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Environmental Evaluation of the Portland East Federal Office Building Preoccupancy and Early Occupancy Results

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Abstract

This report describes the results of the preoccupancy and early first year occupancy tests of the Portland East Federal Building. The National Institute of Standards and Technology installed a diagnostic center in the newly constructed federal office building in Portland OR. The diagnostic center was used to determine the building's air infiltration and ventilation rates, the building envelope tightness, interzone air movement, and the levels of indoor contaminants. The indoor contaminants measured included carbon dioxide, carbon monoxide, respirable particulates, formaldehyde, radon and volatile organic compounds.

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1. Introduction

The National Institute of Standards and Technology (formerly the National Bureau of Standards) has through an interagency agreement with the Public Building Service of the General Services Administration performed an evaluation of the thermal and environmental performance of a new Federal office building in Portland OR. The building was constructed during 1986 and 1987 and occupancy began in August of 1987.

This evaluation is part of a research effort by the Center for Building Technology of NIST to develop methods for evaluating advanced technology buildings. The procedure used for this evaluation was to install in the new office building a diagnostic center capable of monitoring important environmental parameters of the building. The measurements made consisted of air infiltration and ventilation rates, building envelope tightness, interzone air movement, detection of envelope thermal deficiencies, envelope thermal resistance and the levels of indoor contaminants. The indoor contaminants measured include carbon dioxide, carbon monoxide, respirable particulates in the 0.3 to 10 micron range, formaldehyde, radon and volatile organic compounds which could be emitted either by the new building materials and furnishings or the activities of the building occupants. There are over 100 monitoring points in the building installed both in the interior space of the building, the building HVAC systems and the underground parking garage.

2. Description of the Building

The new Federal office building is a seven-story office building with a one-story basement and a two and one-half story underground garage (see figures 1 to 7). Attached to the building on the first floor are a dining room and kitchen (figures 3 and 4). The penthouse of the building houses a mechanical equipment room which serves the first through seventh floors. There are three main HVAC systems which serve respectively the east, center and west cores of the building These three systems have a total capacity of approximately 140 m^3/s (about 3 air changes per hour). Each HVAC systems has one return fan, two cold supply fans and a hot supply fan. These three HVAC systems are variable-air-volume systems (VAV). On the B1 level (occupied basement level-figure 5) there are four air handling systems which serve various sections of the basement. The B1 level also contains the loading dock. Above and to the north of the loading dock is an air handling system for the dining room. In the underground garages there are four exhaust fans which are activated when the carbon monoxide levels in the garage reach 50 ppm. The occupied area of the building is approximately 46,000 m^2 and the volume is 180,000 m^3. The garage is connected to the occupied space by several stair and elevator shafts. The general interior plan of the building (figures 6,7) is that of an open architecture which each occupant having a space enclosed by 5 ft. partitions. On most floors there are enclosed offices for supervisors and enclosed conference rooms that do not have separate air handling systems. The second floor of the building contains a computer facility.

3. Description of Measurement Methods

A diagnostic center was installed in the building during the later stages of construction. A schematic of this diagnostic center is shown in figure 8. The instrumentation [1] of the diagnostic center was designed to measure automatically the air infiltration and ventilation rates of the building, internal temperatures and humidity, exterior temperature, wind speed and direction, the indoor and outdoor levels of carbon dioxide and carbon monoxide and the indoor levels of respirable particles in six size ranges (0.3-0.5, 0.5-0.7, 0.7-1.0, 1-5, 5-10 and >10 microns). Figure 9 shows a view of the instrumentation systems installed in the diagnostic center. In addition, measurements were made of the concentrations of formaldehyde, radon and volatile organic compounds.

The air exchange rate measurements were made using the tracer gas decay technique with an automated measuring system. This system has been used previously to provide continuous measurements of building air exchange rates in office buildings [2]. The automated system is controlled by a microcomputer that controls the tracer gas injection and air sampling, records the SF_6 concentrations, and monitors and records the outdoor weather, indoor temperatures and fan operation. Two such systems were employed in the building enabling sampling of tracer concentrations at twenty locations. These systems operate unattended for long periods of time (approximately one month). For these measurements the system injects sulfur hexafluoride (SF_6) into the building supply fans every two or three hours, allows the tracer gas to mix, and then monitors the decay in tracer concentration at several locations within the building. The tracer gas decay procedure is based on the assumption that the tracer gas is well-mixed with the interior air, and sampling of the SF_6 concentration at several locations enables the verification of this assumption. The rate of decay of the tracer gas concentration provides an estimate of the whole building air exchange rate under the conditions that exist during the measurement. This estimate includes both air exchange due to the intentional intake of outside air through the air handlers and uncontrolled, unintentional air exchange through leaks in the building envelope.

The sampling stations in the building were located in both the interior space and in the air handling systems. In general each air handling system had three air sampling locations: one down-stream of the supply fan, one up-stream of the supply fan and one in the return fan. These sampling points were connected directly to the diagnostic center through 3/8 inch OD nylon or polyethylene tubing. Each air handling system had two injection points for injecting tracer gas (one up-stream and one down-stream of the supply air fans). These points were connected to injection manifolds with 1/8 inch nylon tubing. On each floor there were between 8 to 12 interior space sampling locations at a height of approximately 5 ft. above the floor (figures 10,11). In addition there were sampling points in the exhaust of each air handling system. Typical locations of the sampling points within the occupied space can be seen in figures 4 - 6. These floor sampling locations were connected to floor panel boxes by either nylon or polyethylene 3/8 inch tubing when run under the raised floor, or 3/8 copper tubing (a fire requirement) when run through the ceiling return air plenum. Each floor panel had six 3/8 inch polyethylene tubes which ran to the diagnostic center on the B1 level. These six tubes were connected to the desired floor sample locations. This permitted easy changing of sampling locations, and through the use of tees and jumpers, the creation of a large variety of average sampling strategies. (One particularly useful strategy was to tee together one central location from each floor to obtain an estimate of the average interior space concentration.) Similar sampling also existed on each level of the underground garages. In addition, sampling locations were placed in the exhaust air of the garage's four exhaust fans. Outdoor sampling points were also installed at two locations on the roof and at two locations at street level.

The levels of pollutants were measured using a variety of techniques. Carbon monoxide (CO) and carbon dioxide (CO_2) were measured with an automated system employing infrared absorption analyzers for determining concentrations. The system included a microcomputer to switch among the sampling locations and to record data. This system automatically monitored the CO and CO_2 concentrations at ten locations in the building, each location being monitored once every ten minutes. Particle concentrations were monitored with a light-scattering particle counter that determines particle concentrations in six different size ranges (0.3-0.5, 0.5-0.7, 0.7-1.0, 1-5, 5-10 and >10 microns). Cumulative particle counts were recorded on a disk by a microcomputer based data acquisition system. Formaldehyde concentrations were measured with a passive monitor based on absorption onto a sodium-bisulfite treated filter and analysis by the chromotropic acid colorimetric method. These passive samplers yield average formaldehyde concentrations for periods from 5 to 7 days. Radon concentrations were measured at various interior locations on the B1 level and on floors 1 through 6 and in the underground garages with charcoal canisters for periods of about 3 days. A working level monitor was used to obtain hourly measurements of radon progeny levels.

Volatile organic compounds were measured using active sampling on Tenax and/or charcoal with analysis by a gas chromatograph/mass spectrometer (GC/MS). Air samples were collected on multisorbent samplers containing three sorbent materials in series: Tenax-TA, Ambersorb XE-340, and activated carbon. Samples were analyzed using a thermal desorption and sample concentrating device (Model 810, Envirochem, Inc.) a capillary gas chromagraph (Model 5790A, Hewlett-Packard, Inc.) equipped with an on-column cryogenic focusing device, and a mass-selective detector (Model 5970B, Hewlett-Packard, Inc.). Following thermal desorption, a portion of the sample was split off to a flame-ionization detector for a measurement of total organic carbon. The mass-selective detector was operated in scan mode for qualitative analyses and in selected ion mode for quantitative analyses.

4. Results of the First Year Evaluation

The building ventilation and air infiltration rates are shown in figure 12 as a function of inside-outside temperature difference. Building ventilation rates (open diamonds) are between 0.4 to 2.2 air changes per hour during periods when the building is occupied. The minnimum value of 0.4 occurs during extremely hot summer conditions or extremely cold (for Portland, OR) winter conditions. For comparison, the new ASHRAE ventilation standard requires 20 cfm per person for office buildings. This is equivalent to about 0.7 air changes per hour if the building is occupied at a density of one person per 135 $ft.^2$.

The building air leakage (uncontrolled air exchange when the HVAC fans are off during unoccupied hours - solid squares) is between 0.2 and 0.4 air changes per hour. This is a building designed to be energy efficient and these values indicate that the exterior walls of the building are not tight but can be considered typical of US office buildings. (Note: The surface to volume ratio of an office building is about 1/6 th that of a home. Therefore the walls of this building are equivalent to the walls of a house with an air leakage of about 1.2 to 2.4 air changes per hour - very leaky).

The daily maximum carbon dioxide levels for the months of January through April are shown in figure 14. Figure 15 shown the maximum daily CO_2 level as a function of air exhange rate. Carbon dioxide levels are seldom over 600 ppm on a building average and only a couple of times ever over 1000 ppm at any location in the building. (The new ASHRAE standard proposes a maximum level of 1000 ppm, complaints from building occupants begin to occur when levels exceeded 600 ppm). A closer examination of the hourly CO_2 levels in the building shows that the levels are never at steady state and usually have two daily peaks - one around 11 am and the other around 3 pm. The fact that steady state is not obtained is also shown by the values of the constants of the fitted curve in figure 14. The value of 100 is approximately 1/3 the expected equilibrium value based on the occupancy of the building.

A detailed examination of the SF_6 and CO_2 data shows that the air handling system can easily control the amount of air required for the building. The outside air is well distributed and there is little or no evidence of short circuiting of the outside supply air or poor mixing due to the operation of the variable volume air handling system. In the summer and warmer periods of the fall and spring the typical operational mode of this air handling system is to run the system at 100 percent outside air from early morning to a point in the day when the outside temperature researches about 26 degrees C, at which point the system is run at between 10 to 20 percent outside air. In the winter an economizer mode of operation was used in which the amount of outside air was determined by the cooling requirements of the building.

The levels of carbon monoxide in various parts of the building are shown in figures 15 through 20. Figure 15 gives the daily maximum carbon monoxide levels in the interior space for the months of February to May. Figure 16 shows the high levels of CO occurring in the elevator lobby on the sixth floor. Figure 17 shows the daily peaks of CO on the B2 garage level. Figure 18 gives the peak reading of CO in the elevator lobby on the B1 level. Figure 19 shows similar maxima for the B1 level loading dock. An examination of the data in these figures and the more detailed hourly data shows that during the fall and early winter months, there were occasional incidents of excessive carbon monoxide levels (greater than 10 ppm) in the upper building (figure 16) due to the flow of air from the underground parking garage toward the elevator shafts and stairwells. (Note the ASHRAE required level is 10 ppm and complaints may begin to occur at 5 pp, the National Ambient Air Quality Standard (NAAQS) is 35 ppm for 1 hour and 9ppm for 8 hours.) It seems that the automated sensors in the garage do function as designed, (activating the garage's exhaust fans when the level in the garage exceeds 50 ppm (see figure 17)). However, this intermittent operation is not sufficient to prevent the transport of CO up the elevator shafts (figure 16) and stairwells in extreme weather conditions when the stack effort is strongest. Once the garage exhaust fans (at least two of the four) were operated continuously during occupied hours, the CO level in the office space never exceeded 5 ppm.

Figures 21 and 22 shows the results of the radon testing in the building. The measured radon levels in the building are below 0.007 working levels (the ASHRAE level is 0.01 working levels, the EPA action level is 0.02 working levels) as measured in terms of the equivalent radiation impact of the radon daughters, and are less than 1.2 pCi/l (the ASHRAE recommended level is 2 pCi/l, the EPA action level is 4 pCi/l) in terms of the amount of radon gas. The radon levels in the low garage levels are higher than those those of the upper floors. It is interesting to note that the upper floors of the occupied space are consistently higher in radon level than the lower above ground levels. This can to attributed to the fact the air flows into the elevator shafts and stairwells on the lower levels and out of these shafts on the upper levels.

Figure 23 shows the maximum daily concentrations of respirable particles in the six size ranges of 0.3-0.5, 0.5-0.7, 0.7-1.0, 1-5, 5-10 and greater than 10 microns. The levels of the fine particles in the 0.3 to 0.5 remain fairly constant and show little hourly or daily variation. The three size range of 0.5-0.7, 0.7-1.0 and 1.0 -5.0 have much more pronounced variations. The two size ranges greater than 5 microns are not considered respirable. The high levels of particles in the ranges 0.7-1.0 and 1.0-5.0 micron for the period around October 15 were caused by the sweeping of the parking garage with street-type sweeping machines. The building maintence staff reported that all filters in the air handlers had to be replaced after the sweeping of the garages. In general the levels of respirable particle levels in the building (particles of a size less than 3 microns) are in the 10 to 15 million particles per cubic meter range, typical for office buildings without smoking which we have measured (data from a limited number of buildings). It is difficult to compare the measured particle levels with established standards since the standards are given in micrograms per cubic meter and there is great uncertainty in converting from particle counts per cubic meter to micrograms per cubic meter without more detailed analysis of the composition of the particles present in the building.

The level of formaldehyde in the building was measured in August 1986 during the period when the new furniture was being installed and the occupants were moving into the building. The carpeting (removable carpet squares with a pressure sensitive adhesive) was installed during the months of April through July in most parts of the building. The results of these measurements are shown in figure 24. The measured formaldehyde levels are less than 0.056 ppm (the ASHRAE level is 0.1 ppm, complaints begin at 0.06 ppm, outside levels are typically 0.04 ppm). There is no significant outgassing of formaldehyde from the building's furnishing and carpets.

The last class of pollutants measured was the volatile organics. The results are given in Table 1. The measurements were made on three different occasions: August 4, 1987 when the occupants were moving into the building, October 14, 1987 and January 13, 1988. On each of these dates the building was being operated with three distinct air exhange rates (0.5, 1.36 and 0.24 changes per hour) due to the prevaling exterior weather conditions. Figure 25 shows the effect of building ventilation rate on the total VOC concentration. The curve in figure 25 represents the predicted level in the building using the source strengths in table 1. The source strength of total VOC is remarkably constant over the five month period between the first and last measurements. We have measured and identified 37 volatile organic compounds in the interior building space. There are 5 oxygenated compounds, 6 halogenated compounds, 16 alkanes, 6 cycloaklanes and aklenes, and 5 aromatic hydrocarbons. All are at levels less than 1/1000 th of the OSHA standard environmental levels of industrial work spaces. (Note: The

ASHRAE standard recommends that for indoor air quality the level be not more than 1/10 of OSHA SEL's.) The largest amount of the mass of the VOC's is concentrated in the aklane class (C_{10} to C_{12} branched decanes and undecanes). These are not particularly irritating compounds and there are no OSHA recommended levels for these substances. However very limited studies done in Denmark by Dr. Molhave [3] indicated that many complaints will occur when the total levels of VOC's exceeds 5 mg/m³ and it has been recommended by researchers [4] at EPA Research Triangle Park that a prudent target level for total VOC's be 1 mg/m³. All three measurements sets that were made in the building were greater than 1 mg/m³ and the building exceeded 5 mg/m³ when the ventilation rate was below 0.5 air changes per hour. The sources of these compounds have not yet been identified; however we have tested the major building components and furnishings for outgasing and these are not the sources. We suspect that they are activity related and we are making an effort at identifying these activities. Though operating the ventilation system always at 100 percent outside air would keep the levels near the target of 1 mg/m³, identification and limitation of the sources is generally a better strategy.

5. Summary

The new office building studied is being investigated in order to establish a long-term record of a modern office building's thermal and environmental performance and to document what parameters in the design, construction and operation of a new office building will effect this performance. Other than initial problems associated with "debugging" the HVAC system and controls, the building has adequate ventilation under most operating conditions. The envelope of the building is not tight for a new office building and infiltration is a significant source of building air exchange. The levels of CO_2, HCHO, radon and respirable particles are well within the established guidelines. An area of concern is the airflow from the garage into the occupied space. This airflow can cause high levels of CO in the vicinity of elevator shafts and stairwells on the upper levels and near the loading dock. The garage exhaust fans are adequate to reverse this flow, but in the automatic mode they currently do not operate for a sufficient amount of time to do so. A change in their controls, or an attempt to isolate the vertical shafts (stairs and elevators) from the garage, would alleviate these problems. There is no evidence of any significant outgassing of pollutants from the building's materials and furnishings. There is however a total of at least 37 volatile organic compounds in the building air which seem to be related to the activities occurring in the building. The levels of all these compounds are of at least two orders of magnitude below established limits (1/10th of the TLV's). However the vast amount of VOC's found in the building are compounds for which no extensive amount of research has been done to establish irritant levels and therefore these compounds could be a source of complaints from the building's occupants at low ventilation rates.

Acknowledgments

The authors wish to acknowledge the support of the US General Services Administration in conducting this research. Also without the efforts of Douglas Pruitt, Sandra Krause and Samuel Silberstein of NIST and Richard Syldowski of LBL in installing the miles of tubing, wiring and measuring equipment, this project would not have been possible. The assistance of W. Stuart Dols of NIST in processing and analyzing the tracer gas and CO_2 data must also be acknowledged. Finally the cooperation of the GSA region 9 field staff and the Bonneville Power Administration (BPA) building facility staff was indispensable.

References

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[2] Grot, R.A. and A. Persily "Measured Air Infiltration and Ventilation in Eight Federal Office Buildings", in Measured Air Leakage of Buildings, ASTM, STP 904, H.R. Treschel and P.L Lagus, editors

[3] Molhave, L., "Volatile Organic Compounds as Indoor Air Pollutants" in Indoor Air and Human Health, P. Gammage and S. Kaze editors, Lewis Publications, 1984

[4] Tucker, G., "Factors Influencing Indoor Air Pollutants Originating from Surface Materials" in preprints of conference "Heathy Buildings 88", Swedish Council for Building Research, Stockholm, Sweden, 1988.

Figure 1. Exterior View of the New Federal Office Building

Figure 2. Front Entrance of Building

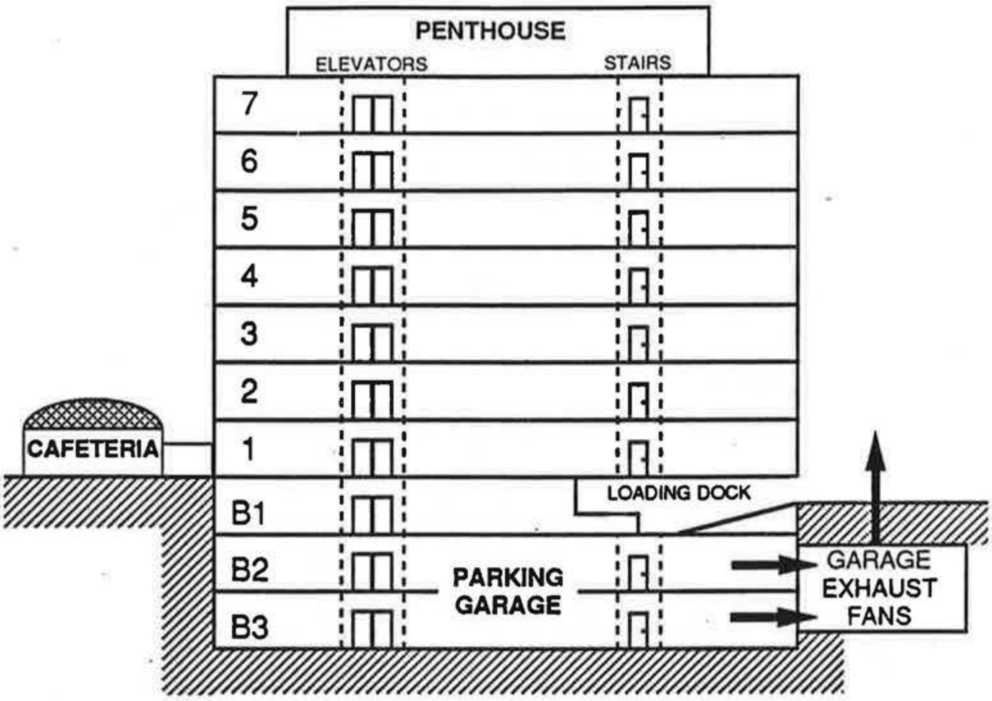


Figure 3. Schematic of the New Federal Office Building

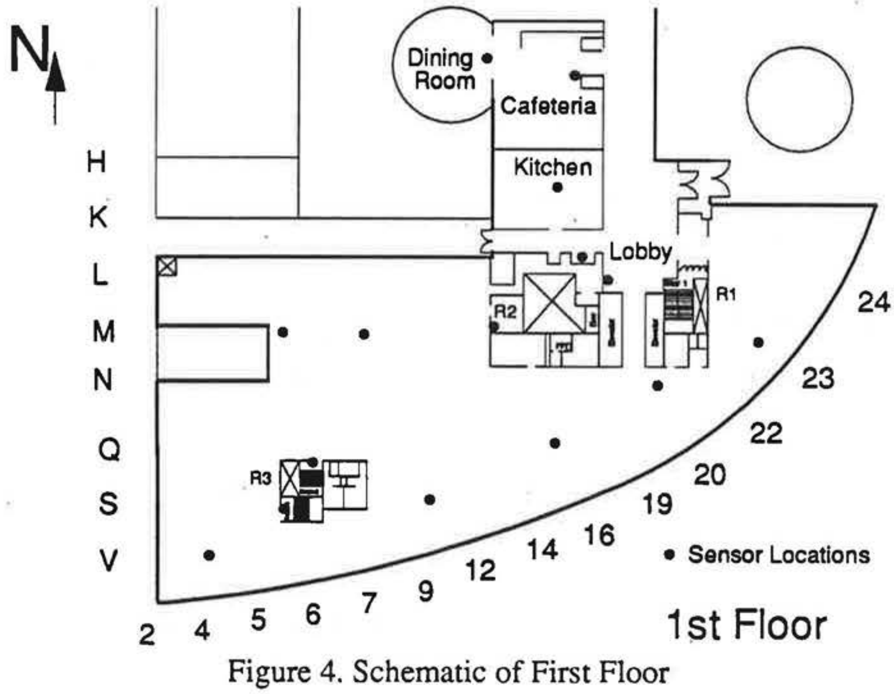


Figure 4. Schematic of First Floor

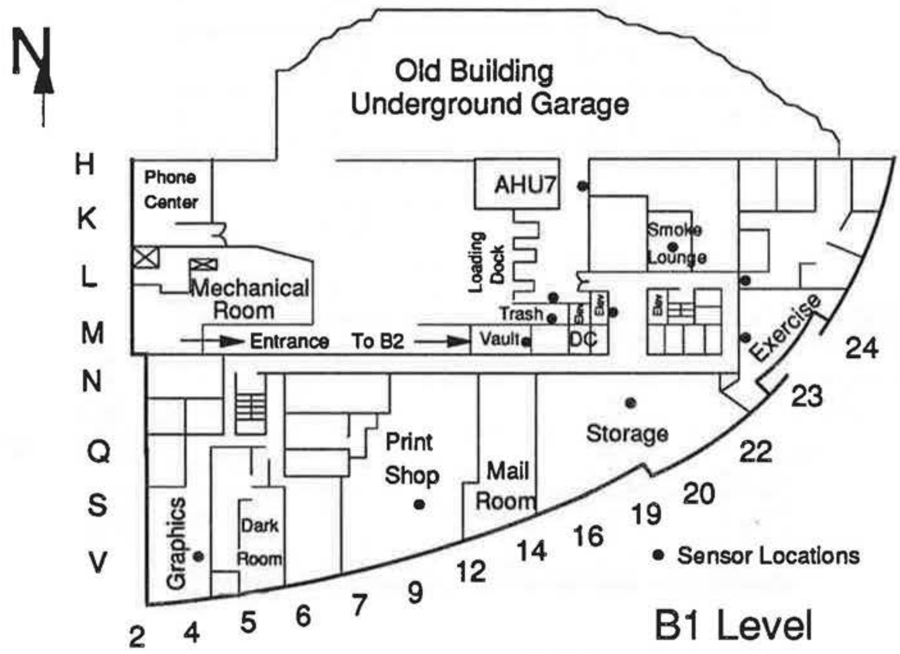


Figure 5. Schematic of B1 Level

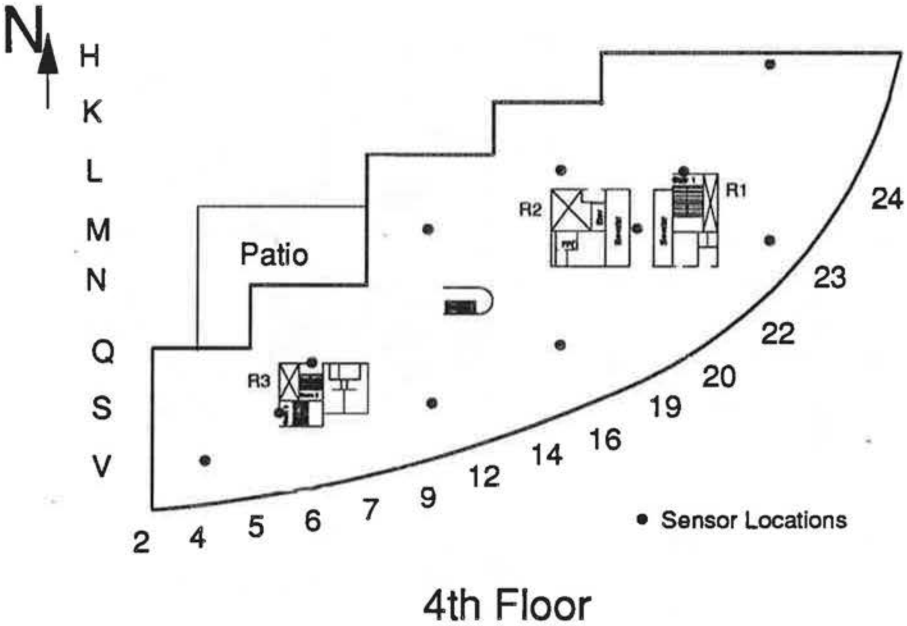


Figure 6. Schematic of Fourth Floor

Figure 7. View of Building Interior

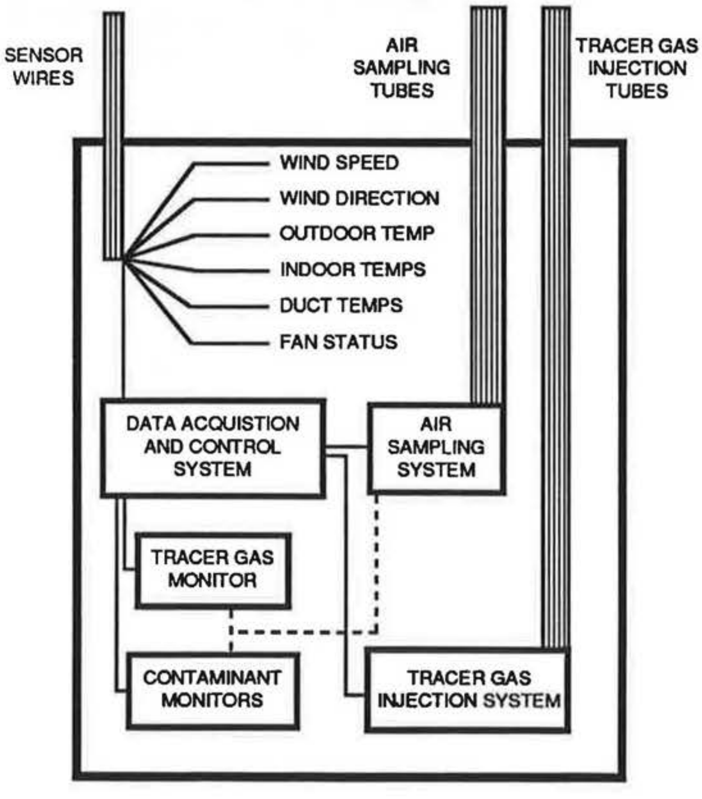


Figure 8. Schematic of Diagnositc Center

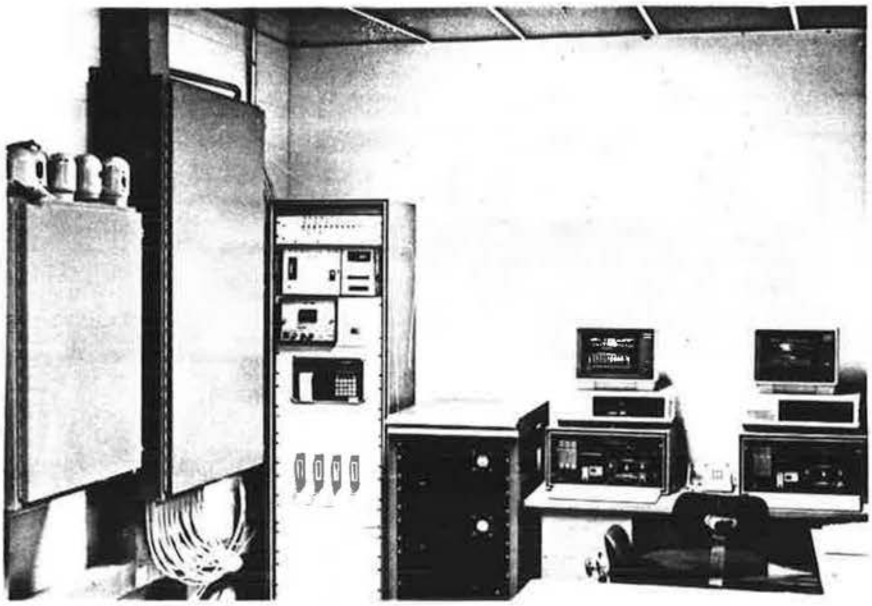


Figure 9. View of Diagnostic Center

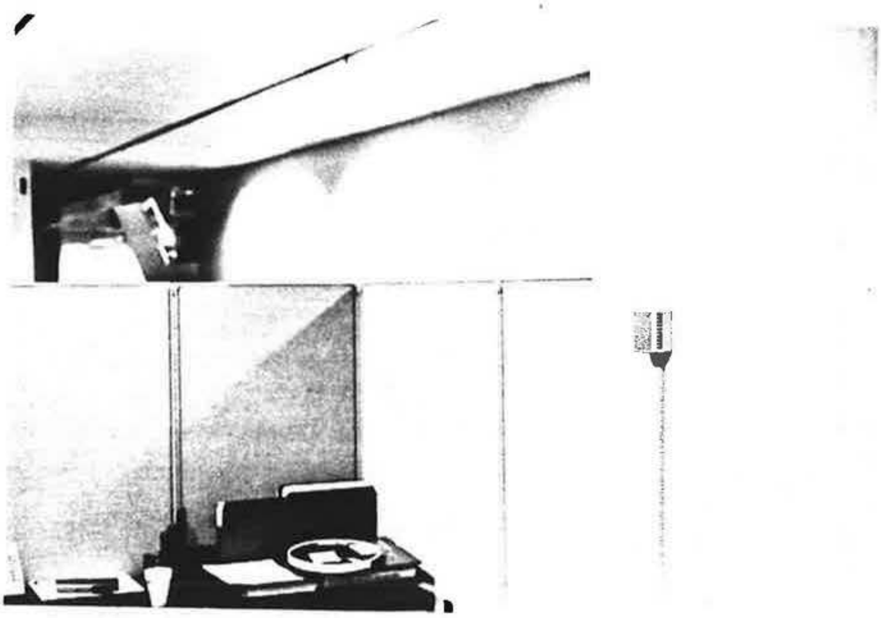


Figure 10. Space Air Sampling Location

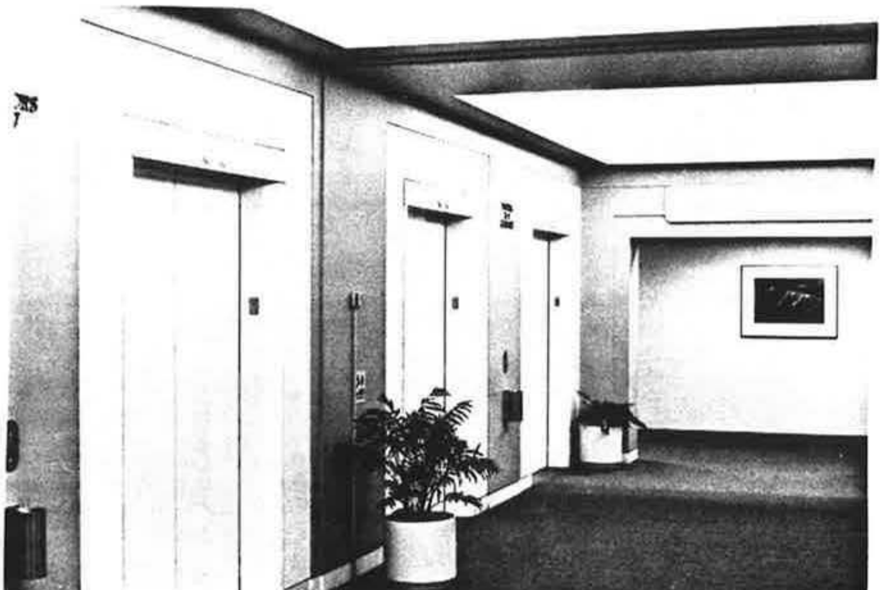


Figure 11. Elevator Lobby Air Sampling Location

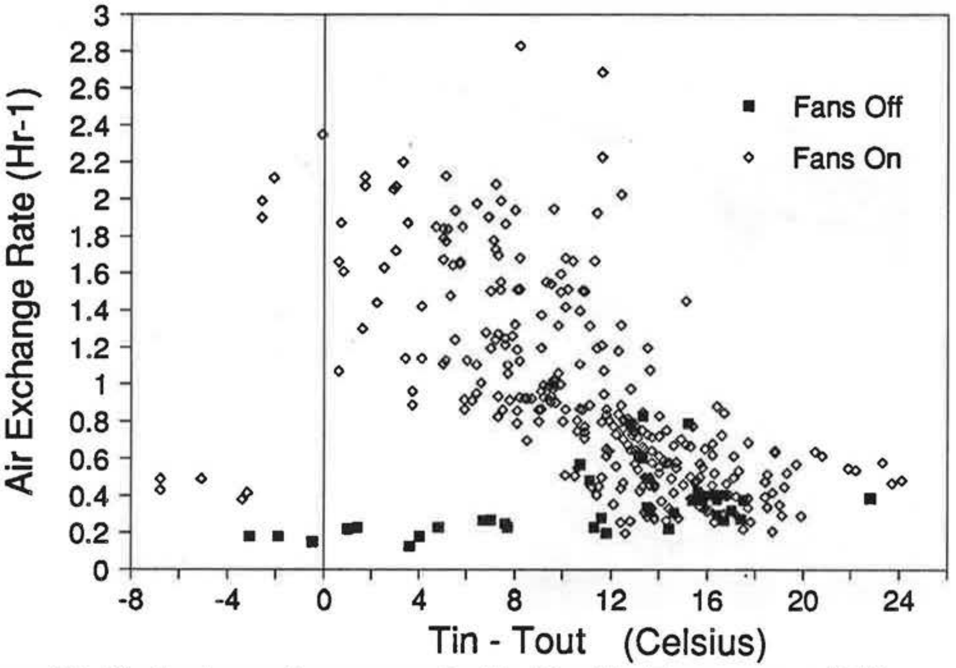


Figure 12. Air Exchange Rate versus Inside-Outside Temeperature Difference

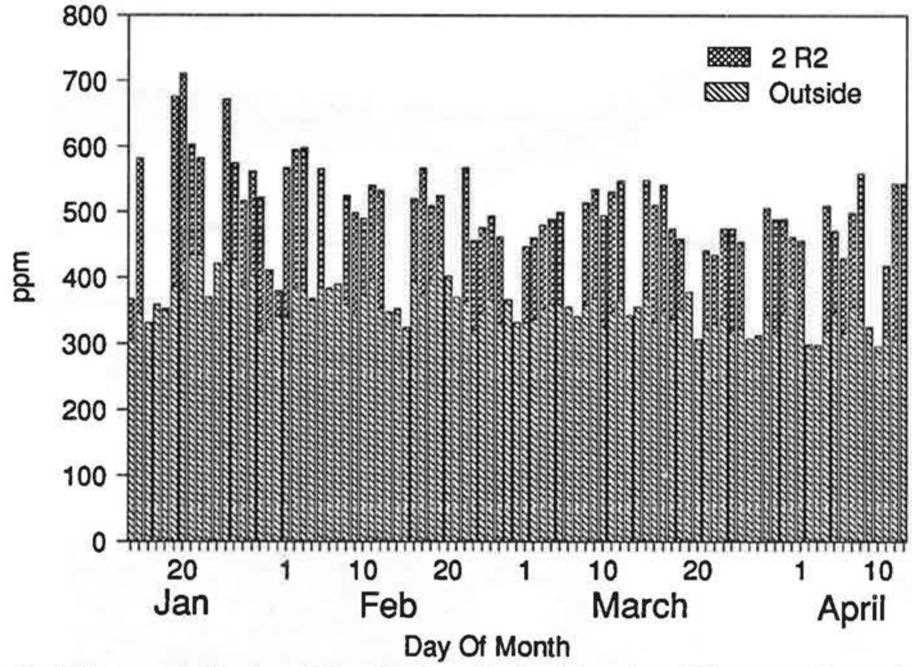
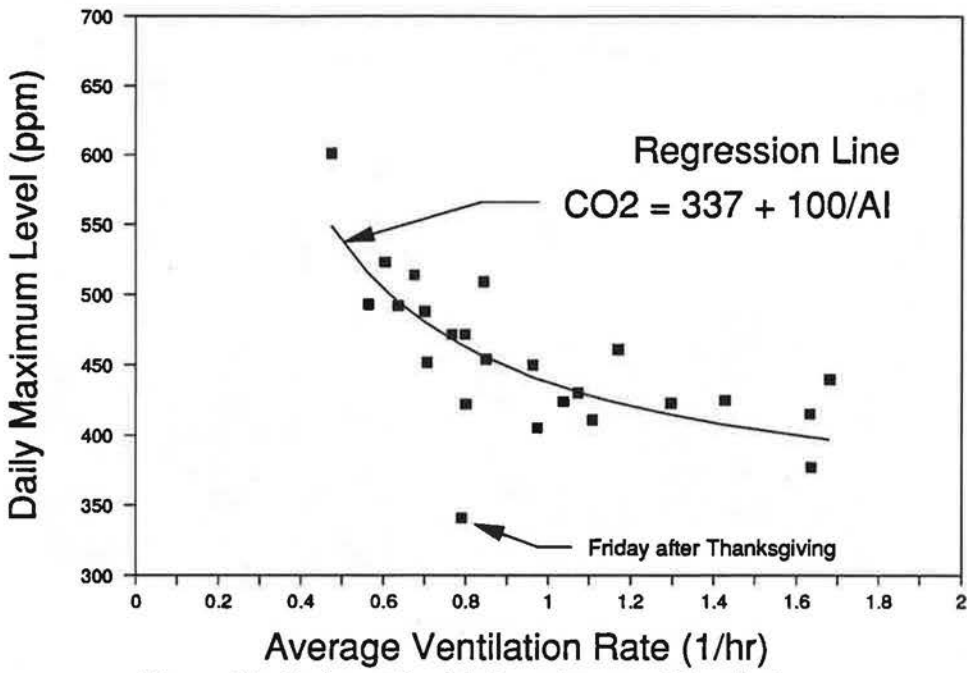


Figure 13. Daily Maximum Carbon Dioxide Levels for Months of January through April 1988



Fiqure 14. Carbon Dioxide Level versus Ventilation

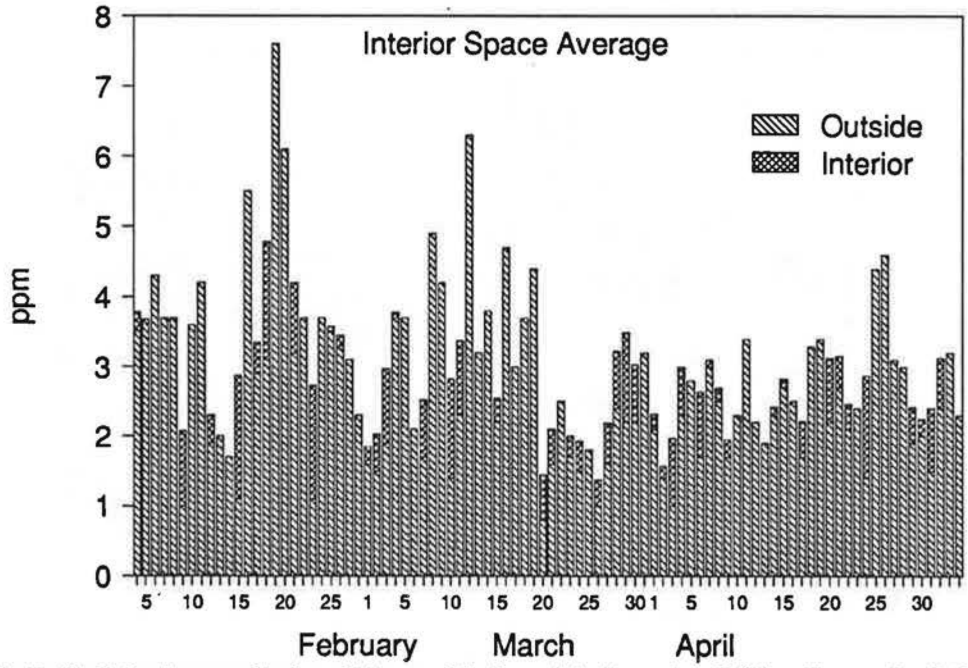


Figure 15. Daily Maximum Carbon Monoxide Level in Interior Office Space for Months of February to May

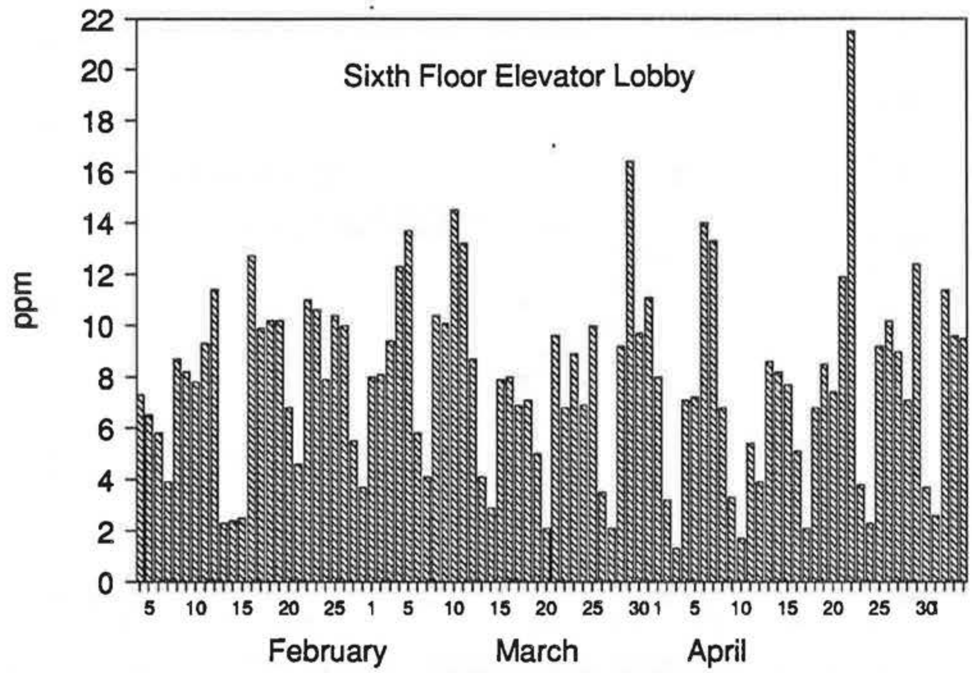


Figure 16. Daily Maximum Carbon Monoxide Level in Sixth Floor Lobby for Months of February to May

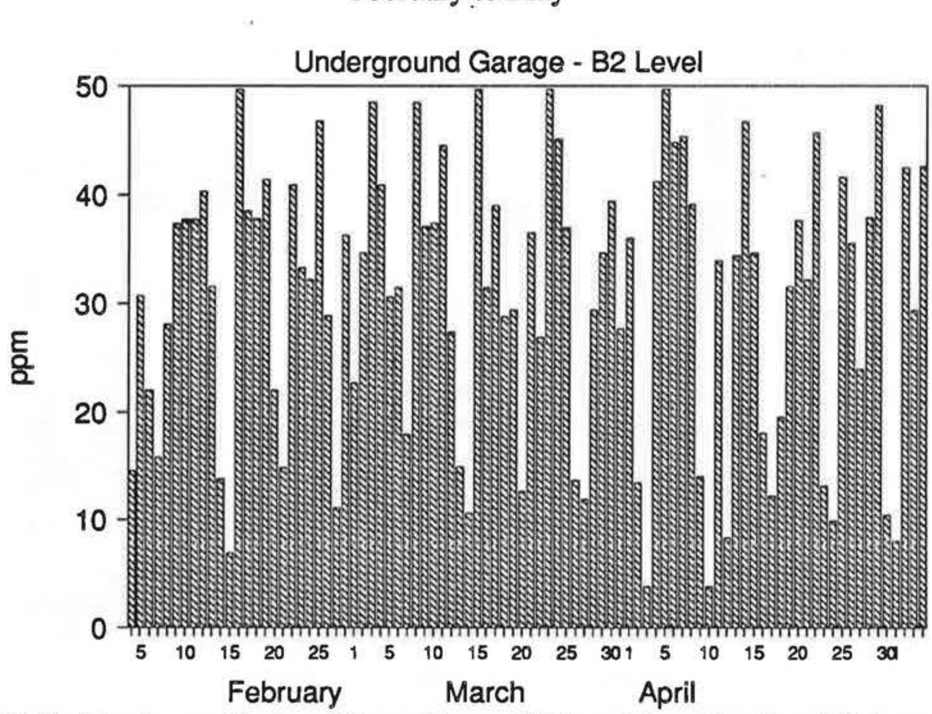


Figure 17. Daily Maximum Carbon Monoxide on B2 Level for Months of February to May

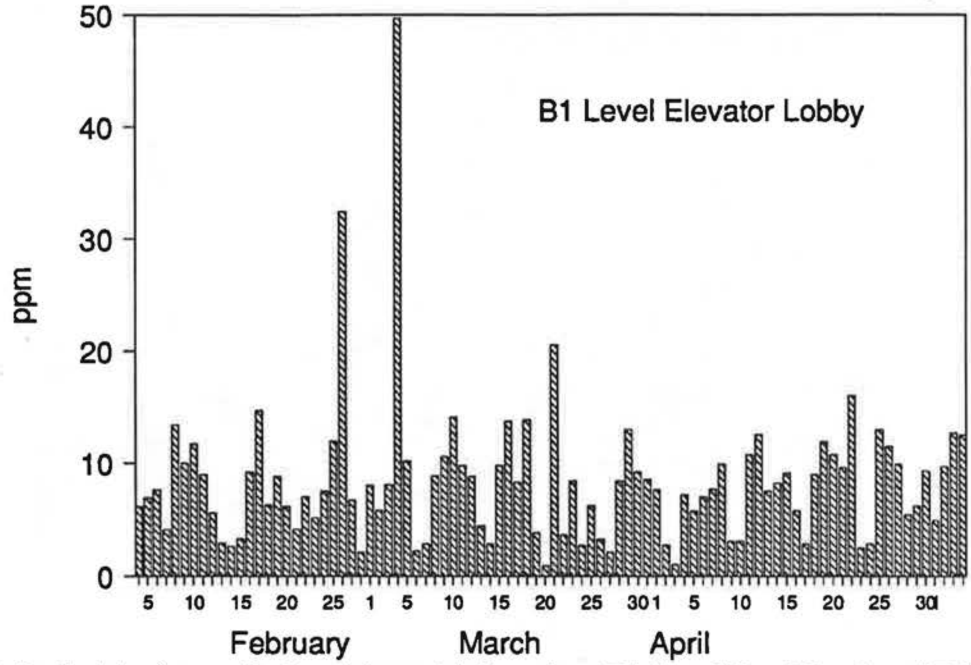


Figure 18. Daily Maximum Carbon Monoxide Level on B1 Level for Months of February to May

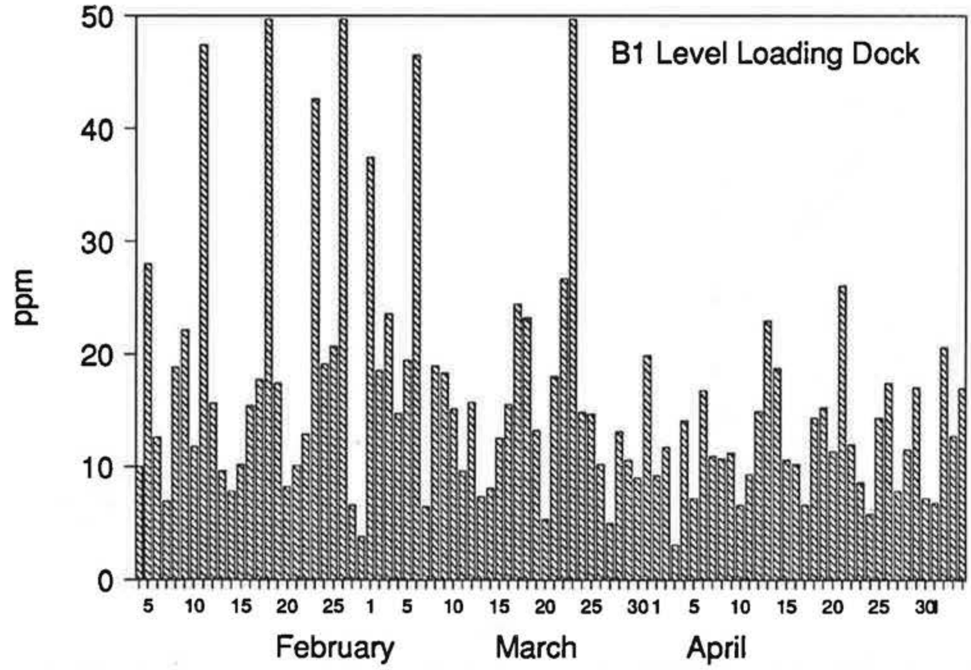


Figure 19. Daily Maximum Carbon Monoxide Level on Loading Dock for Months of February to May

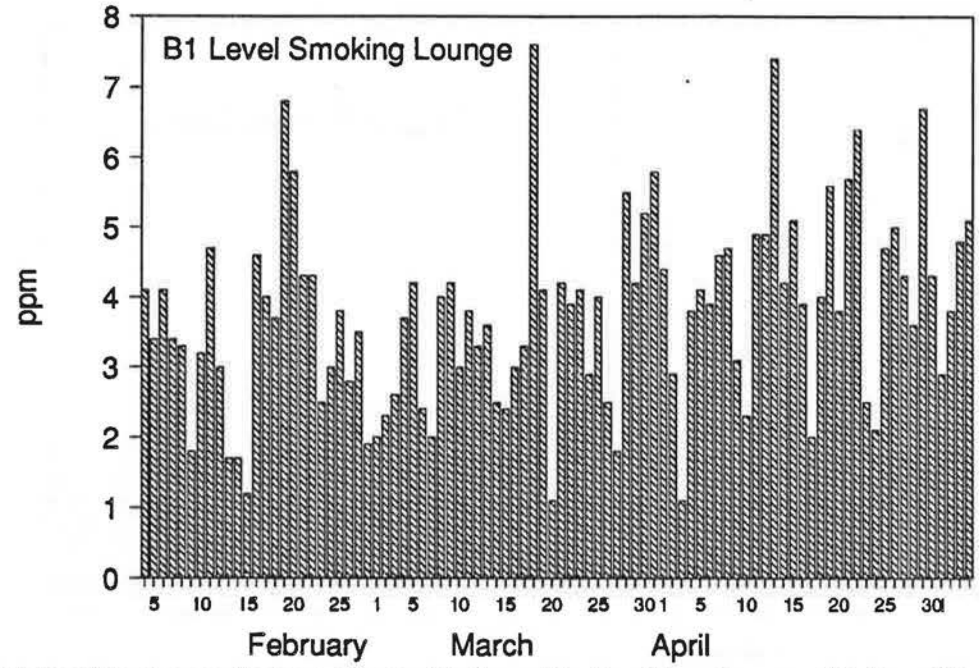


Figure 20. Daily Maximum Carbon Monoxide Level in Smoking Lounge B1 Level for Months of February to May

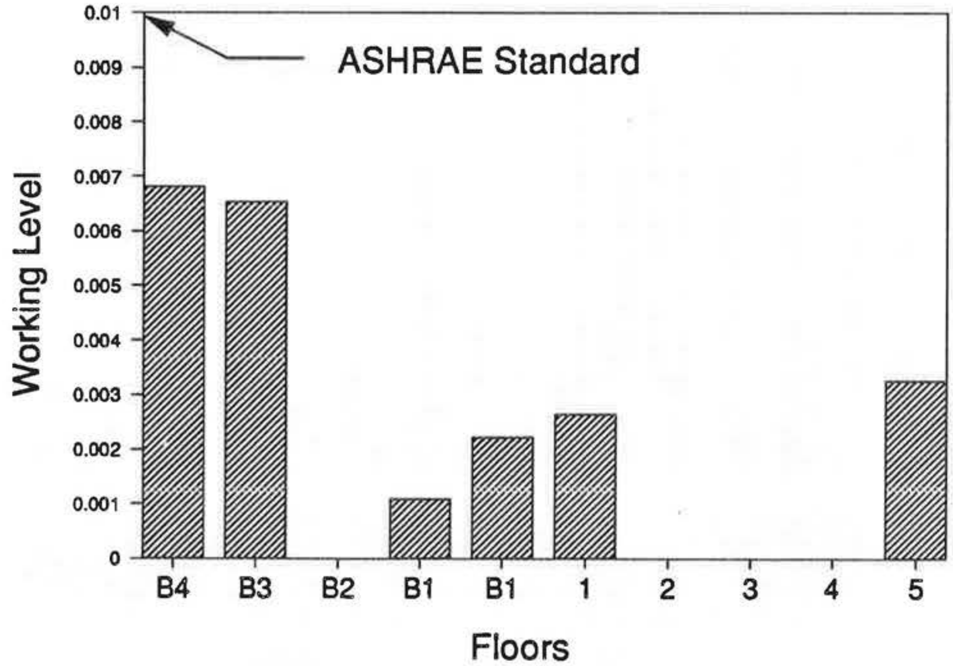


Figure 21. Working Levels of Radon Daughters

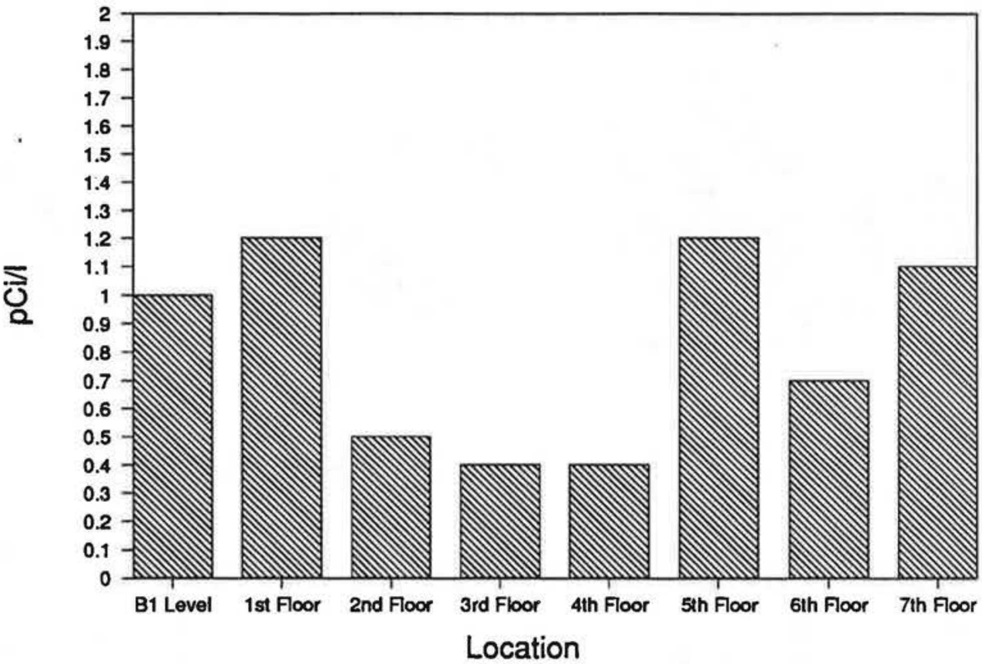


Figure 22. Radon Levels as Measured with Charcoal Canisters