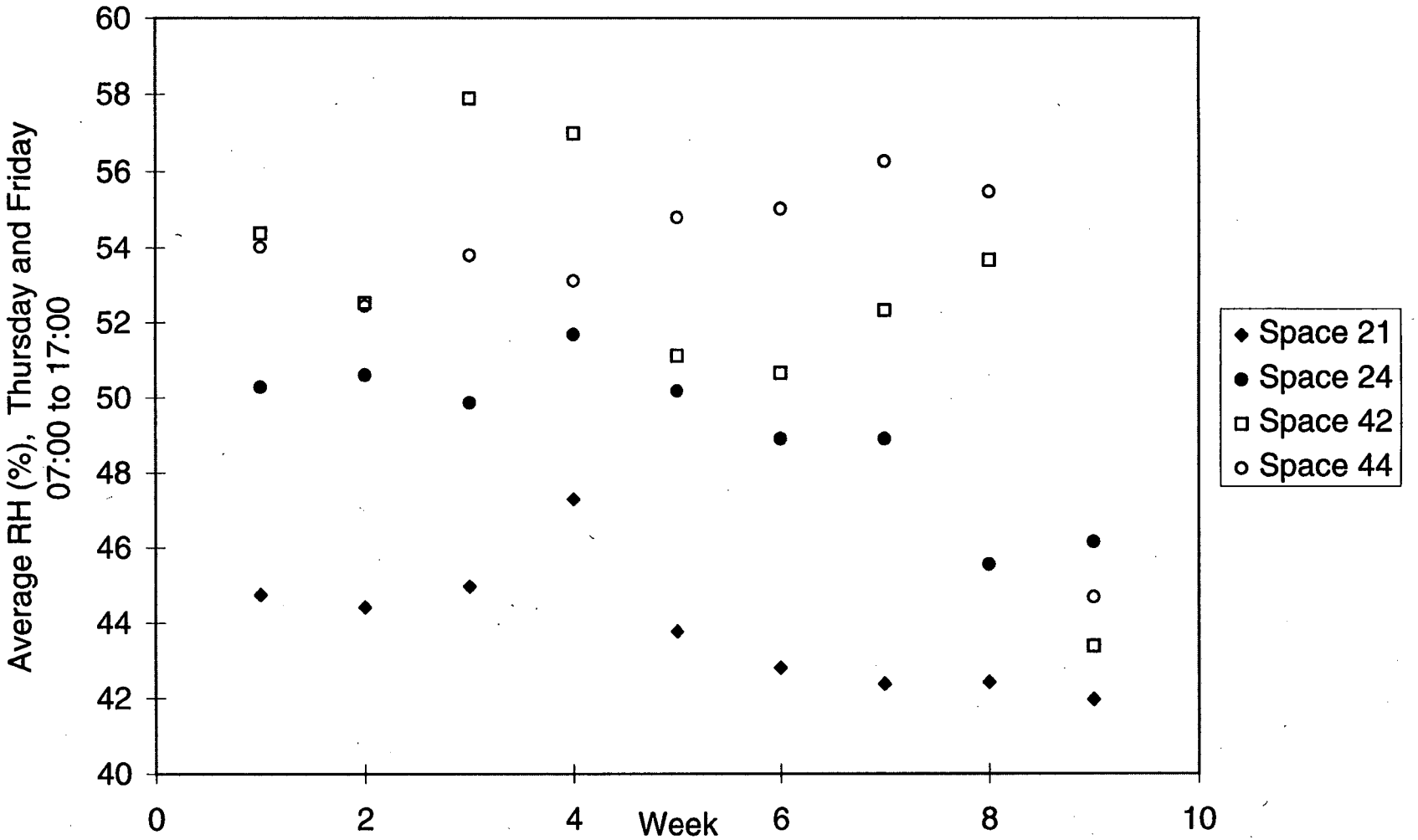


Figure 7. Average relative humidity.

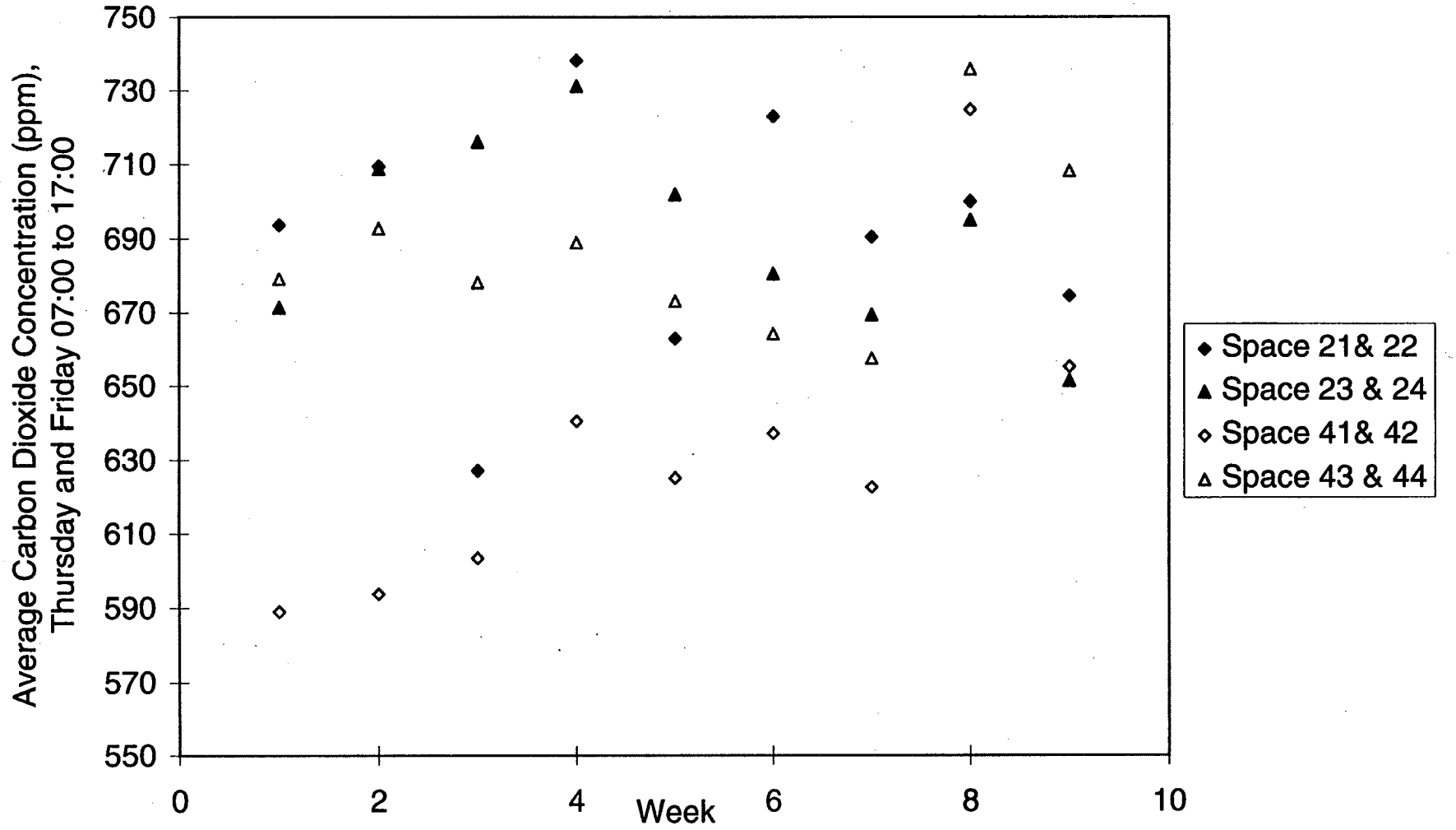


Figure 8. Average carbon dioxide concentration.

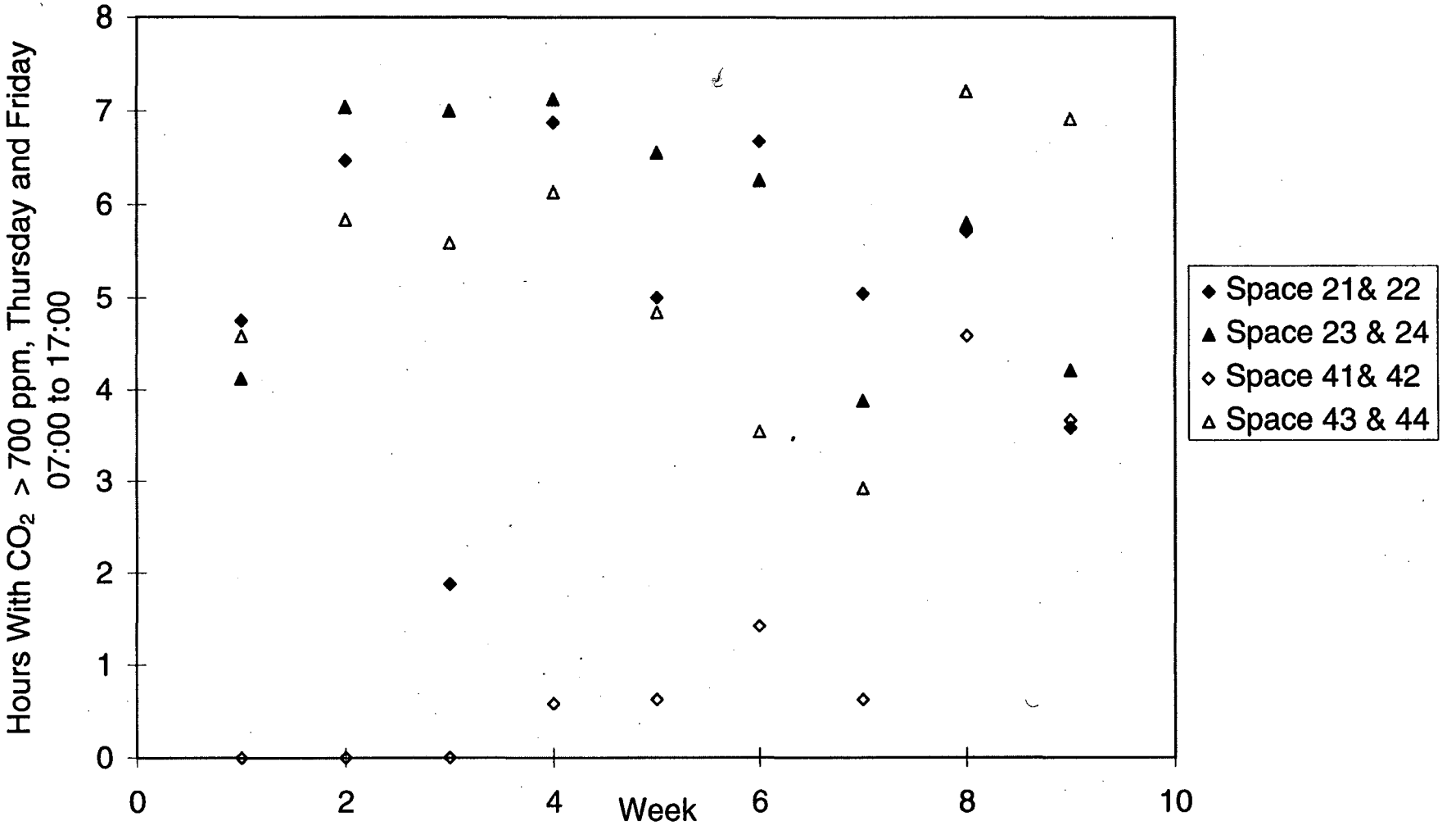


Figure 9. Average hours per day with CO_2 concentration > 700 ppm.

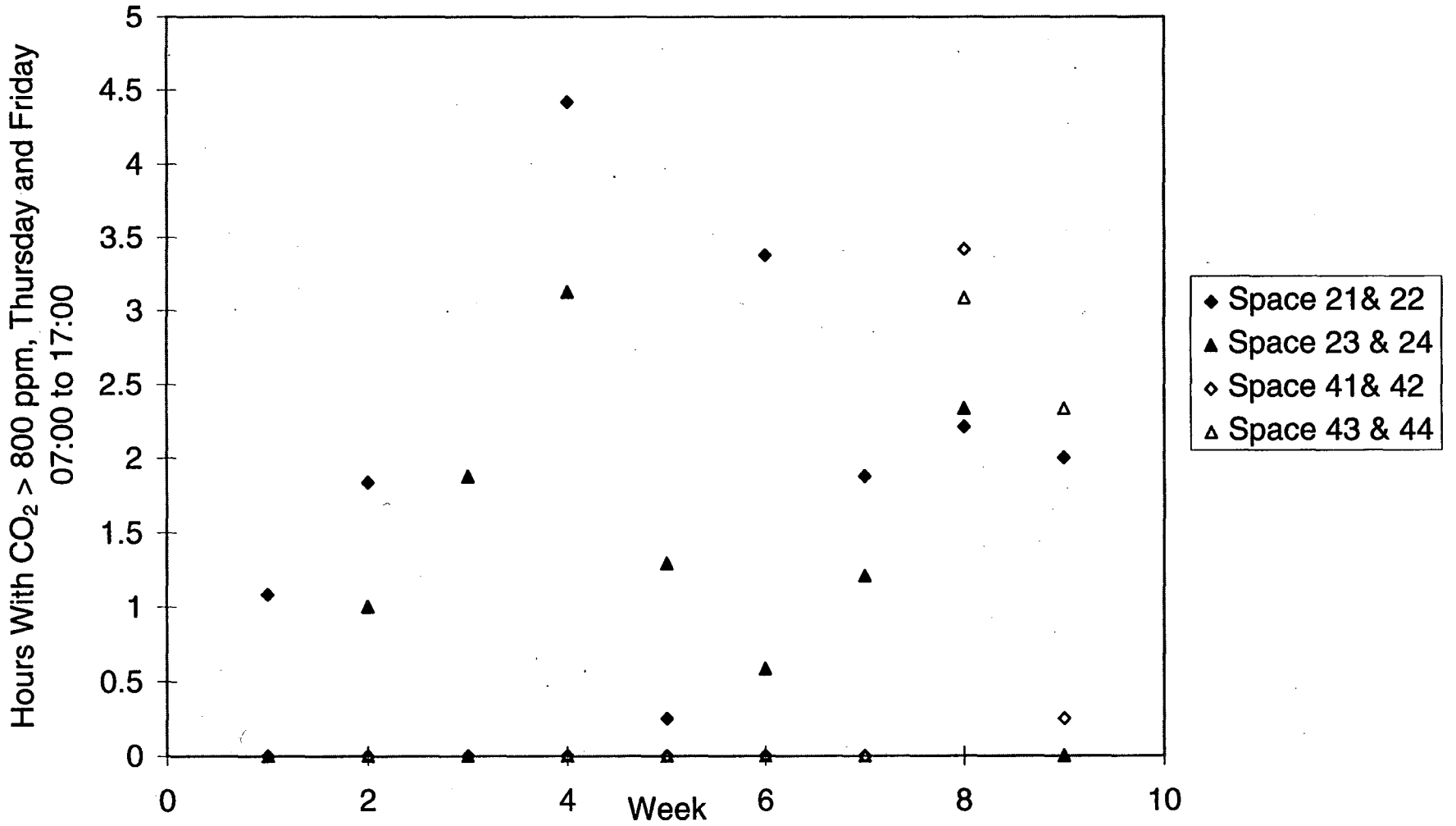


Figure 10, Average hours per day with CO_2 > 800 ppm.

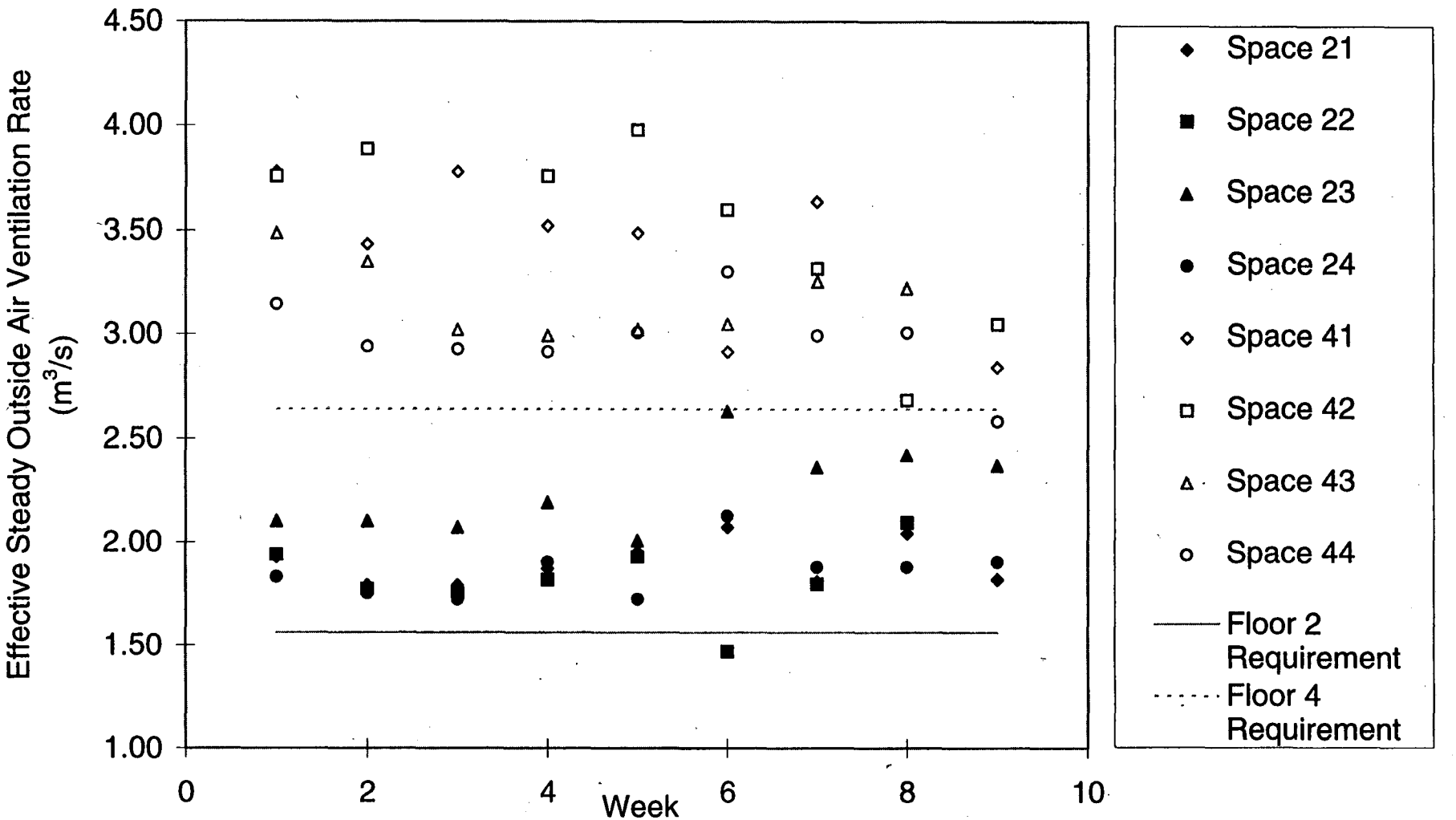


Figure 11. Effective steady ventilation rates, Thursday & Friday workday averages.

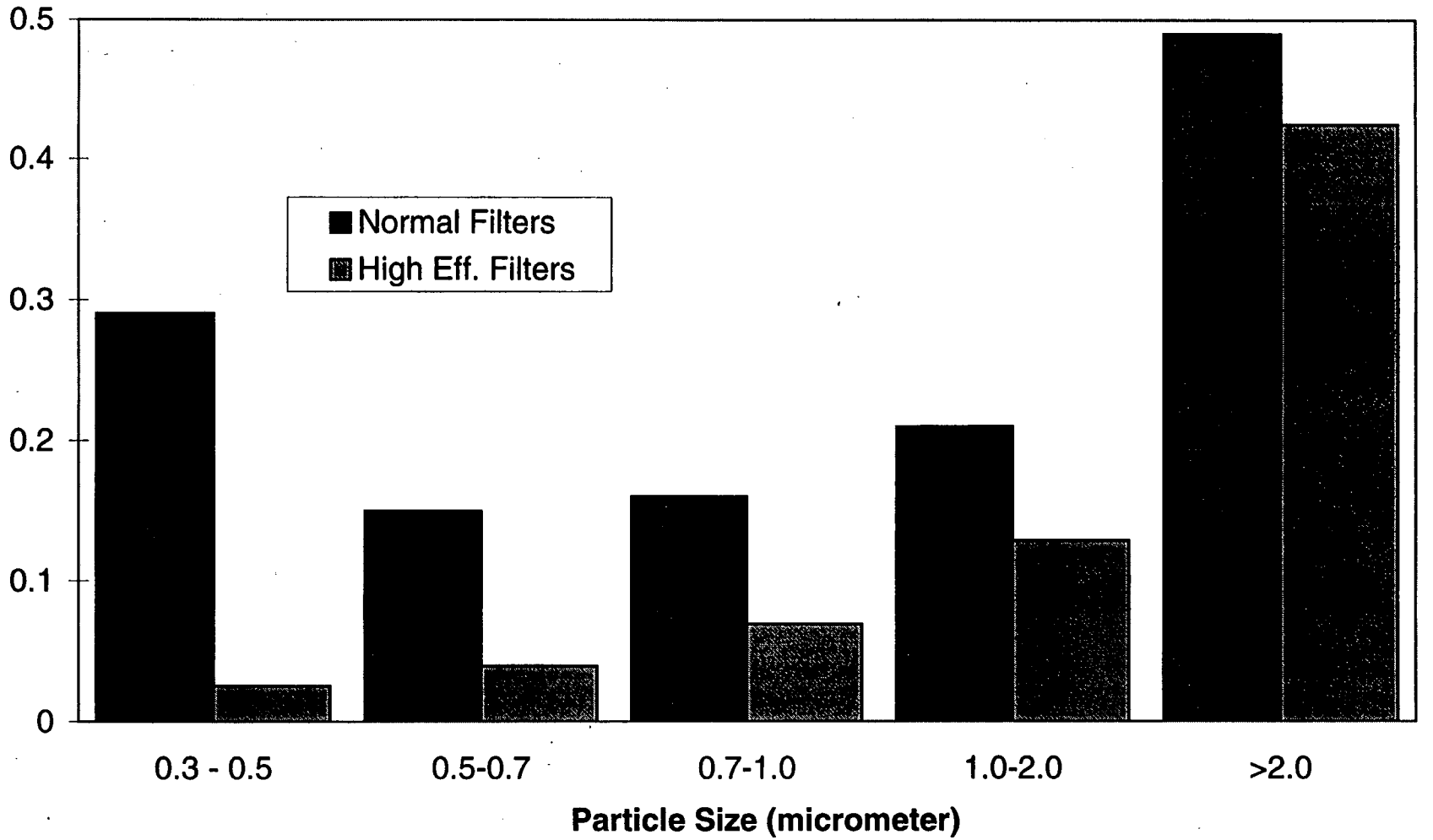


Figure 12. Ratio of indoor to outdoor particle concentration versus particle size from measurements on Floor A.

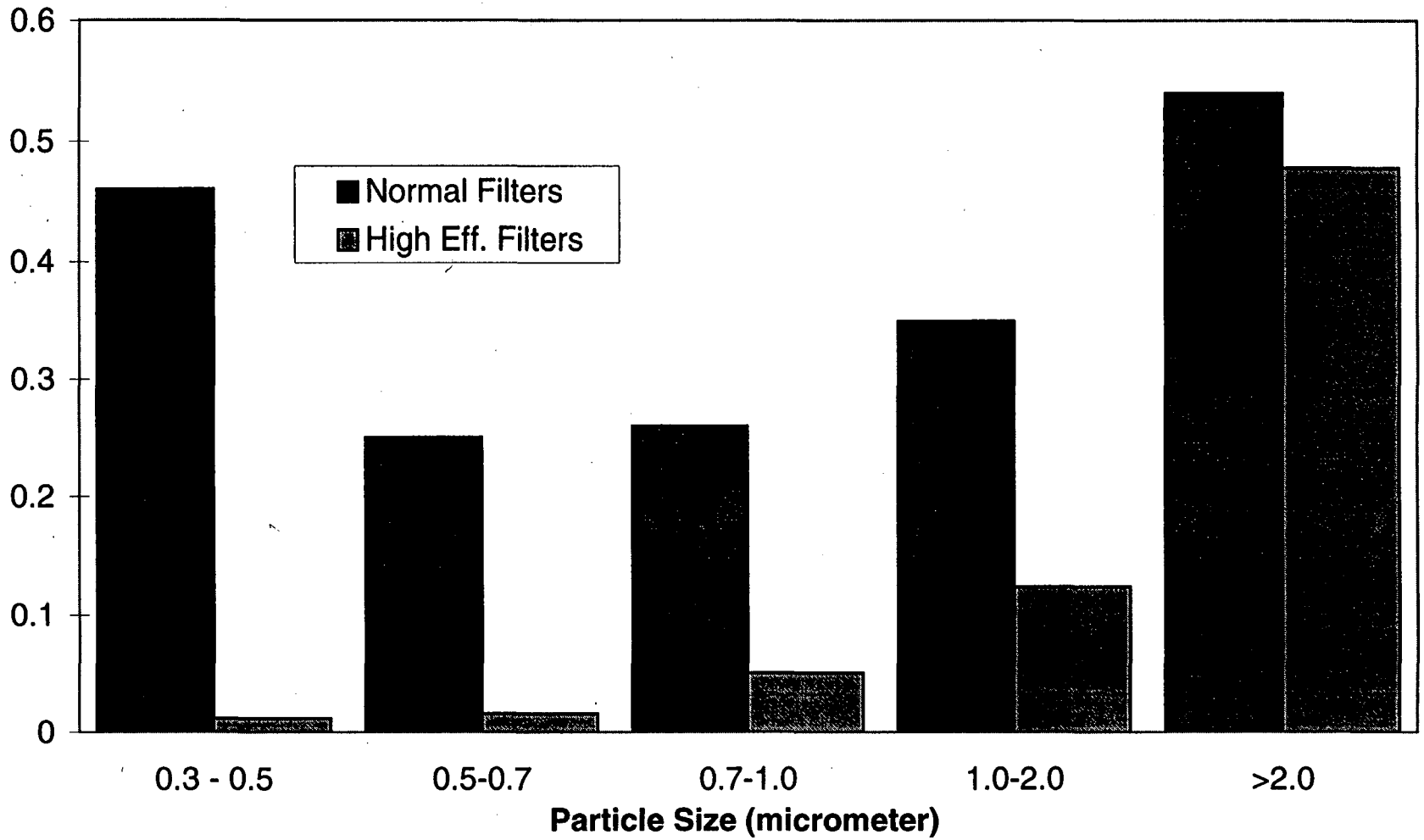


Figure 13. Ratio of indoor to outdoor particle concentration versus particle size from measurements on Floor B.

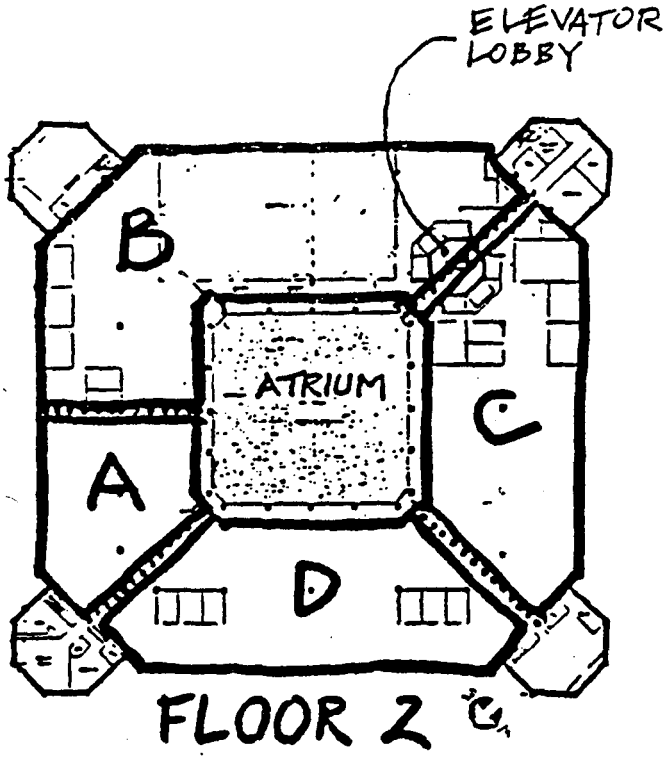
INITIAL QUESTIONNAIRE

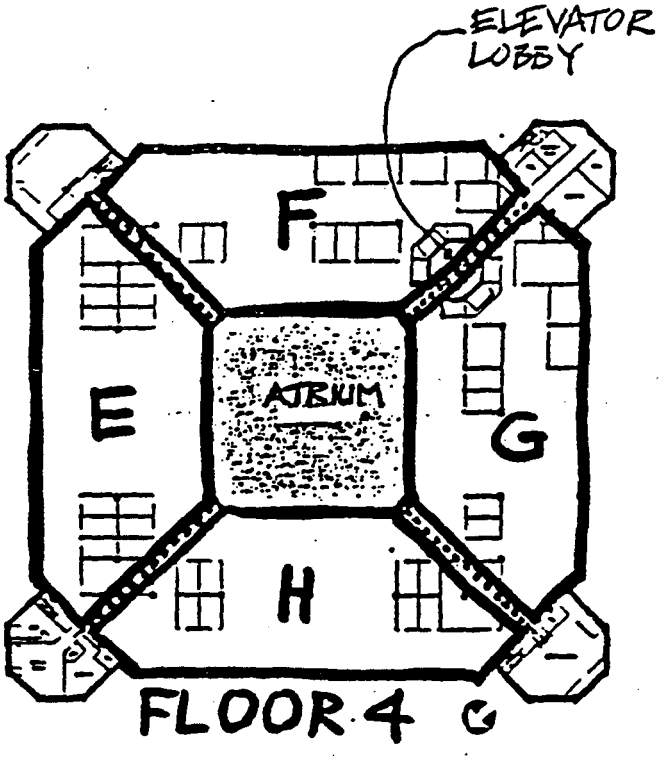
NIOSH/LBNL HEALTHY BUILDINGS INTERVENTION STUDY

YOUR LOCATION IN THE BUILDING

1. Please look at the floor plans below, and mark the number for the location of your usual workstation. (If you are not sure, pick what seems to be the best choice.)

Floor 2				Floor 4				Somewhere else - describe
A	B	C	D	E	F	G	H	I
O	O	O	O	O	O	O	O	O





6786

II. YOUR HEALTH

Symptom Severity Today

- The following questions ask about the severity of specific symptoms people may have.
- For each symptom below, the row of circles represents the full range of severity from none to very severe.
- Please read each symptom, and mark the circle that represents how sever e the symptom has bee n for you **TODAY**.

example:

no dizziness	○○○○○○○●○○○○○○○○○○○○○○○○○○○○	very severe dizziness

SEVERITY TODAY

no dry, itching or irritated eyes	○○○○○○○○○○○○○○○○○○○○○○○○○○○○	very severe dry, itching or irritated eyes
no stuffy or congested nose	○○○○○○○○○○○○○○○○○○○○○○○○○○○○	very severe stuffy or congested nose
no sore back, shoulders or neck	○○○○○○○○○○○○○○○○○○○○○○○○○○○○	very severe sore back, shoulders or neck
no dry, itchy, or irritated skin	○○○○○○○○○○○○○○○○○○○○○○○○○○○○	very severe dry, itchy, or irritated skin
no chest tightness	○○○○○○○○○○○○○○○○○○○○○○○○○○○○	very severe chest tightness
no dry or irritated throat	○○○○○○○○○○○○○○○○○○○○○○○○○○○○	very severe dry or irritated throat
no headache	○○○○○○○○○○○○○○○○○○○○○○○○○○○○	very severe headache
no fatigue or tiredness	○○○○○○○○○○○○○○○○○○○○○○○○○○○○	very severe fatigue or tiredness

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Symptom Frequency in the Last Four Weeks

For each symptom listed below, mark one circle to answer question A and one circle for question B.	A. During the LAST FOUR WEEKS YOU WERE AT WORK, how often have you experienced each of the following symptoms while working in this building? - If you answer "Not in Last 4 Weeks" for a symptom, skip question B. and move to the next symptom.				B. During the LAST FOUR WEEKS, what happened to this symptom WHEN YOU WERE AWAY FROM WORK? (e.g., holidays, weekends)		
Symptoms	Not in Last 4 Weeks	1-3 Days in Last 4 Weeks	1-3 Days Per Week in Last 4 Weeks	Every or Almost Every Workday	Got Worse	Stayed Same	Got Better
dry, itching, or irritated eyes	○	○	○	○	○	○	○
headache	○	○	○	○	○	○	○
dry or itchy skin	○	○	○	○	○	○	○
shortness of breath	○	○	○	○	○	○	○
unusual tiredness or fatigue	○	○	○	○	○	○	○
chest tightness	○	○	○	○	○	○	○

go to next page

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Symptom Frequency in the Last Year

LAST YEAR refers to the 12 month period ending today (or for the time you've worked in the building if less than one year).

Please answer the two questions to the right (A,B) about each symptom listed below:	A. How often during the LAST YEAR* did you experience this symptom while working in the building? (If "never", skip question B. and move to the next symptom).					B. Does the symptom usually change when not at work?		
Symptoms	Never	Rarely	Some-times	Often	Always	Gets Worse	Stays Same	Gets Better
dry, itching, or irritated eyes	○	○	○	○	○	○	○	○
headache	○	○	○	○	○	○	○	○
dry or itchy skin	○	○	○	○	○	○	○	○

go to next page

6786

III. YOUR OFFICE ENVIRONMENT

- The words on the left below describe conditions in an office. Please read each one carefully.
- Then for each condition mark the circle for the answer that best describes your workstation TODAY.

	Not at all	A little	Moderately	Quite a bit	Extremely
stuffy	O	O	O	O	O
drafty	O	O	O	O	O
dusty	O	O	O	O	O
too warm	O	O	O	O	O
too cold	O	O	O	O	O
too dry	O	O	O	O	O
too humid	O	O	O	O	O

6786

IV. HOW ARE YOU FEELING TODAY?

1. The words on the left below describe feelings people have. Please read each one carefully.

   Then for each feeling, mark the circle for the answer that best describes how you have been feeling TODAY.

	Not at all	A little	Moderately	Quite a bit	Extremely
able to think clearly	O	O	O	O	O
clear-headed	O	O	O	O	O
lively	O	O	O	O	O
confused	O	O	O	O	O
energetic	O	O	O	O	O
able to concentrate	O	O	O	O	O
exhausted	O	O	O	O	O
full of pep	O	O	O	O	O
tired	O	O	O	O	O
mixed up	O	O	O	O	O
stressed	O	O	O	O	O
productive	O	O	O	O	O

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2. Do you now have a cold, flu, or infection of your sinuses, lungs, or chest?

O No
O Yes
O Don't know

3. Have you noticed any changes in your office environment this week?

O No (If no, skip to next page -->)
O Yes

3a. If "yes", what difference or change have you noticed? (Please describe).

3b. If "yes", do you think this change has made the office environment:

O Better
O Worse
O Don't know/can't tell

6786

V. BACKGROUND INFORMATION

1. **How long have you worked in this building?**

   O Less than 3 months
   O 3 - 5 months
   O 6 - 11 months
   O 1 - 2 years
   O 3 - 5 years
   O 5 years or more

2. **On average, how many HOURS per WEEK do you work in this building?**

   [ ][ ] Hours per week

3. **Which best describes the space in which your current workstation is located?**

   O Private office
   O Shared private office
   O Cubicle area (in partitions) by yourself
   O Cubicle area (in partitions) with 1 other person
   O Cubicle area (in partitions) with 2 or more persons
   O Completely open area (no partitions)

4. **What is your job category?**

   O Manager/supervisor
   O Computer specialist/operator
   O Military personnel clerk
   O Secretary/clerical
   O Other (describe) _____

5. **What age were you on your last birthday?**

   O under 20
   O 20-29 years
   O 30-39 years
   O 40-49 years
   O 50-59 years
   O over 59 years

6. **Are you:** O Male O Female

7. **What is the highest grade level you completed in school?**

   O 8th grade or less
   O Some high school
   O High school graduate
   O Some college
   O College degree
   O Graduate degree

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8. What is your race/ethnic group?

O Black

O White/Caucasian

O Asian/Pacific Islander

O Other (specify) [ ]

O Decline to state

9. Are you of Spanish/Hispanic origin?

O No

O Yes

O Decline to state

10. What is your tobacco smoking status?

O Never smoked

O Former smoker

O Current smoker

11. Have you ever been told by a doctor that you had any of the following?
(mark one circle for each answer)

	No	Yes
asthma	O	O
hay fever *or* pollen allergy	O	O
mold allergy	O	O

12. Overall, how *satisfied* are you with your job?

O not at all satisfied

O slightly satisfied

O moderately satisfied

O very satisfied

13. Overall, how *stressful* do you find your job?

O not at all stressful

O slightly stressful

O moderately stressful

O very stressful

What is the date today? [ ][ ] / [ ][ ] / 9 6

What time is it now? [ ][ ] : [ ][ ] O A.M. O P.M.

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WEEKLY QUESTIONNAIRE

NIOSH/LBNL HEALTHY BUILDINGS INTERVENTION STUDY

I. YOUR LOCATION IN THE BUILDING

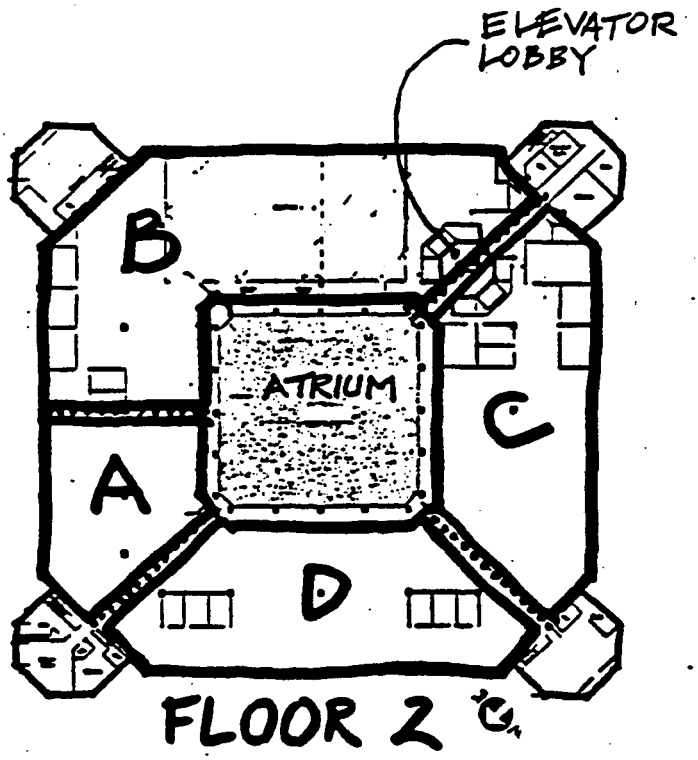
1. Has the location of your workstation changed since last week?

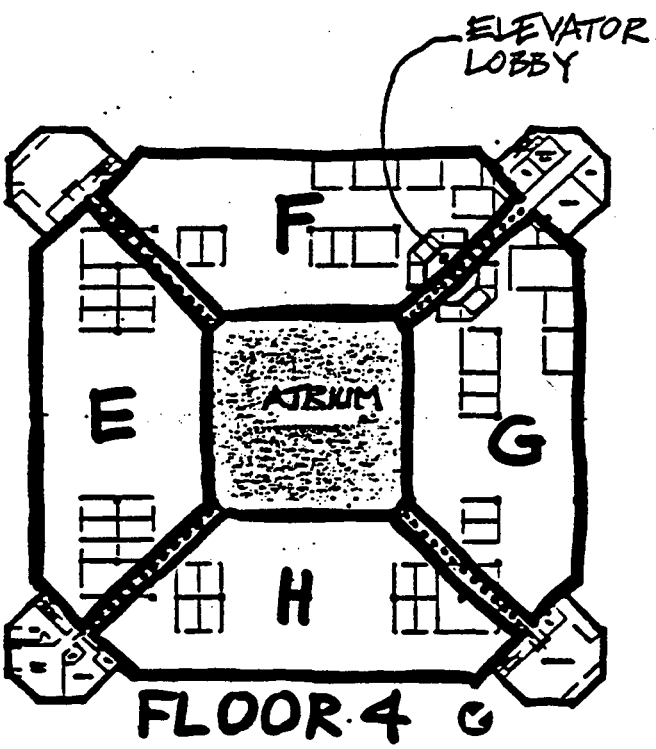
   ○ No (if "no," please skip the questions below and go to the next page. ——>)

   ○ Yes (if "yes," please complete the question below.)

2. Please look at the floor plans below, and mark the number for the location of your usual workstation. (If you are not sure, pick what seems to be the best choice.)

Floor 2				Floor 4				Somewhere else - describe
A	B	C	D	E	F	G	H	I
○	○	○	○	○	○	○	○	○





19687

II. YOUR HEALTH

Symptom Severity Today

- The following questions ask about the severity of specific symptoms people may have.
- For each symptom below, the row of circles represents the full range of severity from **none** to **very severe**.
- Please read each symptom, and mark the circle that represents how severe the symptom has been for you **TODAY**.

example:

no **dizziness**	○○○○○●○○○○○○○○○○○○○○○○○○○○○○	very severe **dizziness**

SEVERITY TODAY

no **dry, itching or irritated eyes**	○○○○○○○○○○○○○○○○○○○○○○○○○○○○	very severe **dry, itching or irritated eyes**
no **stuffy or congested nose**	○○○○○○○○○○○○○○○○○○○○○○○○○○○○	very severe **stuffy or congested nose**
no **sore back, shoulders or neck**	○○○○○○○○○○○○○○○○○○○○○○○○○○○○	very severe **sore back, shoulders or neck**
no **dry, itchy, or irritated skin**	○○○○○○○○○○○○○○○○○○○○○○○○○○○○	very severe **dry, itchy, or irritated skin**
no **chest tightness**	○○○○○○○○○○○○○○○○○○○○○○○○○○○○	very severe **chest tightness**
no **dry or irritated throat**	○○○○○○○○○○○○○○○○○○○○○○○○○○○○	very severe **dry or irritated throat**
no **headache**	○○○○○○○○○○○○○○○○○○○○○○○○○○○○	very severe **headache**
no **fatigue or tiredness**	○○○○○○○○○○○○○○○○○○○○○○○○○○○○	very severe **fatigue or tiredness**

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III. YOUR OFFICE ENVIRONMENT

- The words on the left below describe conditions in an office. Please read each one carefully.
- Then for each condition mark the circle for the answer that best describes your workstation TODAY.

	Not at all	A little	Moderately	Quite a bit	Extremely
stuffy	○	○	○	○	○
drafty	○	○	○	○	○
dusty	○	○	○	○	○
too warm	○	○	○	○	○
too cold	○	○	○	○	○
too dry	○	○	○	○	○
too humid	○	○	○	○	○

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IV. HOW ARE YOU FEELING TODAY?

1. The words on the left below describe feelings people have. Please read each one carefully.

   Then for each feeling, mark the circle for the answer that best describes how you have been feeling TODAY.

	Not at all	A little	Moderately	Quite a bit	Extremely
able to think clearly	○	○	○	○	○
clear-headed	○	○	○	○	○
lively	○	○	○	○	○
confused	○	○	○	○	○
energetic	○	○	○	○	○
able to concentrate	○	○	○	○	○
exhausted	○	○	○	○	○
full of pep	○	○	○	○	○
tired	○	○	○	○	○
mixed up	○	○	○	○	○
stressed	○	○	○	○	○
productive	○	○	○	○	○

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V. OTHER QUESTIONS

1. Do you now have a cold, flu, or infection of your sinuses, lungs, or chest?

- ○ No
- ○ Yes
- ○ Don't know

2. Have you noticed any changes in your office environment this week?

- ○ No (If no, skip to question 3 **below**)
- ○ Yes

2a. If "yes", what difference or change have you noticed? (Please describe).

2b. If "yes", do you think this change has made the office environment:

- ○ Better
- ○ Worse
- ○ Don't know/can't tell

3. What is the date today? ☐☐ / ☐☐ / 9 6

4. What time is it now? ☐☐ : ☐☐ ○ A.M. ○ P.M.

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