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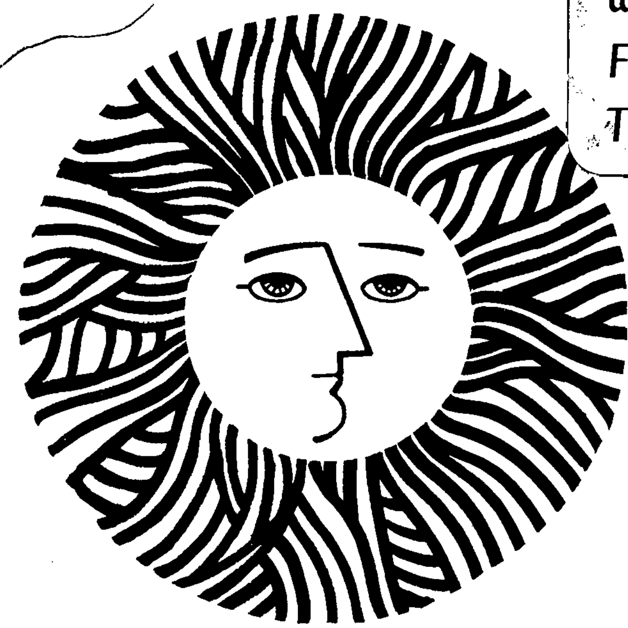

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ABSTRACT

Indoor air quality was monitored at an office building in San Francisco, CA where occupants had registered eye, nose and throat irritation complaints. Portable air pollution monitoring equipment was placed on site to monitor air outdoors and at three indoor sites (a waiting room, an interview room and an office room), and data were taken under two different ventilation rates. The parameters measured were outside air flow rates, temperature, relative humidity, odor perception, microbial burden, particulate mass, formaldehyde and other organics, carbon dioxide, carbon monoxide, and nitrogen dioxide.

Carbon dioxide concentrations increased as the ventilation rate decreased; odor perceptibility increased slightly at the lowest ventilation rate, and other pollutants generally showed very low concentrations, which increased when ventilation was reduced. In no case, however, did levels exceed current health standards for outdoor air, nor was any one contaminant found to be responsible for the medical symptoms reported by occupants. It is possible that a synergistic effect of the various contaminants and environmental conditions may account for the discomfort of occupants.

Keywords: air pollution, airborne microbes, carbon dioxide, carbon monoxide, energy conservation, indoor air quality, office buildings, odors, particulate mass, ventilation.

INTRODUCTION

Institutional and commercial buildings together use approximately 13% of the primary energy consumed in the United States. Office buildings alone account for 2% of our total energy consumption (about 1.45 x 10^{15} Btu/yr in 1975).[1] More than half of this energy is used for heating, cooling, and ventilation (see Figure 1). Because heating or cooling outside air as it enters a building requires a significant amount of energy, considerable savings can usually be effected by minimizing the amount of outdoor air used for ventilation. One of the ramifications of reducing ventilation rates, however, is that indoor air quality may deteriorate, compromising the health and comfort of building occupants.[2]

The indoor air quality of the office building environment has become the subject of much attention.[3] Several public health agencies have recently begun epidemiological and indoor air quality studies in selected office buildings where large numbers of complaints (eye, nose, throat irritation) have been registered.[4] During the Fall of 1979, the Building Ventilation and Indoor Air Quality group at the Lawrence Berkeley Laboratory (LBL) monitored indoor air quality in an eight-story office building housing the San Francisco Social Services (SFSS) Department. This indoor air quality study was initiated because of health-related complaints registered by building occupants.

There are two approaches to evaluating the quality of indoor air in buildings: the first is to directly measure the concentrations of indoor air pollutants and the second is to measure the ventilation rate and, from it, draw inferences about the quality of the indoor air. In this paper we discuss the results of direct measurements of indoor air quality in the recently constructed SFSS building. The building is located adjacent to an elevated freeway and had been occupied for one year at the time of our study. All windows are sealed. We restricted the study to the following parameters:

(1) temperature and humidity

(2) CO, CO_2 and NO_2

(3) formaldehyde and other organics

(4) particulates

(5) odors

(6) microbial burden

MEDICAL SURVEY OF SFSS EMPLOYEE SYMPTOMS

A medical survey of complaints and/or symptoms of the SFSS building occupants was carried out by one of the authors (Dr. Molly Joel Coye, Chief of Occupational Health Clinic, San Francisco General Hospital) prior to monitoring the indoor air quality of the building.[5] For comparative purposes, a nearby building was also surveyed. Occupants in the study and "control" groups did not differ significantly in age, sex, years of work with the present employer, or days/hours per week spent in the building. There was a moderate difference in the racial composition of the respective work forces, Caucasians constituting 55% in the SFSS building and 37% in the control building and Blacks constituting 16% in the SFSS building and 37% in the control building. The relative percentages of Asian and Hispanic groups did not differ significantly in the two buildings.

No significant difference was found in the percentage of smokers in the two groups, although there were more smokers in the SFSS building (42%) than in the control building (32%).

In terms of medical histories, no significant difference was found between the two groups with respect to the incidence of bronchitis, dermatitis, eczema, asthma, hay fever, frequency of headaches, medication usage, or smoking history. In terms of the specific complaints lodged by occupants of the SFSS building -- eye irritation and itching, frequent irritation of nose or throat, increased shortness of breath, and chest tightness -- the difference in report rates between the two groups was found to be statistically significant (< 5% probability that the difference is by chance). The results are tabulated in Table I. Reports of eye inflammation/infection and skin dryness, also higher among SFSS building occupants than controls, approached but did not reach statistical significance

The survey results described here match very closely the medical reports amassed on those SFSS employees who went to the Occupational Health Clinic at San Francisco General Hospital for examination and treatment.[6] The medical and public health personnel carrying out the survey and clinical examinations concluded that the agents causing the symptoms reported by SFSS building occupants were primarily airborne irritants.

EXPERIMENTAL SITE CHARACTERISTICS AND METHODS

The Office Building and its Mechanical Ventilation System.

The SFSS building contained two separate mechanical ventilation systems serving the office portion of the building, one for the first floor and another for the second through eighth floors. On the first floor, where our monitoring was conducted, the ventilation system mixes outside air with recirculated air which is then passed through an air-conditioning unit (see Figure 2). The fresh air intake was located at the rear of the building adjacent to odor sources such as garbage dumpsters, sewers, and motor vehicle traffic. Air from the air-conditioning unit is transmitted to induction terminal devices, some of which have heating coils located above the ceiling of the conditioned space. Return and recirculated air enter this plenum above the ceiling through slots in the lighting fixtures. Air from this plenum is then either induced to recirculate back into the occupied space, returned to the air-conditioning unit, or exhausted from the building.

According to the design documents for the first-floor ventilation system varying percentages of outside air are supplied depending upon outside-air and return-air temperatures. The percent outside air is 14.3 when the outside-air temperature is 1.67°C (35°F), (99% winter design condition for this location) and the return air is 21.1°C (70°F). When the outside air temperature is 12.8°C (55°F) and the return air is 23.9°C (75°F), the percent outside air is 81.3. When the outside air temperature is above 21.1°C (70°F), the outside air damper is held in a 25% open position.

A preliminary survey of the ventilation system revealed that the outside-air intake grill was partially covered with leaves, paper, and other debris. This debris was removed before air quality testing began. In addition, the exhaust fans could not be operated for extended periods of time because the motor-overload protective devices appeared to be undersized.

The interview area on the first floor is almost triangular in shape and contains a large waiting room and several interview and office cubicles with partitions approximately 2.2 m (7 ft) high (see Figure 3). Smoking is permitted only in the office cubicles. The dimensions of this area, ~20% of the total first-floor space, are approximately 30.5 m x 27.5 m x 39.6 m (100 ft x 90 ft x 130 ft) with a 3.35 m (11 ft) high ceiling -- a volume of 1405 m^3 (50,000 ft^3).

The air in the first-floor applicant interview area and the outside air were monitored simultaneously. Measurements were made with the air-conditioning unit in both a recirculation mode (~15% outside air) and an all-outside-air mode. In both cases the ventilation system was manually fixed in its mode. In the recirculation mode the outside air ventilation rate in the interview area ranged from 7 to 10 m^3/h (4-6 cfm) per person during high-occupancy conditions (~100 occupants). As noted above, the outside air flow is normally this low only when the outside air temperature is quite low. In the all-outside-air mode the ventilation rate ranged from 34 to 57 m^3/h (20-33 cfm) per person during periods of high occupancy. These ventilation rates were measured by SF_6 and CO_2 tracer-gas techniques and by measuring air flow in the ventilation ducts.[7] According to present standards set by the American Society of Heating Refrigerating and Air Conditioning Engineers (ASHRAE), minimum ventilation rates for general office space are 26 m^3/h (15 cfm) per person and for waiting rooms, 17 m^3/h (10 cfm) per person.[8] If adequate temperature control is provided in addition to filtering equipment for particulate control, the outdoor air requirements may be reduced to 33% of the minimum recommended rate, but in no case to less than 8.5 m^3/h (5 cfm) per occupant. Typically, the design criterion for occupant density in waiting rooms is approximately one person per 3 m^2 (~30 ft^2).[9] Under high occupancy conditions in the waiting room, occupant density was one person per 4 m^2 (~40 ft^2).

Gaseous and Particulate Measurements

Monitoring equipment was taken to the SFSS building site for a three-week period. Sampling points were designated at one outdoor site, the waiting room, an interview cubicle, and an office cubicle and, except for carbon dioxide (CO_2), separate instruments were stationed at each site. In the case of CO_2, air from each of four sites was drawn through teflon sampling lines into a single infrared analyzer for analysis. The four sites were sequentially sampled for ten-minute intervals; thus, each site was monitored for CO_2 every forty minutes.

Carbon monoxide (CO) concentrations were periodically measured on a real-time basis with an electrochemical device that permits carbon monoxide to pass through the analyzer where it reacts chemically with an acid and produces an electrical current that is proportional to the concentration of carbon monoxide.

Nitrogen dioxide (NO_2) concentrations were measured with passive samplers.[10] Air samples were collected over a one-week period. The sampler consists of a short plastic tube with a cap at each end. One cap is sealed and contains three stainless steel screens coated with triethanolamine, a compound that absorbs NO_2. Sampling begins with removal of the other cap to expose the absorptive surfaces. The rate of transfer of the NO_2 depends upon its coefficient of diffusion, the ambient concentration, and the dimensions of the tube. Analysis is carried out by one of the adding a Saltzmann reagent and spectrophotometrically determining the resultant color intensity, which is proportional to the quantity of NO_2 trapped.

Particulates, total aldehydes, formaldehyde and other organics, and microbial content were measured on a time-integrated basis. Particulate matter was collected for 12 hours on teflon filters by automated dichotomous air samplers (ADAS) developed at LBL.[11] The ADAS uses a flow-controlled virtual impaction system to separate the aerosols into fine (below 2.5 μm) and coarse (2.5 to 15 μm) particulate size fractions. The samples were then analyzed at LBL using beta-ray attenuation to measure mass concentration, and X-ray fluorescence to determine chemical composition for 28 elements.

Formaldehyde and total aliphatic aldehyde concentrations were measured by drawing air from one outdoor site and one indoor site through teflon sampling lines into a portable sampler containing refrigerated bubblers. The sampler contained four sampling trains; each train contained two impingers in series. Air was sampled continuously for a six hour period within the 7:30 A.M. to 6:00 P.M. time interval. Samples packed in ice were transported back to the laboratory for analysis. Indoor and outdoor formaldehyde levels were determined using a formaldehyde-specific pararosaniline colorimetric technique developed at LBL.[12] Indoor and outdoor total aliphatic aldehydes were determined using the 3-methyl-2-benzothiazolinone hydrazone (MBTH) method recommended by the American Public Health association.[13]

Sampling for indoor and outdoor air for organic air contaminants, involved drawing air through cartridges containing Tenax, a porous polymer, at one standard liter per minute for time intervals ranging from 20 to 60 minutes. After shipment back to LBL, trapped organic contaminants were thermally desorbed into small quantities of solvent which were then injected into a gas chromatograph-mass spectrometer (GC/MS) for identification of specific organic compounds.

Odor Measurements

The Research Corporation of New England (TRC), under contract to LBL, operated their mobile laboratory at the SFSS building to conduct odor perception tests.[14] Odor panelists were recruited from people in the area who were not regular occupants of the building. Air samples from the waiting room, taken under both ventilation conditions, were collected in 100-liter Tedlar bags and brought to the TRC mobile laboratory.

The sensory perception of odors was measured in two ways: The first method employed a forced-choice triangle olfactometer for determining the number of dilutions necessary to bring an odorous air sample to a level at which 50% of the members of the odor panel could no longer detect it; this "neutral" level is expressed as ED_{50}.[15] As illustrated in Figure 4, the olfactometer is equipped with five stations; the first four present dilution ratios of 81, 27, 9, and 3, and the fifth presents the undiluted odor. There are three glass sniffing ports at each station; two ports supply filtered outside air and the other port supplies the air from within the building in one of the five concentrations, progressing from weakest to strongest (undiluted). For each of the five concentrations, the odor panelist indicates which of the three ports he or she believed delivered odorous air. The second method for testing odor intensity, used immediately after the first, employed a device called a butanol olfactometer[16] (see Figure 5). The panelists were presented with the undiluted odor and asked to compare it with progressively increasing concentrations of butanol until they perceived a match between the intensity of the butanol and the intensity of the undiluted sample.

In addition to the procedures described above, both the odor panelists and the building occupants filled out questionnaires (see Figure 6) twice daily, by rating on a nine-point scale their reactions to various comfort parameters of the waiting-room environment, in addition to their response to odors. Each aspect was also rated in broad terms of "acceptability".

TRC also collected air samples for laboratory analysis of odorant composition. For this purpose, two liters of room air were passed through tubes packed with Tenax, which adsorbs the odorants present in the air. The odorants adsorbed were then identified by GC/MS techniques and their character and intensity were determined by GC/odorogram techniques.[17] The GC/odorogram, technique consists of splitting the samples into two parts: One part enters a flame ionization detector (FID) and the remaining part goes to a sniffing port. Each compound (or group of compounds) eluting from the column is smelled by a trained odor observer, and odorous peaks are noted on the chromatogram trace. Total hydrocarbon content (less methane) of each sample is determined by FID response to dodecane ($C_{12}H_{26}$).

Microbial Measurements

The microbial burden was measured by means of Anderson samplers[18] modified and operated by the Naval Biosciences Laboratory (NBL) of the University of California at Berkeley, under contract to LBL. The samplers draw air through six perforated plates (stages) whose holes decrease in size from the top plate (Stage 1) to the last plate (Stage 6). Semi-solid growth medium is placed under each plate. The largest collectable particles (7-8 μm in diameter) accumulate on Stage 1, the smallest (0.8 to 1 μm) on Stage 6, and intermediate sizes collect in four more-or-less overlapping rages between Stages 1 and 6.

Twenty-minute samples were taken four times a day and analyzed by NBL personnel. Any particle containing at least one living bacterial cell capable of growing on the medium (forming a visible spot called a "colony") is termed a "colony-forming-particle" (CFP). A light-scattering device was used to measure total particulate concentrations.

RESULTS AND DISCUSSION

Gaseous Measurements.

Figure 7 illustrates CO_2 concentration as a function of time in the waiting room on a day when the ventilation system was in the all-outside-air mode. Figure 8 illustrates CO_2 concentration as a function of time in the waiting room on a day when the ventilation system was in the constant recirculation mode (reduced ventilation) with both the outside and return air dampers in fixed positions. The CO_2 concentration at any specific time was found to vary only slightly (~10%) among the three indoor locations where CO_2 was continuously monitored. The outside CO_2 concentration was found to be essentially constant (585 mg/m^3 or 325 ppm) throughout the entire study period. In general, CO_2 concentration followed occupancy patterns rather closely. The maximum concentration never exceeded 3600 mg/m^3 (2000 ppm). The average eight-hour concentration was approximately 1800 mg/m^3 (1000 ppm), which is well below the U.S. Occupational Safety and Health Administration (OSHA) standard for CO_2 -- (9000 mg/m^3 (5000 ppm) for a time-weighted average over a 10-hour maximum workshift.[19]

The concentration of CO was low at all four sites monitored. The indoor and outdoor concentrations at any given time were generally similar and less than 4.6 mg/m^3 (4 ppm), which is lower than the U.S. Environmental Protection Agency (EPA) ambient air quality standard of 10 mg/m^3 (9 ppm) for an eight-hour period.[20]

NO_2 was measured both inside and outside the building but only in the all-outside-air ventilation mode. Indoor concentrations on the 1st, 3rd and 6th floors were found to be similar to each other and equal to the outdoor NO_2 concentration. The average NO_2 concentration during the first week was approximately 90 $\mu g/m^3$ (45 ppb). During the second week the average concentration was about 30 $\mu g/m^3$ (15 ppb). The EPA long-term (one year) ambient air quality standard for NO_2 is 100 $\mu g/m^3$ (50 ppb).[21] The short-term (one hour) California standard is 470 $\mu g/m^3$ (250 ppb). It appears that the source of NO_2 found in the SFSS building is outdoor air. The indoor NO_2 concentration was found to be always lower than outdoor air quality standards.

As shown in Table II, indoor formaldehyde levels in one of the interview cubicles in the waiting area averaged 41 ± 7 ppb during periods when the ventilation system was operated in the recirculation mode. When all outside air was used for ventilation, indoor formaldehyde levels dropped to 21 ± 2 ppb in the interview cubicle. The total aliphatic aldehyde level in the interview cubicle during period when the ventilation system was operated in the recirculation mode was 90 ± 11 ppb and, as with formaldehyde, dropped (to 37 ± 7 ppb) in the all-outside-air ventilation mode. Outdoor concentrations of formaldehyde and total aliphatic aldehydes remained constant at 5 ± 2 ppb and 12 ± 5 ppb, respectively.

The formaldehyde levels observed were well below those considered to pose a health hazard. Formaldehyde standards at various stages in the promulgation process are shown in Table III. The Occupational Safety and Health Administration (OSHA) has promulgated a threshold-limiting value of 3600 mg/m^3 (3000 ppb) in the workplace environment. Several European countries have recommended standards for non-occupational environments in the range of 100 to 700 ppb.[22] In this country, the states of California, Minnesota, and Wisconsin are considering standards of 500 ppb or less, but have not yet promulgated such standards.[23] All of these proposed standards, while considerably below the OSHA standard, are still greater than formaldehyde levels observed in this study. The health hazards associated with exposure to total aliphatic aldehydes are not known and no standards governing exposure levels presently exist in the United States.

Comparison of indoor and outdoor levels reveals that formaldehyde and aliphatic aldehydes are primarily indoor pollutants. A fivefold increase in the amount of outdoor air used for ventilation reduced levels of both contaminants to approximately half their former levels, indicating that under these circumstances, dilution by ventilation is a relatively inefficient method of reducing the concentration of formaldehyde or aliphatic aldehydes.

A variety of gas-phase organic contaminants was observed in both indoor and outdoor samples analyzed at LBL by GC/MS techniques.More gas-phase organic compounds were observed in indoor than outdoor air. Although not quantified, solvent-related compounds (e.g., benzene, toluene, xylene, tetrachloroethylene, trimethyl benzene and a considerable number of aliphatic hydrocarbons) were in higher concentrations in indoor air than in outdoor air. The majority of the organic contaminant burden is composed of hydrocarbons, for which there are no promulgated indoor air quality standards. With respect to those specific organic contaminants (for which OSHA standards have been promulgated), the levels observed here were all well below existing standards.

GC/MS analysis, conducted by TRC, on air collected during all-outside air and reduced ventilation conditions also identified a large number of organic compounds (see Tables IV and V), nine of which were found to be odorous. The odorous peaks were associated with benzene, toluene (the most intense), 2-ethyl-1-butanol, trimethylcyclohexane, xylene, n-nonane, 2-methylnonane, and 2,2,4-trimethylheptane. Odorous compounds also found in outdoor air included benzene, toluene, and xylene (see Table IV). The data in Table IV were all taken on the same day under all outside air conditions. In the all-outside-air mode the inside and outside concentrations of the compounds shown are seen to be similar and are well below OSHA standards. Under reduced ventilation conditions the indoor concentrations (Table V) of the same compounds were generally higher (however still much below OSHA standards). Unfortunately, outside air data is not available for those days that reduced ventilation data was taken. Therefore, we cannot determine the source of the various organics found indoors as we do not know if the outdoor levels of the compounds shown in Tables IV and V were significantly different on days the data in those two tables were taken.

The average total hydrocarbon concentration was 1627 ± 26 $\mu g/m^3$ (2.5 ppm expressed as methane) under reduced ventilation and 364 ± 40 $\mu g/m^3$ (0.56 ppm) in the all-outside air made of ventilation. As has been found in other buildings,[24] the total hydrocarbon concentration is inversely proportional to the ventilation rate. These concentrations can be compared with an outdoor concentration of 210 ± 60 $\mu g/m^3$ (0.32 ppm). Comparable values were reported for two office sites in a recent study by Moschandreas.[25] Biweekly mean indoor concentrations of non-methane hydrocarbons of 1920 $\mu g/m^3$ (2.94 ppm expressed as methane) and

7130 $\mu g/m^3$ (10.9 ppm) were observed at the two sites with concurrent outdoor concentrations of 1330 $\mu g/m^3$ (2.04 ppm) and 1540 $\mu g/m^3$ (2.36 ppm) respectively. The overall higher values reported in the Moschandreas study in part reflect the use of a total hydrocarbon analyzer that responds to all organic compounds present, as opposed to the solid sorbent sampler used in this study that does not quantitatively collect either very light ($\sim < C_6$) or very heavy ($\sim > C_{14}$) organic compounds.

All of the above hydrocarbon concentrations, especially the indoor values, are well in excess of the National Ambient Air Quality Standard of 160 $\mu g/m^3$ (0.24 ppm). It must be emphasized, however, that this standard was established on the basis of hydrocarbons acting as precursors for photochemical smog, and does not imply that hydrocarbons themselves are harmful.

Particulate Measurements

As noted above, particulate mass was measured with automated dichotomous air samplers. Because the instruments malfunctioned on a number of days, data are not available for the entire study period. Available data indicate that the concentration of fine particulates outdoors ranged from 4 to 16 $\mu g/m^3$ (averaging 9 $\mu g/m^3$) and represented approximately 40% of total respirable (< 15 μm) particulate mass.

In the all-outside-air mode of ventilation, both the fine and total respirable particulate mass found indoors was approximately the same as the respective outdoor masses. In the recirculation mode, however, both the fine and total particulate mass indoors increased by approximately 50% over their respective concentrations in the all-outside-air mode.

These data suggest that some of the particulates in the SFSS building are indoor-generated. The small number of samples collected (three days at each ventilation rate) and the large standard deviation make it impossible to determine whether the differences in relative concentration of fine and total particulates from all-outside-air ventilation to reduced ventilation are statistically significant. Data taken by NBL also show that more fine particulates are present under reduced ventilation than under all-outside air ventilation. The present U.S. ambient air quality standard for total suspended particulates is 75 $\mu g/m^3$ for a one-year average and 260 $\mu g/m^3$ for a twenty-four hour average. The 12-hour average for total indoor particulates obtained in this study was well below these limits for both ventilation modes (31 $\mu g/m^3$ under reduced ventilation and 21 $\mu g/m^3$ under all-outside-air ventilation conditions).

Analysis of the particulates by X-ray fluorescence revealed only trace amounts of most of the 28 elements measured. All elements were found to have lower indoor than outdoor concentrations. Indoor concentrations of lead (presumably from vehicle exhaust) were approximately 50-400 ng/m^3 and outdoor levels were approximately twice the indoor levels. The California air quality standard for lead is 1500 ng/m^3 averaged over a three-month time period. Sulfur was present in concentrations of approximately 0.5 to 1.2 $\mu g/m^3$ (1.5 to 3.6 mg/m^3 as $SO_4^=$). Chlorine concentrations ranged from 0.5 to 1.4 $\mu g/m^3$ indoors. Outdoor levels for sulfur (as $SO_4^=$) and chlorine were as high as 6 $\mu g/m^3$ and 8 $\mu g/m^3$, respectively. The California air quality standard for sulfates is 25 $\mu g/m^3$ averaged over a 24-hour period.

Odor Measurements

The sensory perception of odors, their "acceptability," and the chemical (organic) composition of indoor air were studied with the ventilation system in the all-outside air mode for four days and in the recirculation mode (reduced ventilation) for six days. Odor measurements were taken twice daily, once in the morning and again in the afternoon, to coincide with peak occupancy periods.

Figure 9 summarizes the odor detectability (ED_{50}) and odor intensity data in the waiting room. As indicated, under all-outside air ventilation conditions, the ED_{50} of the inside and outside air is almost the same. The odor detectability data indicate that indoor odor levels were perceived to be higher than outdoor levels when ventilation was reduced, and higher under reduced ventilation than under all-outside-air ventilation. In terms of odor intensity, there were no significant differences between reduced and all-outside air ventilation. During the time period when the ventilation system was in the all-outside air mode, outdoor odor levels were higher than during the time period when the ventilation system was in the reduced mode and, as is evident in the figure, this condition tended to cause higher indoor odor levels during the week the ventilation system was in the all-outside-air mode.

Responses of odor panelists and employees to a questionnaire on odor "acceptability" are summarized in Table VI. Not shown in this summary table is the finding that both groups rated the morning odor levels higher than the afternoon levels, a response that corresponds well with measured ED_{50} values. Surprisingly, the visitors (odor panelists) indicated greater acceptance of odor levels than did the occupants, even though they both rated the odor magnitude at nearly the same value. ASHRAE 62-73 states that in determining the acceptability of outdoor air, at least 60% of a panel of no fewer than ten untrained observers must agree that the air is free of objectionable odors. If this standard were applied to indoor air in the SFSS building, the air would be deemed acceptable by visitors under both all-outside air and reduced ventilation conditions. If the occupants alone were used as judges, then the odor level would be right at the 60% acceptability level.

Microbial Burden

NBL's sampling of waiting room and interview room air for microbial burden is summarized in Table VII. As shown, the difference between all-outside air and reduced ventilation is significant in the waiting room, probably because the occupancy and activity levels are higher in this room than in the interview area. Sampling on the roof indicated fewer than 20 CFP/m^3, suggesting that the source of airborne microbes is indoors. This assumption is reinforced by the finding that reducing ventilation caused the concentration of airborne microbes to increase. No evidence was found to suggest that the levels of airborne microbes are time-dependent.

Figure 10 compares, under reduced ventilation conditions, the size distribution of all particles to those containing viable bacteria. Because the probability of having at least one viable microbe per particle is related to the volume of the particle, it was not surprising that bacteria were found to be more frequently associated with larger particles than with smaller particles. The number median diameters (NMD)* for total particles and for colony-forming particles are approximately 2.6 µm and 4µm, respectively.

While the increase in airborne microbes under reduced ventilation is statistically significant, the actual measured values fall in the same range of values obtained in other buildings where no health-related complaints have been registered (see Table VIII).

CONCLUSIONS

Indoor air quality studies at the SFSS Building indicated that concentrations of all of the contaminants measured did not exceed any of the pertinent health standards, (See Table IX for a summary of air quality measurements and standards.) whether the ventilation system was in the all-outside-air or the recirculation mode. A number of contaminants, such as carbon dioxide, fine particulates, hydrocarbons and formaldehyde, however, were found to have higher indoor than outdoor concentrations and even higher indoor concentrations in the recirculation mode than in the all-outside-air mode.

The potential health hazard from the combined effects of the various compounds found in the SFSS building cannot be assessed at this time. No single compound was present in high enough concentration to be singled out as a health hazard by existing OSHA criteria. On the other hand, it is important to note that OSHA criteria have typically been established for the workplace environment where unusually high exposures to a single compound are encountered.

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* The NMD value is the size at which half the particles are larger and half smaller than the NMD size.

A comparison of health-related symptoms (eye, throat, and nose irritation, chest tightness and shortness of breath) between the SFSS building and control building occupants indicated that there is a statistically significant difference between the two groups. No one contaminant was identified in the air within the SFSS building that would clearly account for the symptoms reported by occupants. The possibility cannot be ruled out, however, that a number of contaminants acting synergistically may be responsible for the higher incidence of symptoms among the SFSS building occupants.

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Table I. Comparison of health-related complaints at SFSS building and control building

Symptom Or Complaint	% Positive Responses At SFSS Building	% Positive Responses At Control Building	"p Value"
Eye irritation/itching	54.9	36.1	0.0493
Frequent irritation of nose or throat	52.5	23.5	0.0024
Increased shortness of breath	18.9	3.0	0.0405
Chest tightness	20.6	3.0	0.0268
Eye inflammation/infection	19.5	3.4	0.0586
Skin dryness	35.1	22.4	0.0625

Table II. Formaldehyde and total aliphatic aldehyde concentrations measured at SFSS building.

Date	Ventilation Mode	Formaldehyde[a] (ppb)		Total Aliphatic Aldehyde[b] (ppb)	
		Waiting Room	Outdoor	Waiting Room	Outdoor
9/17	Recirculation	33	6	86	22
9/18	Recirculation	46	2	106	13
9/19	Recirculation	41	7	81	10
9/20	Recirculation	47	---	---	14
9/21	Recirculation	43	4	86	11
	Average =	41 ± 7	5 ± 2	90 ± 11	14 ± 4
9/26	All outside air	21	4	43	8
9/27	All outside air	20	4	29	6
9/28	All outside air	21	5	35	10
	Average =	21 ± 2	4 ± 1	36 ± 7	8 ± 2

[a] Determined using the LBL modified pararosaniline colorimetric method. Each figure shown is the average of two samples, each of which was analyzed in triplicate. The error associated with the average is the relative standard deviation for all of the samples.

[b] Determined by the American Public Health Association recommended 3-methyl-2-benzothiazolone hydrazone (MBTH) colorimetric method. Each figure shown is derived from a single sample which was analyzed in triplicate. The error associated with the average is the relative standard deviation. The levels are expressed as equivalents of formaldehyde.

Table III. Formaldehyde Standards

	Level (0.1 ppm ≅ 120 μg/m^3)	Status	Ref.
AMBIENT AIR			
U.S.	0.1 ppm max	Recommended by AIHA	1
INDOOR AIR			
U.S.			
California	0.2 ppm	Proposed	2
Minnesota	0.5 ppm	Proposed emergency standard	3
Wisconsin	0.4 ppm	Proposed effective 05/1/80	4
	0.2 ppm	Proposed effective 05/1/81	4
Denmark	0.12 ppm max	Recommended	5
Netherlands	0.1 ppm max	Recommended by Ministers of Housing and Health	6
Sweden	0.1 ppm max, new buildings 0.4 ppm min, old buildings (a) 0.7 ppm max, old buildings (a)	Proposed by the National Board of Health and Welfare	7
Federal Republic of Germany	0.1 ppm max	Recommended by the Ministry of Health	8
OCCUPATIONAL AIR			
U.S.	3 ppm, 8 hr time-weighted average	Promulgated by OSHA	9
	5 ppm, ceiling	Promulgated by OSHA	9
	2 ppm, threshold limit value	Recommended by ACGIH	10
	1 ppm, 30 minute max	Recommended by NIOSH	11

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Note

(a) 0.4 to 0.7 ppm is a border area. Levels higher than 0.7 ppm do not meet the standard. Levels lower than 0.4 ppm do meet the standard. Levels within the border area do not meet the standard if the dwellers complain. In recently built houses, 0.7 ppm should be acceptable during the first six months.

Table IV. Organic compounds identified in the air from the interview room and outdoors during the all-outside-air ventilation mode by gas chromatography.[a]

Formula	Compound Name	Concentration (μg/m^3) Interview Room A.M.	Interview Room P.M.	Outdoors
C_6H_6	benzene	34[b]	9	13
C_7H_{16}	2-methylhexane	-	-	13
C_7H_{16}	3-methylhexane	10	6	13
C_2HCl_3	trichloroethylene	8	6	8
C_7H_{14}	alkene	4	4	10
C_7H_{16}	n-heptane	5	5	4
C_7H_{14}	methylcyclohexane	3	4	3
C_7H_{14}	methylalkylcyclohexane	3	2	1
C_7H_8	toluene	15	7	16
C_7H_{18} & $C_6H_{14}O$	alkanes and 2-ethyl-1-butanol	10	13	8
C_8H_{16}	dimethylcyclohexane	3	5	3
C_8H_{18} & C_2Cl_4	alkanes and tetrachloroethylene	9	11	8
C_9H_{20}	2,4-dimethyl-3-ethylpentane	4	6	4
C_9H_{18}	alkyl cyclohexane	2	3	1
C_9H_{20} & C_9H_{18}	alkanes, xylene & cycloalkanes	15	16	12
C_9H_{20}	branched alkanes	16	13	13
C_9H_{20}	n-nonane	9	10	9
$C_{10}H_{22}$	2-methylnonane	9	8	8
$C_{10}H_{22}$	alkane	101	81	126
$C_{10}H_{12}$ & C_9H_{10}	alkylbenzene and methylstyrene or indane	17	17	17

[a] Data collected and analyzed by Dr. Frank Jarke of Illinois Institute of
Technology Research Institute.

[b] This value is a total of three peaks, one of which is benzene.

Table V. Organic compounds identified in the air from the interview room during the reduced ventilation mode by gas chromatography.[a]

Formula	Compound Name	Concentration (μg/m³)
C_6H_6	benzene	27
C_7H_{16}	2-methylhexane	9
C_7H_{16}	3-methylhexane	12
C_2HCl_3	trichloroethylene	10
C_7H_{14}	alkene	4
C_7H_{16}	n-heptane	7
C_7H_{14}	methylcyclohexane	8
C_7H_{14}	methylalkylcyclohexane	5
C_7H_8	toluene	28
$C_6H_{14}O$	2-ethyl-1-butanol	23
C_7H_{18}	branched alkanes	
C_8H_{16}	dimethylcyclohexane	13
C_8H_{18}	branched alkanes	32
C_8H_{18} & C_2Cl_4	n-octane and tetrachloroethylene	37
C_9H_{20}	2,4-dimethyl-3-ethylpentane	10
C_9H_{18}	alkyl cyclohexane	13
C_9H_{20} & C_9H_{18}	alkanes and cycloalkanes	10
C_9H_{18}	trimethylcyclohexane	19
C_8H_{10}	xylene	44
C_9H_{20}	branched alkanes	144
C_9H_{20}	n-nonane	63
$C_{10}H_{22}$	2-methylnonane	73
$C_{10}H_{22}$	alkane	719
$C_{10}H_{12}$ & C_9H_{10}	alkylbenzene and methylstyrene or indane	105

[a] Data collected and analyzed by Dr. Frank Jarke of Illinois Institute of Technology Research Institute.

Table VI. Summary of responses to questionnaires on odor perception, SFSS Building[a]

	Odor Scale (1-9)		Acceptability (%)	
	All-Outside Air Ventilation	Reduced Ventilation	All-Outside Air Ventilation	Reduced Ventilation
Panelists	5.7	5.8	81	90
Occupants	5.9	5.7	57	62

[a] Data collected and analyzed by The Research Corporation (TRC) of New England (see Reference 14).

Table VII. Mean values of CFP/m^3, SFSS building[a]

Ventilation conditions	Waiting Room	Office Cubicle	Outdoor Air
All-outside air mode (20-33 cfm/person)	105	56	<20
Recirculation mode (4-6 cfm/person)	179	58	<20

[a] Data collected and analyzed by Dr. Robert Dimmick, University of California, Naval Biosciences Laboratory (see Reference 18).

Table VIII. Mean values (no. per cubic meter) of number of airborne colony-forming particles at various sites.[a]

Elementary School	Ventilation Conditions		
	Automatic	Dampers Closed	Sealed
Classroom	269	283	360
(Auditorium - Gymnasium had Peak Value of 1200)			

High School Ventilation Rate (cfm/occupant)	Room 1	Room 2
13.5	160	107
2.5	115	75

Hospital #1	
Eye Operatory	40
Hospital #2	
Cast Room	333
Hospital #3	
Cast Room	523
Patient Room	900
Proctology	62
Obstetrics	125
Pediatrics	183
Sports Arena	200
Conference Room	180
Men's Rest Room	132
Research House	
Sealed and Vacant	17
Blower On and Vacant	550

[a] Data collected and analyzed by Dr. Robert Dimmick, University of California, Naval Biosciences Laboratory (See Reference 18).

Table IX. Summary of average indoor air quality measurements (recirculation mode) and air quality standards.

	SFSS Building Air Quality		Air Quality Standards	
Contaminant	Concentration	Averaging Time	Concentration	Averaging Time
Carbon monoxide	4.6 mg/m^3(4 ppm)	1 hr	40 mg/m^3(35 ppm)[a]	1 hr
Carbon dioxide	1800 mg/m^3(1000 ppm)	8-10 hrs	9,000 mg/m^3[b] (5,000 ppm)	8 hrs
Nitrogen dioxide	60 μg/m^3 (30 ppb)	1 week	100 μg/m^3(50 ppb)[a]	1 yr
Hydrocarbons (non-methane)	1627 μg/m^3 (2.5 ppm)	30 minutes	160 μg/m^3[a] (0.24 ppm)	3 hours (6-9 am)
Formaldehyde	49 μg/m^3 (41 ppb)	6 hours	120-840 μg/m^3[c] (100-700 ppb)	maximum
Aliphatic aldehydes	108 μg/m^3 (90 ppb)	6 hours	No standard	
Particulates	31 μg/m^3	12 hours	75 μg/m^3[a] 260 μg/m^3[a]	1 yr 24 hrs
Lead	0.2 μg/m^3	12 hours	1.5 μg/m^3[d]	3 months
Sulfur (as $SO_4^=$)	2.5 μg/m^3	12 hours	25 μg/m^3[d]	24 hrs
Airborne Microbes	179 CFP/m^3	20 minutes	No Standard	

[a] U.S. EPA Ambient Air Quality Standard for outdoor air.

[b] U.S. Occupational Safety and Health Administration (OSHA) standard.

[c] Range of recommended standards (see Table 3).

[d] State of California Air Quality Standard for outdoor air.

OFFICE BUILDING FIGURE CAPTIONS

Figure 1. Primary energy use for all non-residential buildings is shown divided into four main functional uses.

Figure 2. A cross-section schematic of the first floor of the SFSS building illustrates the heating, ventilation and air conditioning system and the flow of ventilation air throughout the plenum and occupied space.

Figure 3. The layout plan of the first floor area of the San Francisco Social Services building. Air quality monitoring locations are shown.

Figure 4. Forced-Choice triangle olfactometer. The subject chooses, by smell, which of the three nozzles of one station of the forced-choice triangle olfactometer emits odorous air.

Figure 5. A subject is shown using the butanol binary dilution olfactormeter to find a level of butanol intensity that matches the percent intensity of the "occupancy odor."

Figure 6. The questionnaire filled out by building occupants and odor panelists was used to obtain subjective information on odor perception and other room environment variables.

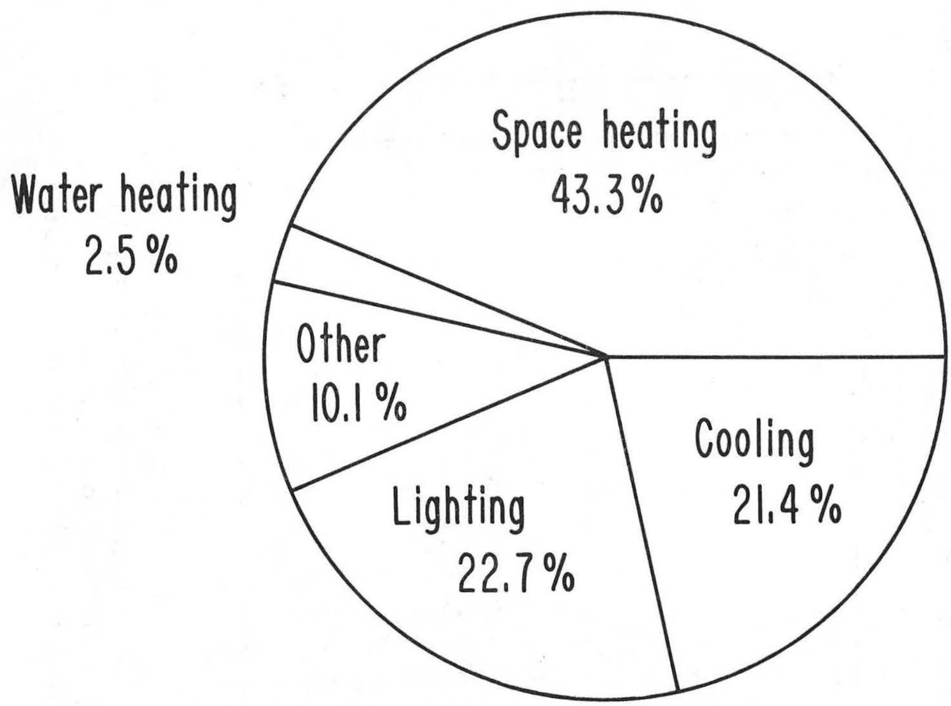
Figure 7. The time dependence of occupancy and of carbon dioxide concentrations in the waiting room of the San Francisco Social Services building during the period when the ventilation system is in the all-outside-air mode.

Figure 8. The time dependence of occupancy and of carbon dioxide concentrations in the waiting room of the San Francisco Social Services building during the period when the ventilation system is in the reduced ventilation mode.

Figure 9. Summary data on odor detectability and odor intensity for the San Francisco Social Services waiting room.

Figure 10. The size distributions of colony-forming and total particles in the San Francisco Social Services building waiting room are compared in the reduced ventilation mode.

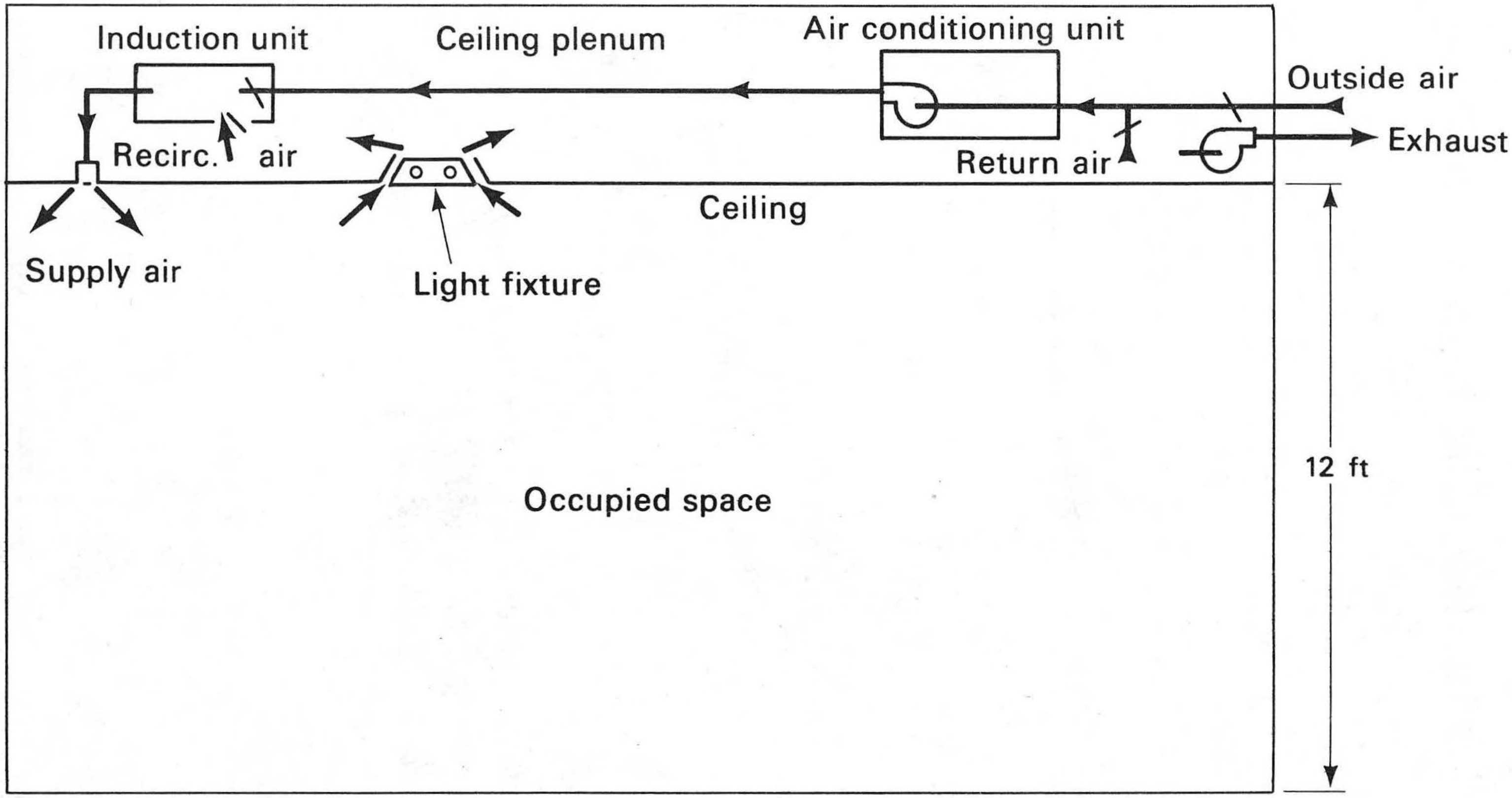
INSTITUTIONAL AND COMMERCIAL BUILDING ENERGY USE (1975)



From: Commercial Energy Use: A Disaggregation by Fuel, Building Type and End Use, ORNL/CON-14 Oak Ridge National Laboratory, Oak Ridge, Tennessee

XBL 796-10231

Figure 1. Primary energy use for all non-residential buildings is shown divided into four main functional uses.



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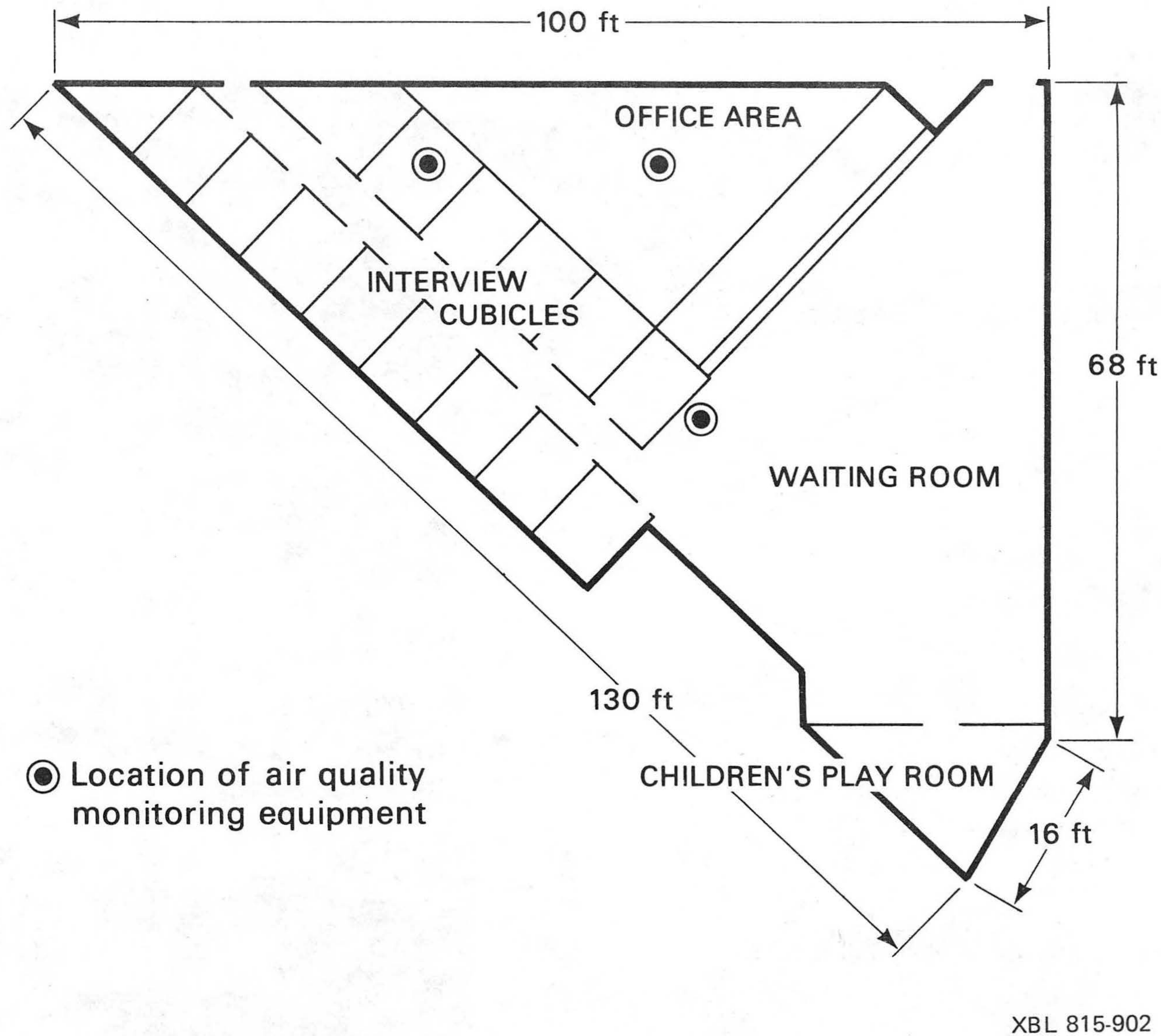

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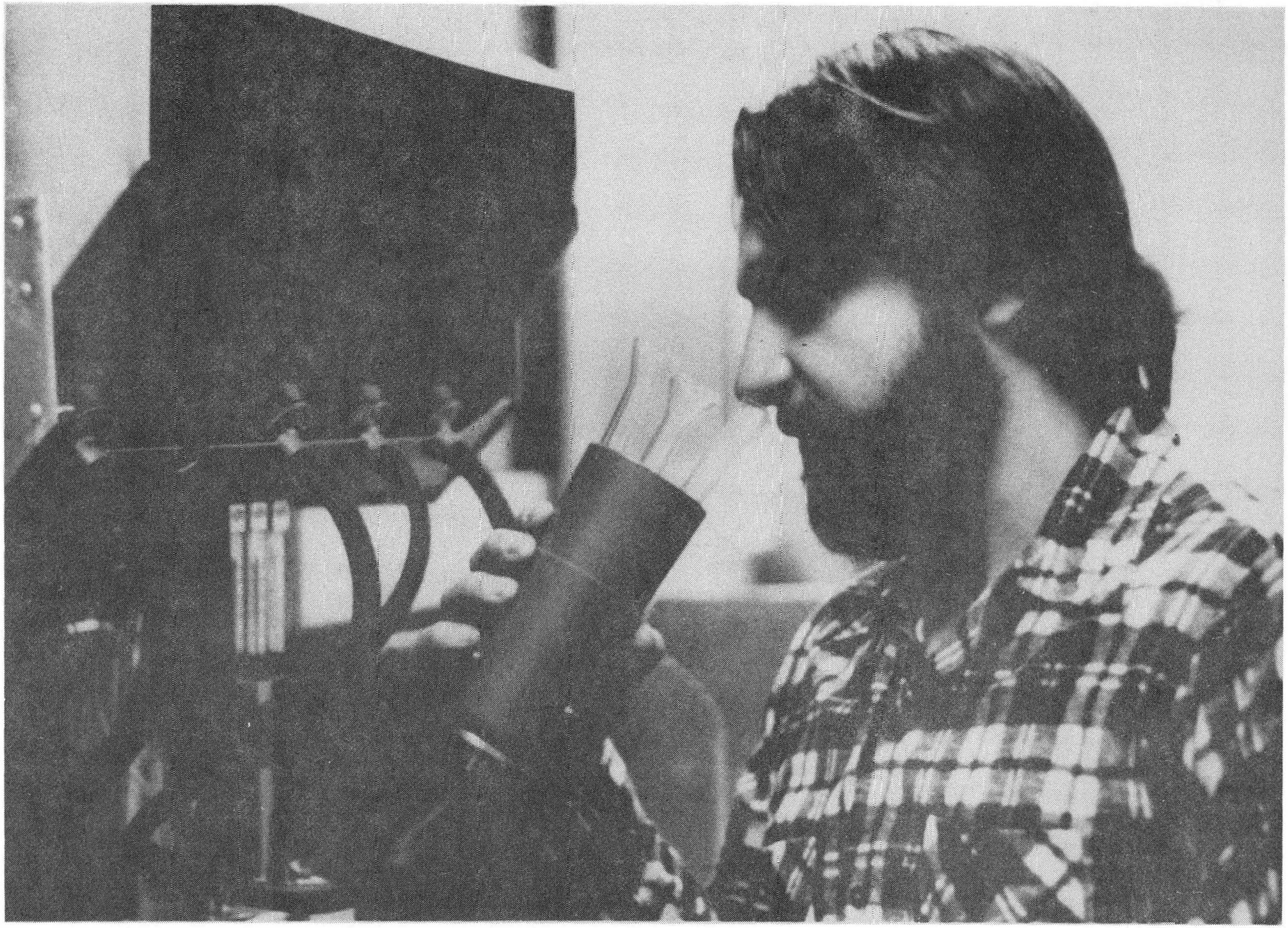

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Figure 4. Forced-Choice triangle olfactometer. The subject chooses, by smell which of the three nozzles of one station of the forced-choice triangle olfactometer emits odorous air.

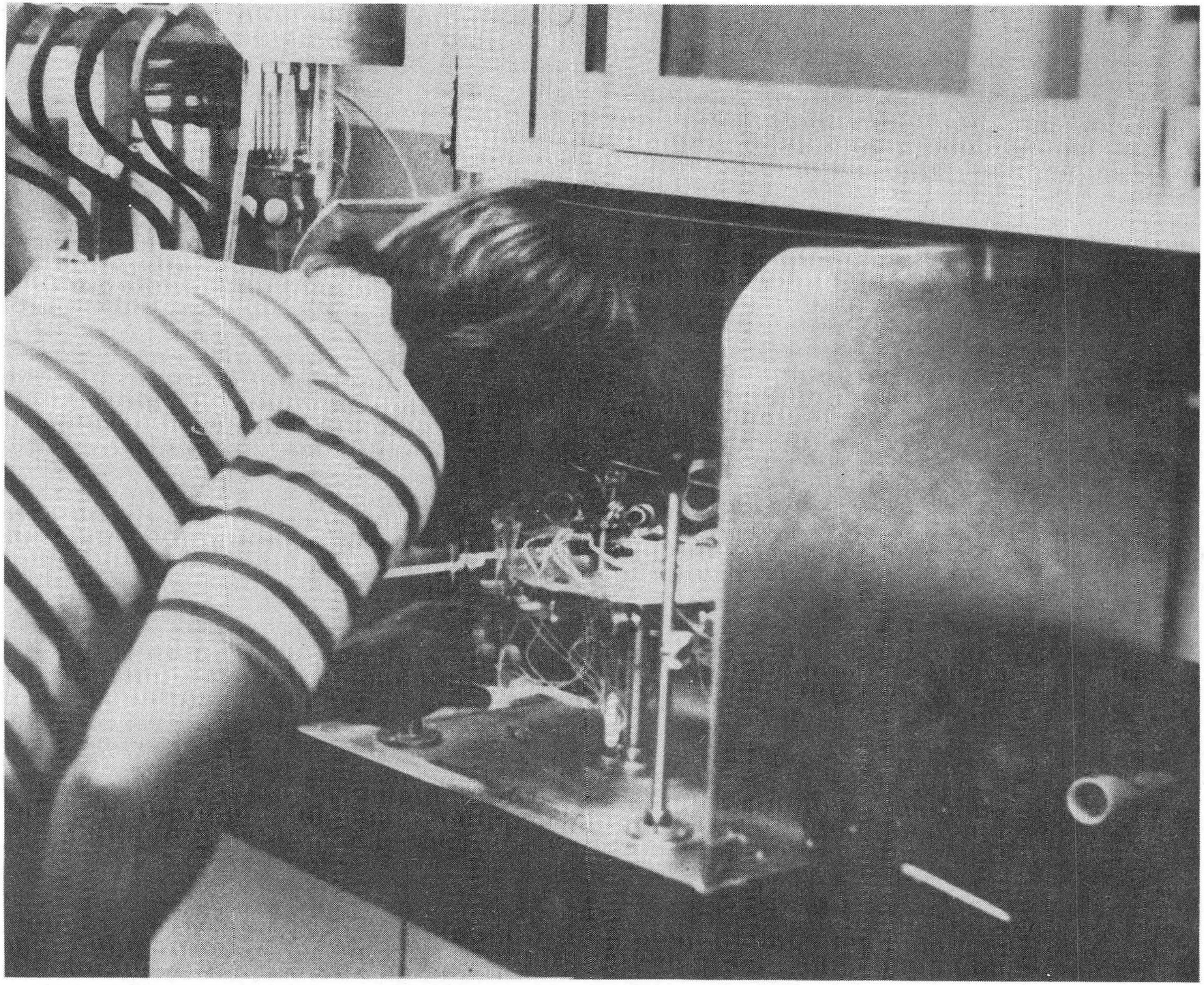

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Figure 5. A subject is shown using the butanol binary dilution olfactometer to find a level of butanol intensity that matches the percent intensity of the "occupancy odor."

Day Number ____________ Date ____________ Time ____________ Room Number ____________

EVALUATION SHEET

Rating of Individual Elements of the Room Environment	Acceptable	Unacceptable
Cold ___:___:___:___:___:___:___:___:___ Hot	☐	☐
Humid ___:___:___:___:___:___:___:___:___ Dry	☐	☐
Drafty ___:___:___:___:___:___:___:___:___ Stuffy	☐	☐
Stale ___:___:___:___:___:___:___:___:___ Fresh	☐	☐
No odor ___:___:___:___:___:___:___:___:___ Strong odor	☐	☐
Loud noise ___:___:___:___:___:___:___:___:___ No noise	☐	☐

Overall Rating of the Room Environment

Acceptable ___:___:___:___:___:___:___:___:___ Unacceptable

1. Do you have a cold today?

   Yes ☐ No ☐

2a. If you are a smoker, about how many hours ago today did you have your last smoke?

   _____ hours ago

2b. If you are not a smoker or if you did not smoke today, check this box . . . . ☐

Figure 6. The questionnaire filled out by building occupants and odor panelists was used to obtain subjective information on odor perception and other room environment variables.

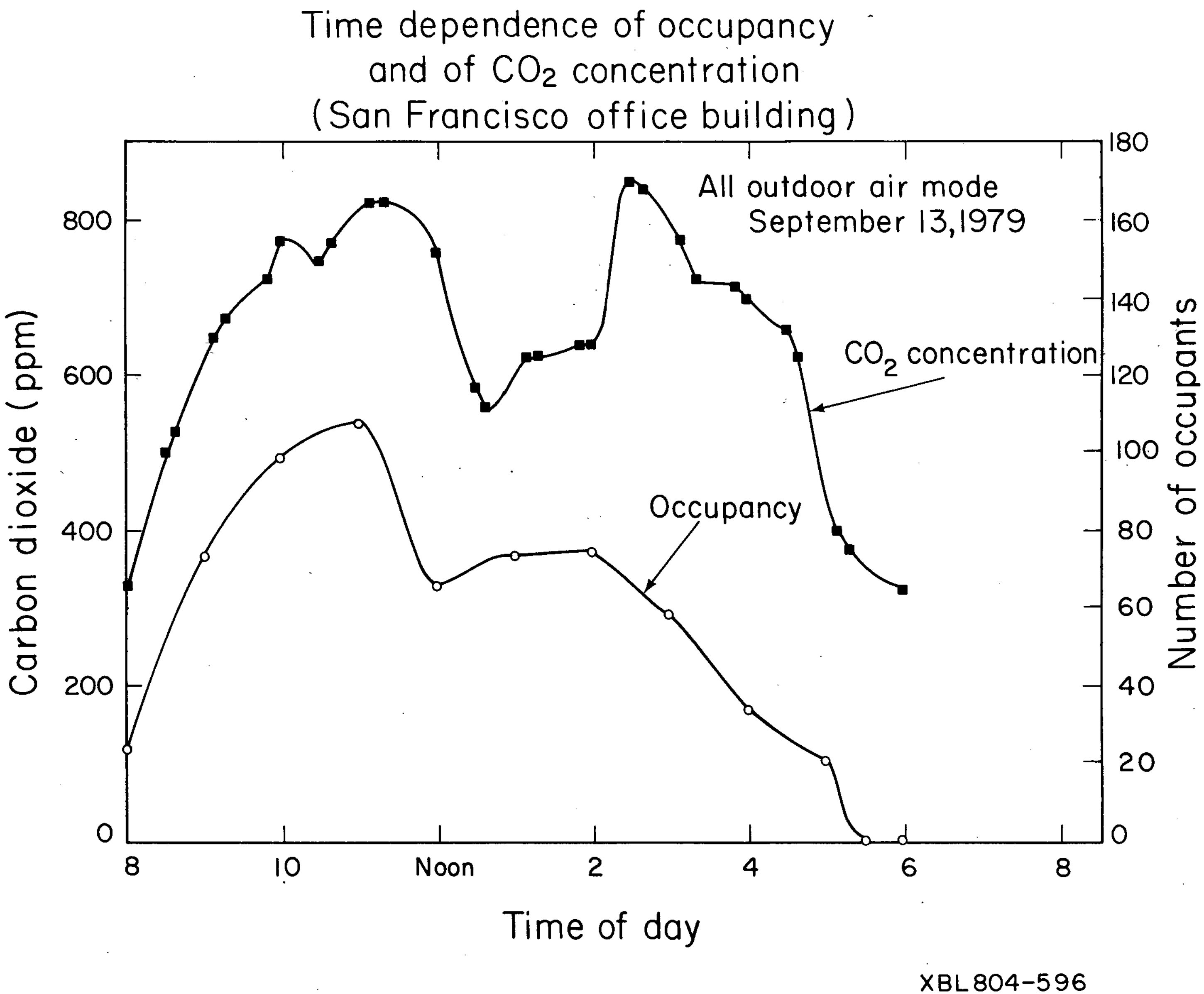


Figure 7. The time dependence of occupancy and of carbon dioxide concentrations in the waiting room of the San Francisco Social Services building during the period when the ventilation system is in the all-outside-air mode.

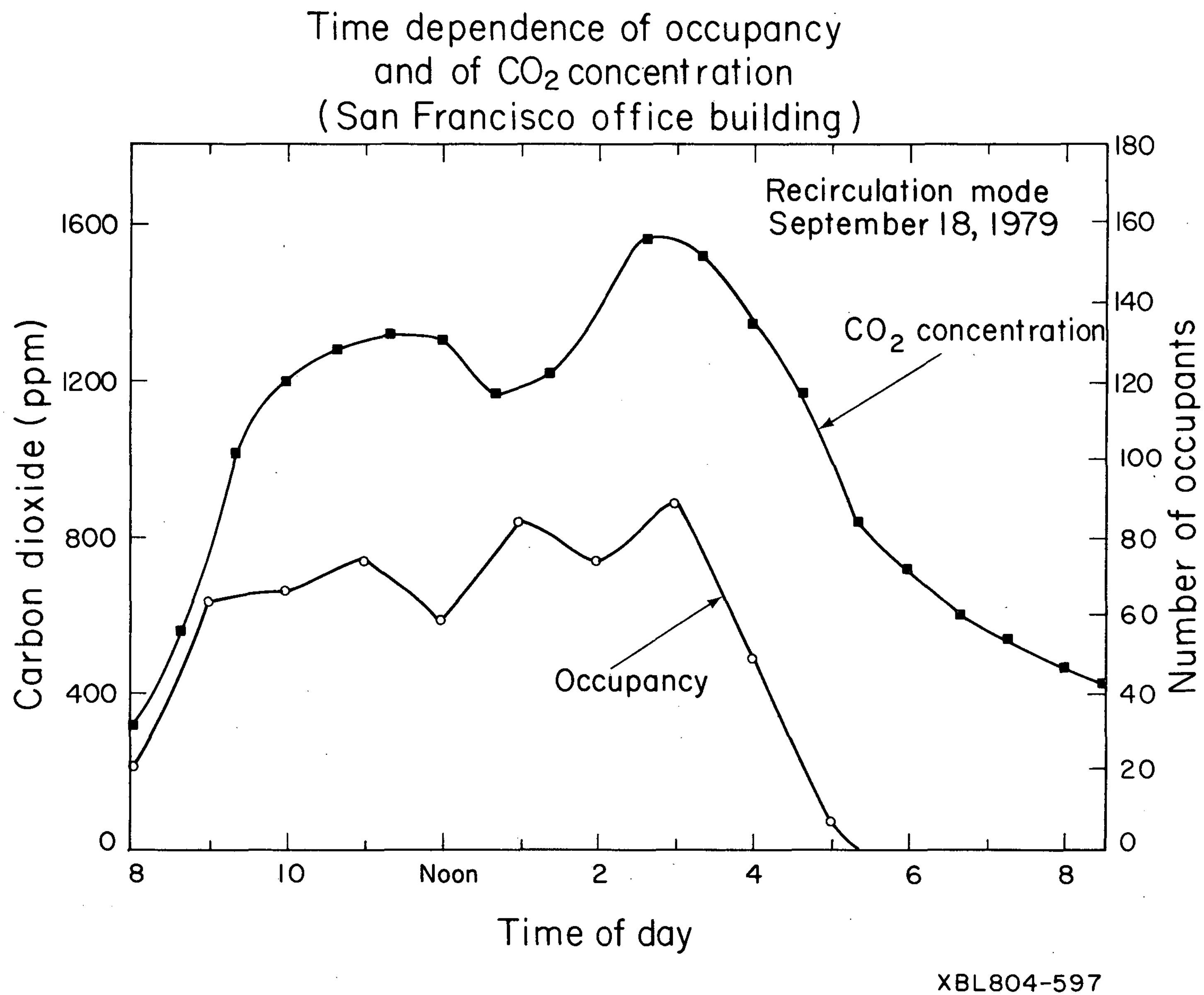
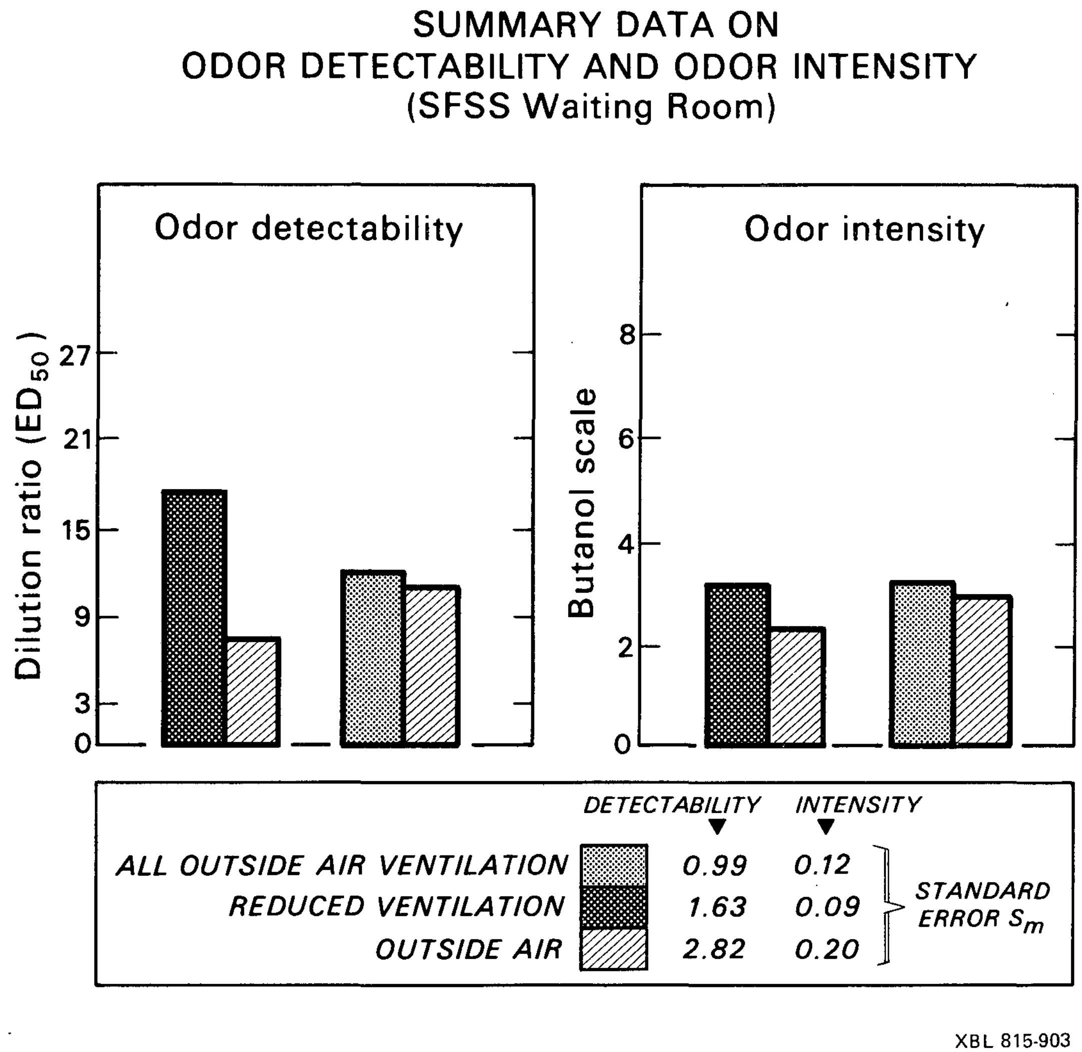


Figure 8. The time dependence of occupancy and of carbon dioxide concentrations in the waiting room of the San Francisco Social Services building during the period when the ventilation system is in the reduced ventilation mode.



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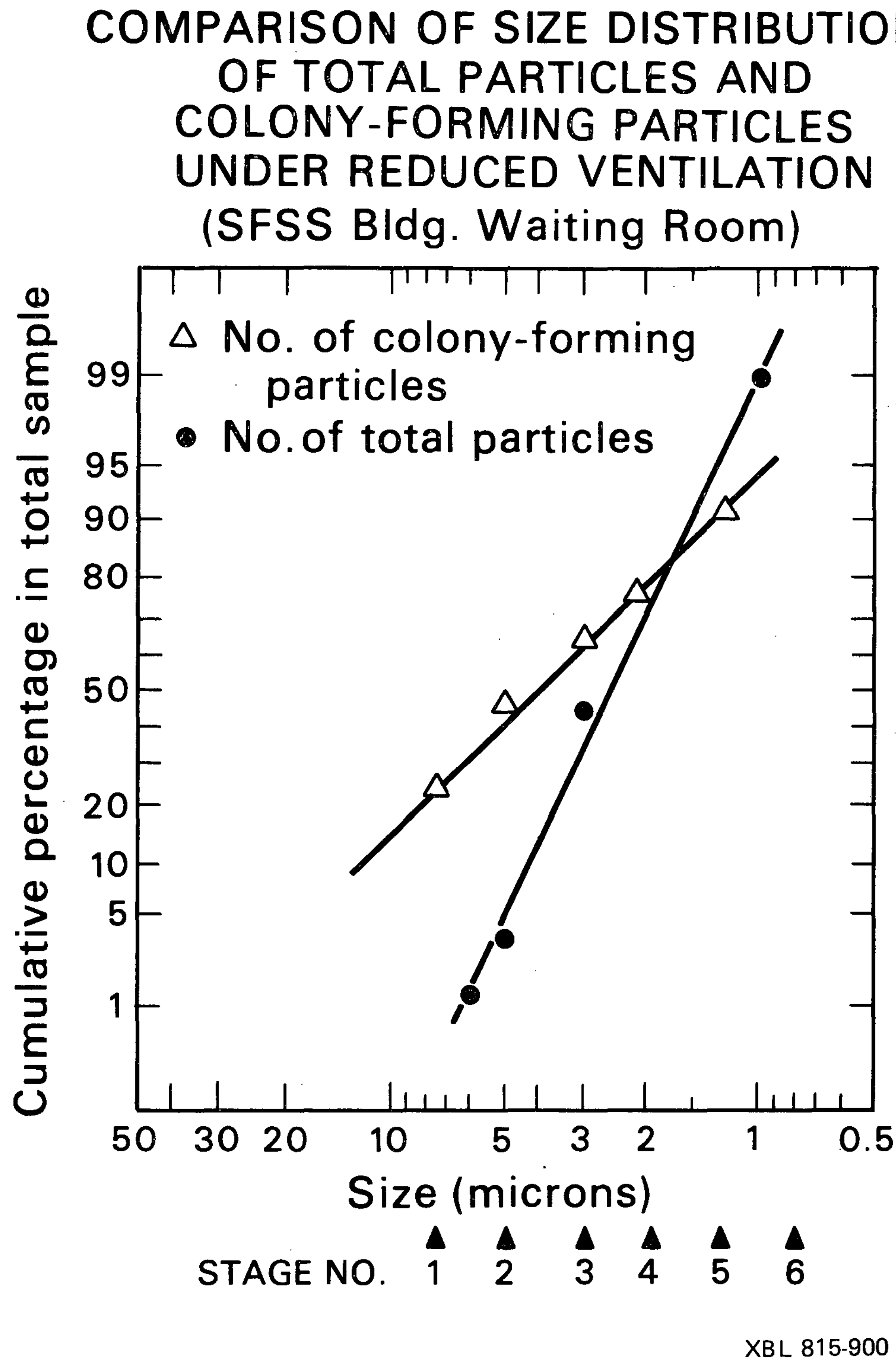

Figure 10. The size distributions of colony-forming and total particles in the San Francisco Social Services building waiting room are compared in the reduced ventilation mode.

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