NISTIR 4883

Environmental Evaluation of the Federal Records Center in Overland Missouri

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Abstract

The National Institute of Standards and Technology (NIST) is studying the thermal and environmental performance of new federal office buildings for the Public Buildings Service of the General Services Administration (GSA). This project involves long-term performance monitoring starting before occupancy and extending into early occupancy in three new office buildings. The performance evaluation includes an assessment of the thermal integrity of the building envelope, long-term monitoring of ventilation system performance, and measurement of indoor levels of selected pollutants. This is the second report describing the study of the Federal Records Center in Overland, Missouri, and this report presents measurement results from preoccupancy to full occupancy. Ventilation rates ranged from 0.3 to 2.6 air changes per hour (ach) with the minimum levels being below both the building design value of 0.8 ach and the recommended minimum in ASHRAE Standard 62-1989. The measured radon concentrations were 2 pCi/L or less on the sub-basement level, and less than or equal to 0.4 pCi/L on the other levels. Formaldehyde concentrations ranged from 0.03 to 0.07 ppm. Daily peak levels of carbon dioxide in the building were typically between 500 and 800 ppm. Maximum carbon monoxide levels were typically on the order of 1 to 2 ppm, essentially tracking outdoor levels induced by automobile traffic. There have been some occasions of elevated carbon monoxide and carbon dioxide levels in the building associated with unexplained episodic increases in the outdoor levels.

Key words: carbon dioxide, carbon monoxide, formaldehyde, indoor air quality, office building, radon, ventilation

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1 Introduction

In the early 1980s, the Public Buildings Service of the General Services Administration (GSA) committed resources to the construction of advanced-technology office buildings. This initiative was directed at offering cost effective innovations in all facets of building design and construction with special emphasis on environmental control, building thermal performance and occupant productivity. In order to verify the accomplishment of these objectives, the actual performance of the buildings must be quantified through diagnostic evaluations. Previous diagnostic studies in new office buildings proved useful in evaluating building performance and have revealed cases of excessive energy consumption, poor thermal comfort and indoor air quality complaints [Grot et al. 1985 and 1989]. In order to assess the performance of their advanced-technology federal office buildings, GSA entered into an interagency agreement with the Building and Fire Research Laboratory at the National Institute of Standards and Technology to evaluate the thermal and environmental performance of three office buildings. The NIST effort began with the development of specifications for thermal and environmental performance evaluations in advanced-technology office buildings [Persily 1986]. These specifications contain detailed descriptions of the tests to be conducted as part of the diagnostic program, provided examples of performance standards for the test results, and introduced the concept of a building "diagnostic center," a facility within a building for the coordination of a building environmental evaluation program. The diagnostic center contains diagnostic test equipment and serves as a terminus for sensor lines transmitting building performance data from throughout the building to this equipment. The diagnostic center concept was successfully employed in the evaluation of the Portland East Federal Building [Grot et al. 1989] and is being applied in the evaluation of the Federal Records Center in Overland, Missouri. This is the second report describing the Overland evaluation, the first containing a detailed description of the building, the diagnostic center installation and results of the monitoring effort prior to full occupancy of the building [Persily et al. 1991]. This report contains the results of the building evaluation beginning at the time of initial occupancy of the building and ending several months after full occupancy. These results include the measurement of the indoor levels of radon, carbon dioxide, carbon monoxide and formaldehyde, along with measurements of whole building air change rates.

2 Building Description

The Federal Records Center (FRC) is located in Overland, Missouri, about four miles west of St. Louis. The center consists of two buildings, an existing facility constructed in 1956 and a new one which is the subject of this study. Construction of the new FRC began in 1988 and occupancy began late in 1990. The new building consists of seven floors, levels 1 through 5 above grade and levels B1 and B2 below grade. A photograph of the building is shown in Figure 1. The building has a total floor area of about 35,100 m^2 (378,000 ft^2) and a volume of about 129,000 m^3 (4,570,000 ft^3). The new building is connected to the old building by doorways on levels B1, 1 and 3. Most of the new FRC consists of open office space that is divided into smaller cubicles by 1.5 m (5 ft) high partitions. The building also contains a limited number of private offices, conference rooms and classrooms with floor-to-ceiling walls. Level 1 contains a meeting hall that is two stories high, and there is a computer facility located in the center of level B2. The floor plan for a typical upper floor of the building is shown in Figure 2. The building is basically square, with a skylit atrium extending from the first floor. Stairwells are located in each corner of the building. Mechanical rooms are located in the east and west corners, and rest rooms are located in the north and south corners. A bank of six passenger elevators and a freight elevator are located in the south corner of the building. A detailed description of the building and floor plans for the entire building are given in Persily et al. [1991].

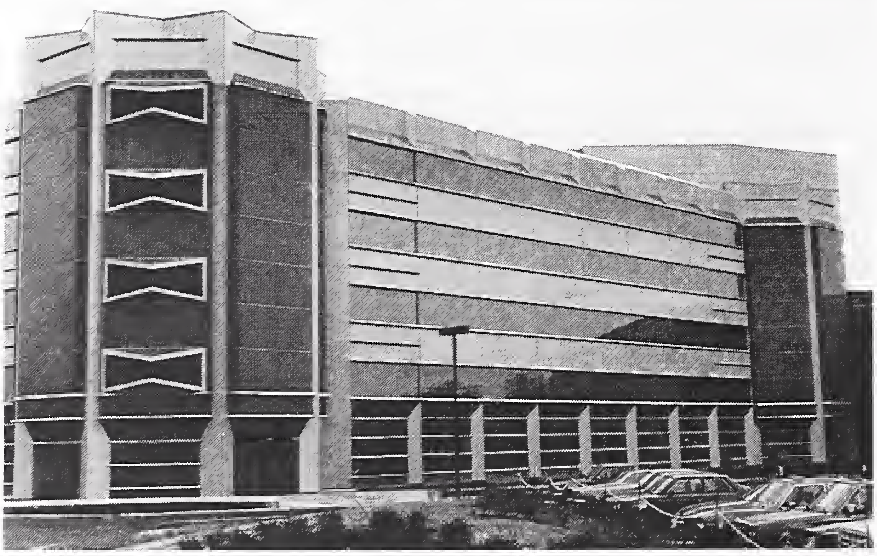
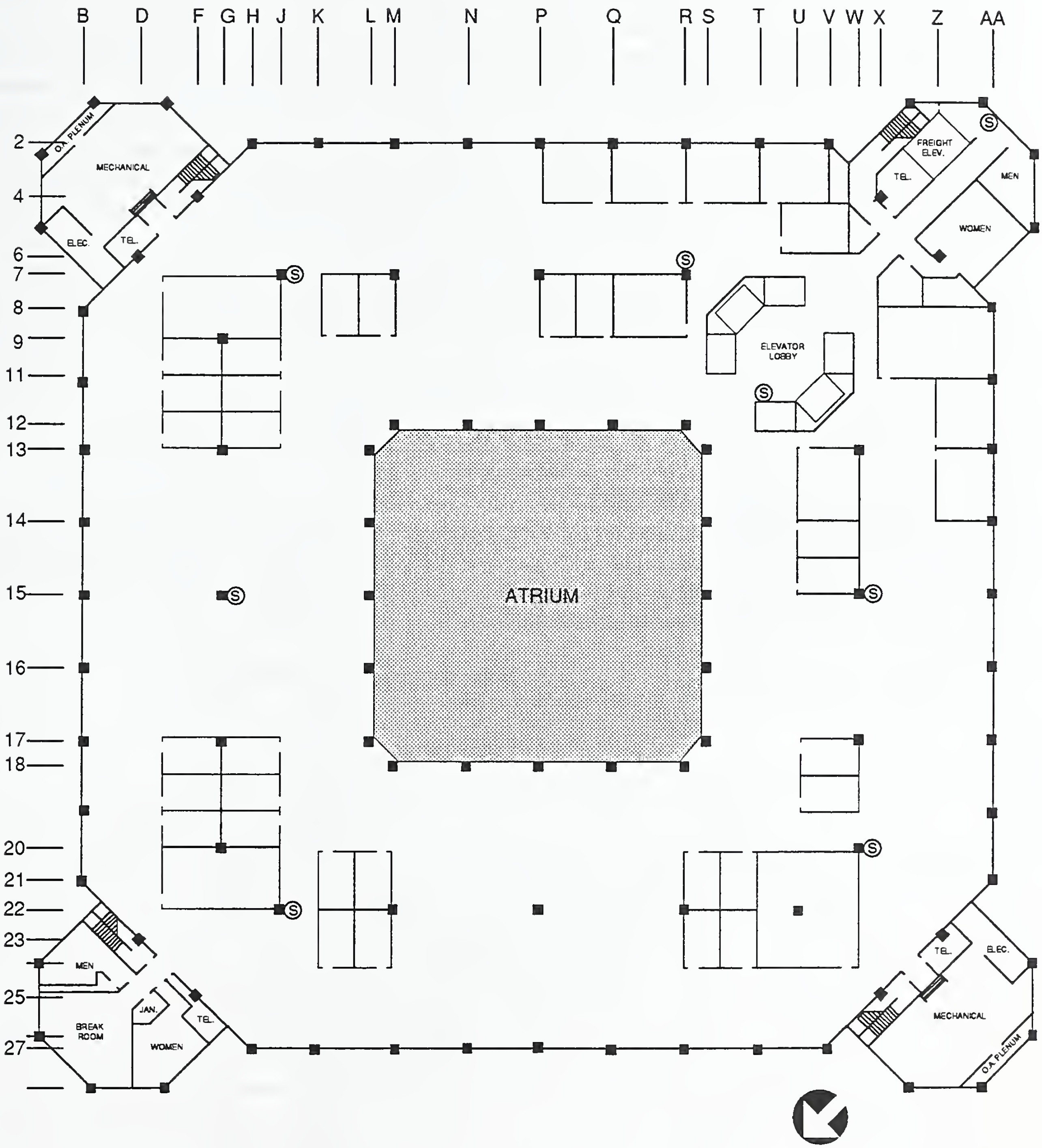


Figure 1 - Photograph of The Federal Records Center



Ⓢ = Sample Location

Figure 2 - Typical Floor Plan

The HVAC system is a variable air volume (VAV) system which utilizes unpowered VAV units in the interior zones of the building and fan powered units in the perimeter zones. The terminal units do not have a minimum damper position setting. The building ventilation system is zoned horizontally with air handling equipment located in two mechanical rooms serving each floor of the building. A separate mechanical room serves the atrium. A schematic of a typical mechanical room is shown in Figure 3. Each mechanical room contains two air handlers that are connected to a common supply duct system that serves either the east or west side of the building. Each fan serving levels 1 through 5 has a design airflow capacity of 7.6 m^3/s (16,000 cfm), yielding a total supply capacity of 15.1 m^3/s (32,000 cfm) on each side of the building. The fans serving levels B1 and B2 have a design capacity of 5.6 m^3/s (12,000 cfm), yielding 11.3 m^3/s (24,000 cfm) on each side of the building. The minimum outdoor air intake specification for these systems is 3.0 m^3/s (6400 cfm) on each side of levels 1 through 5, 2.3 m^3/s (4800 cfm) per side on level B1, and 1.5 m^3/s (3200 cfm) per side on level B2. The supply airflow rate capacity of the atrium air handlers is 11.3 m^3/s (24000 cfm), and the minimum outdoor air intake is 2.3 m^3/s (4800 cfm). Outdoor air is brought in through an outdoor air plenum located upstream of the air handlers; a return air damper is located in the bottom of the duct that connects the plenum to the air handler. Return air from the occupied space flows directly into the mechanical room from the return air plenum above the suspended ceiling. Therefore the mechanical rooms themselves are part of the return air system. Such an arrangement can lead to indoor air quality problems if the mechanical room is not kept clean or is used for storing inappropriate materials. Two features are employed to control the supply static pressure: a relief air fan that draws air from the mechanical room into a relief air shaft and a damper in the supply air duct that allows supply air to spill into the mechanical room.

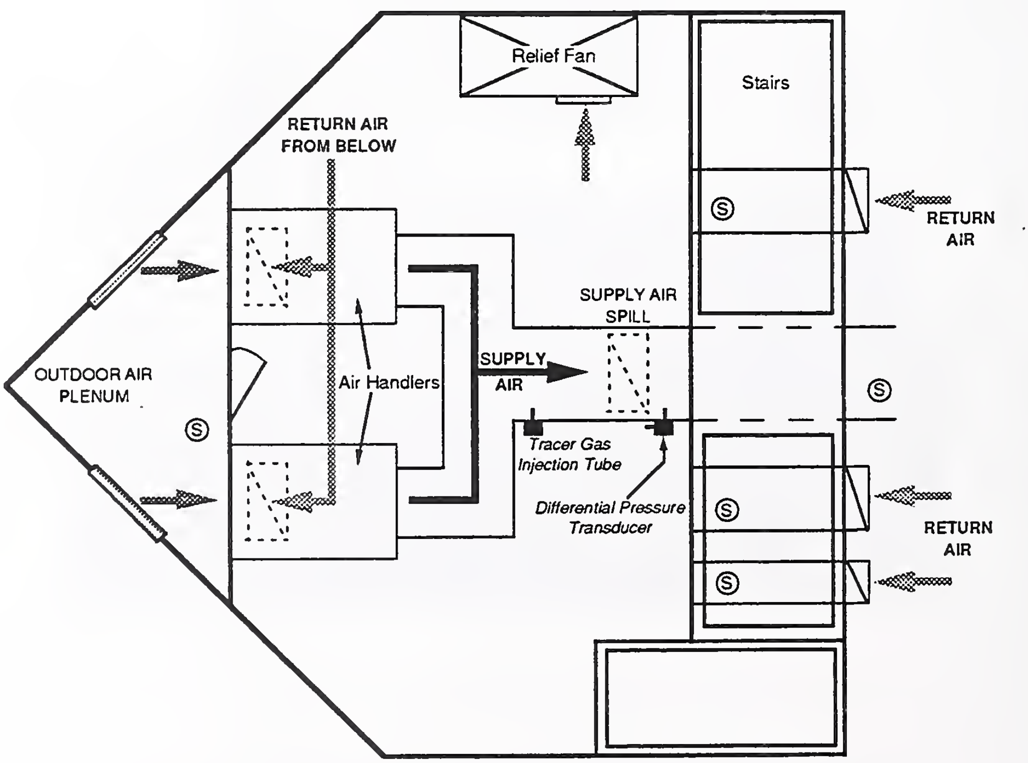


Figure 3 - Typical Mechanical Room

In summary, the mechanical ventilation system of the FRC consists of 30 supply fans with a total capacity of 208 m^3/s (440,000 cfm), corresponding to about 5.8 air changes per hour (ach). However, the supply air fans are controlled to never exceed 60% of their rated capacity, therefore the actual supply airflow rate capacity of the building is 125 m^3/s (264,000 cfm) or 3.5 ach. The design value for minimum outdoor air intake for the building is 28 m^3/s (58,700 cfm), corresponding to 0.77 ach. The minimum outdoor air intake rate for the individual floors is 1.3 ach on levels 1 through 5, 1.1 ach on levels B1 and B2, and 0.7 ach in the atrium. ASHRAE Standard 62-1989 recommends a minimum ventilation rate of 10 L/s (20 cfm) per person for office space. Assuming 14.3 m^2 (143 ft^2) of floor area per person and a ceiling height of 3.5 m (11.5 ft) including the return air plenum, the ASHRAE recommendation corresponds to 0.72 ach. The occupant density in the atrium is much lower than in office space, and the ceiling height is much larger. Therefore, the ASHRAE recommendation would correspond to an air change rate in the atrium that is well below 0.72 ach. The minimum outdoor air intake rate specifications for all floors in the building are above the minimum recommendation in ASHRAE Standard 62-1989.

3 Diagnostic Center Description

The diagnostic center (DC) used in the thermal and environmental evaluation of the building consists of systems for air sampling, indoor and outdoor environmental monitoring, fan status monitoring, tracer gas injection, and instrumentation used to measure tracer gas and pollutant concentrations. A detailed description of the DC instrumentation is contained in Persily et al. [1991]. The monitoring systems employ a network of air sampling and tracer gas injection tubes and sensor wires running through the building and leading back to the DC, where the majority of the monitoring and control equipment is located. A schematic of the DC is shown in Figure 4, and a photograph of the equipment in the DC is shown in Figure 5.

The air sampling system consists of a tubing network and a set of air sampling pumps. There are approximately 90 air sampling locations in the occupied space, mechanical system, and the outdoors. These sampling locations are listed in Table 1. Except as noted, the air sample tubing is low-density polyethylene with a 9.5 mm (3/8 in) outside diameter. There are 52 sample points within the occupied space with approximately seven locations on each floor. The sample points in the occupied space are located about 1.5 m (5 ft) above the floor and are covered by vented thermostat covers as shown in the photograph in Figure 6. One location on each floor employs a 9.5 mm (3/8 in) outside diameter soft copper tube for use in sampling particulates . The return air sample points are located inside the mechanical rooms where the return air flows from the return air plenum into the mechanical room (see Figure 3). The return air sample provides an estimate of the average return air concentration for the side of the building served by the corresponding air handler. Supply air sample points are located in the supply air ducts approximately 6 m (20 ft) downstream from where the two supply ducts merge. Outdoor air samples are taken through a tube that runs through the outdoor air intake plenum and extends approximately 0.3 m (1 ft) beyond the outdoor air intake grille. On each floor there is a junction box (floor panel) to which all sample tubes and wires for that floor are connected. Six tubes from each floor panel run down to the main junction box (DC panel) located in the diagnostic center. This system allows for a wide variety of sampling schemes by using jumpers within the junction boxes to connect between the sample locations on that floor and the six tubes running down to the DC panel. For example, to obtain an average air sample of the occupied space on a single floor, the sample lines of all occupied space sample locations for that floor are connected to one of the six lines running to the DC panel. In the diagnostic center there are twenty air sampling pumps that draw air from the sampling locations to the tracer gas and pollutant monitoring systems. These air sampling pumps run continuously at an airflow rate of about 0.028 m^3/s (35 scfh) in order to provide a current air sample to the monitoring equipment. A 9.5 mm (3/8 in) polyethylene tube runs from the inlet of each pump to the DC panel, and the outlets of the pumps are connected to the tracer gas and pollutant monitoring equipment. A separate pump is used to connect the copper particulate sampling tubes to the particulate monitoring system. The inlet of the particle sampling pump is connected to an automated 30-port sample valve that allows continuous sampling of up to 30 different locations.

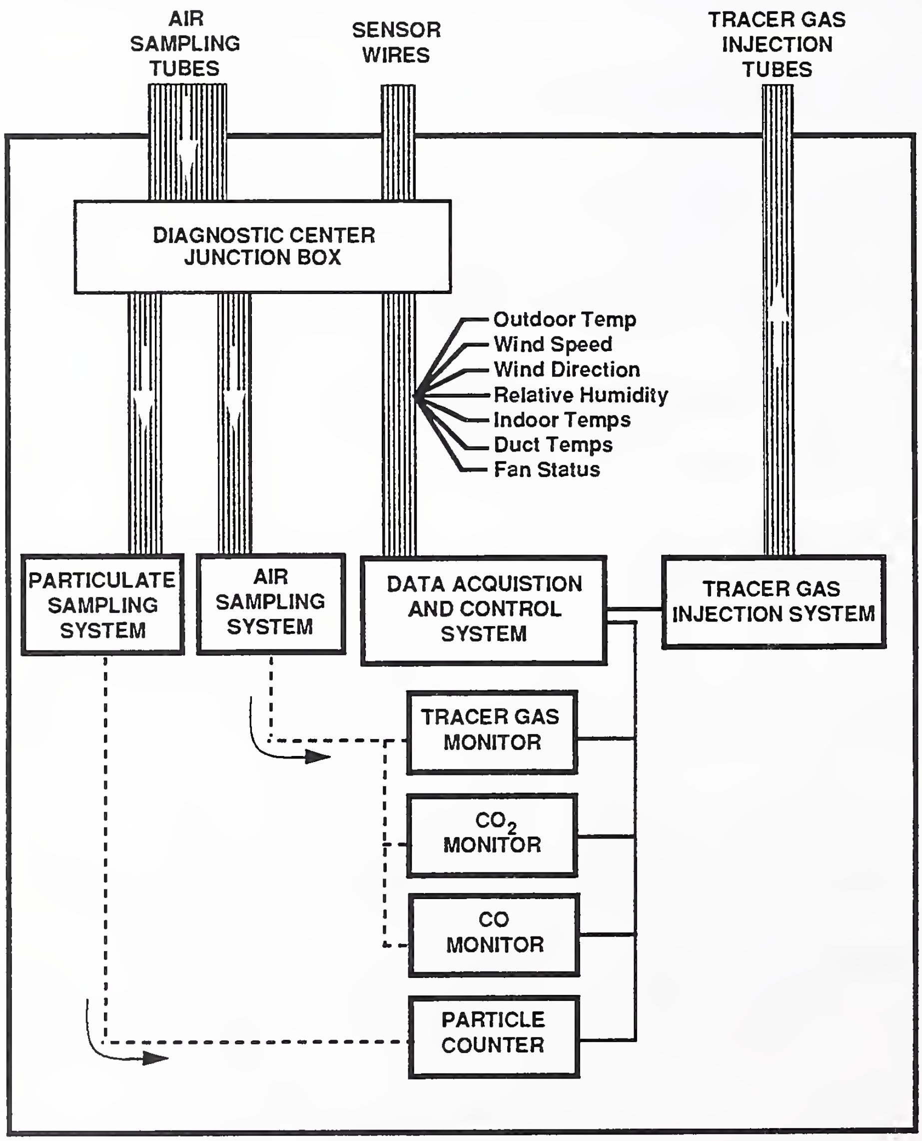


Figure 4 - Schematic of Diagnostic Center

Figure 5 - Diagnostic Center

Figure 6 - Air Sample Location

Sample Location	Level	Sample Tube Material
Elevator Lobby	B2	Polyethylene
Freight Elev. Hall	B2	Polyethylene
G9	B2	Polyethylene
G20	B2	Polyethylene
N14	B2	Polyethylene
U2	B2	Polyethylene
Return East	B2	Polyethylene
Supply East	B2	Polyethylene
Return West	B2	Polyethylene
Supply West	B2	Polyethylene
Elevator Lobby	B1	Polyethylene
Freight Elev. Hall	B1	Polyethylene
D23	B1	Polyethylene
L15	B1	Polyethylene
Q12	B1	Copper
Q18	B1	Polyethylene
W17	B1	Polyethylene
Old Building	B1	Polyethylene
Return East	B1	Polyethylene
Return West	B1	Polyethylene
Supply East	B1	Polyethylene
Supply West	B1	Polyethylene
Elevator Lobby	1	Polyethylene
Freight Elev. Hall	1	Polyethylene
G15	1	Polyethylene
J7	1	Polyethylene
J22	1	Polyethylene
R7	1	Polyethylene
U22	1	Copper
W15	1	Polyethylene
Old Building	1	Polyethylene
Return East	1	Polyethylene
Supply East	1	Polyethylene
Return West	1	Polyethylene
Supply West	1	Polyethylene
Return Atrium	1	Polyethylene
Supply Atrium	1	Polyethylene
Outdoor Atrium	1	Polyethylene
Outdoor Air	1	Copper
Elevator Lobby	2	Polyethylene
Freight Elev. Hall	2	Polyethylene
G15	2	Polyethylene
J7	2	Polyethylene
J22	2	Polyethylene
R7	2	Polyethylene
U22	2	Copper
W15	2	Polyethylene
Return East	2	Polyethylene
Supply East	2	Polyethylene
Outdoor East	2	Polyethylene
Return West	2	Polyethylene
Supply West	2	Polyethylene
Outdoor West	2	Polyethylene

Sample Location	Level	Sample Tube Material
Elevator Lobby	3	Polyethylene
Freight Elev. Hall	3	Polyethylene
G15	3	Polyethylene
J7	3	Polyethylene
J22	3	Polyethylene
R7	3	Copper
U22	3	Polyethylene
W15	3	Polyethylene
Return East	3	Polyethylene
Supply East	3	Polyethylene
Return West	3	Polyethylene
Supply West	3	Polyethylene
Elevator Lobby	4	Polyethylene
Freight Elev. Hall	4	Polyethylene
G15	4	Polyethylene
J7	4	Polyethylene
J22	4	Polyethylene
R7	4	Copper
W15	4	Polyethylene
W20	4	Polyethylene
Return East	4	Polyethylene
Supply East	4	Polyethylene
Return West	4	Polyethylene
Supply West	4	Polyethylene
Elevator Lobby	5	Polyethylene
Freight Elev. Hall	5	Polyethylene
G9	5	Polyethylene
G15	5	Polyethylene
J22	5	Polyethylene
R7	5	Copper
W15	5	Polyethylene
W20	5	Polyethylene
Return East	5	Polyethylene
Supply East	5	Polyethylene
Outdoor East	5	Polyethylene
Return West	5	Polyethylene
Supply West	5	Polyethylene
Outdoor West	5	Polyethylene

Table 1 - Sample Locations

The diagnostic system can monitor twenty indoor air temperatures, two outdoor air temperatures, one outdoor and two indoor relative humidities, and wind speed and direction. Indoor air temperatures can be monitored at any of the locations listed in Table 1. Temperatures are measured with thermistors that are accurate within 0.4°C (0.7°F). Relative humidity is monitored using bulk polymer resistance sensors with an accuracy of 3% RH. Outdoor air temperature, relative humidity and wind conditions are monitored on the roof of the building. Wind speed is measured with a light-weight cup anemometer that is based on a DC generator. Wind direction is measured with a vane anemometer employing a 360 degree potentiometer. The wind sensors are mounted on a mast, approximately 10 m (30 ft) above the roof of the building.

The fan status monitoring system employs differential pressure transducers located in the supply air duct of each air handling system to indicate whether the fans are operating. These transducers provide a contact closure when a pressure differential of at least 38 Pa (0.15 inches of water) exists between the high and low pressure ports of the instrument. The low pressure side of the transducer is in the mechanical room and a tube from the high pressure side is located inside the supply duct. Therefore, if an air handler is operating, a pressure differential will exist across the transducer producing a switch closure. Pressure transducers are mounted on the supply air duct in each mechanical room, just downstream of where the air streams from the two air handlers merge (see Figure 3). Therefore, the operation of only one fan will cause the transducer to indicate a fan-on status. These pressure transducers are wired directly to the tracer gas injection panel, located in the diagnostic center.

The tracer gas injection system consists of a cylinder of sulfur hexafluoride (SF_6), a tracer gas distribution system, and an injection panel. The distribution system consists of tubing from the injection panel to the fifteen tracer gas injection locations. The tracer gas injection panel consists of solenoid valves, relays and timers that enable computer control of the tracer gas injection. The tracer gas cylinder is connected to the normally-closed inlets of eight electronically actuated solenoid valves, one for each of the seven floors plus the atrium. The outlets of the valves serving the seven floors are connected to the inlets of two adjustable flow meters, one for each side of the building, and the outlet of the atrium solenoid valve is connected to a single flow meter. A 3.2 mm (1/8 in) diameter nylon tube runs from the outlet of each flow meter to the supply air duct inside of each mechanical room as indicated in Figure 3. Two-conductor wires from the fan status pressures switches are wired to the injection panel such that tracer gas is injected only when an air handler in that mechanical room is running. This arrangement avoids injecting tracer gas into an air handling system that is not operating.

The diagnostic center contains the data acquisition and control systems, tracer gas and pollutant monitors, the tracer gas injection panel, and the air sampling systems. There are three microcomputer based data acquisition and control systems: one for the building air infiltration rate measurement systems, one for the CO_2 and CO monitors and one for the particle counter.

The building air change rate is measured using the tracer gas decay technique [ASTM 1990], employing two automated air infiltration rate measurement systems. Each system consists of a microcomputer-based data acquisition and control system and a gas chromatograph (GC) equipped with an electron capture detector. The electron capture detectors are capable of determining SF_6 concentrations over a range of about 5 to 300 parts per billion (ppb) with an accuracy of 1%. Ten air sample lines are connected to each system. A ten-port sample valve in each system is controlled by the microcomputer to direct the air samples to the SF_6 detector. Timing of the injection of the tracer gas as well as the amount of tracer gas injected are controlled by one of the microcomputers. The same microcomputer also monitors fan status, indoor and outdoor temperatures, and wind speed and direction. Tracer gas is injected into the supply air ducts every three hours and allowed to mix for a period of twenty to thirty minutes to obtain a uniform concentration throughout the building. The concentrations at each of the twenty sample locations are measured every ten minutes until the start of the next injection period. The total building air change rate, mechanical ventilation plus infiltration, is then determined by performing a linear regression of the logarithm of the tracer gas concentration versus time. Tracer gas concentrations, temperatures, wind speed and direction, and the number of seconds per hour that each fan was operating are stored on a floppy disk. The system is capable of operating unattended for up to one month.

Another automated system is used to continuously monitor carbon dioxide (CO_2) and carbon monoxide (CO) concentrations. CO_2 and CO are monitored with infrared absorption analyzers. The CO_2 monitor has a range of 0 to 2500 parts per million (ppm) and is accurate to within +/- 0.5% of full scale. The CO monitor has a range of 0 to 50 ppm and is accurate to within +/- 1% of full scale. These two monitors are connected to the outlets of ten of the twenty air sampling pumps, therefore ten of the twenty locations monitored by the tracer gas system are also monitored by the CO/CO_2 system. The sample air streams of these two instruments are connected in series, with sample air flowing first into the CO_2 monitor and then into the CO monitor. A small sample pump in the CO monitor draws air through both monitors continuously. This system's microcomputer controls a 10-port valve that connects one of the ten inlet lines to the monitors for sixty seconds and stores the measured concentrations on floppy disk. The system also monitors and records the relative humidity at one outdoor and two indoor locations.

The particle counter utilizes a light scattering measurement technique and yields counts of particles in six different size ranges: 0.3 to 0.5, 0.5 to 0.7, 0.7 to 1.0, 1.0 to 5.0, 5.0 to 10.0 and greater than 10.0 micrometers (μm). Air samples for this system are provided by the particle sampling system described previously. The particle counter is used in conjunction with a thirty-port sample valve to switch among air sampling locations in the building. A single pump is used with the sample valve to draw building air to the system. The particle counter is programmed to control the sample valve and outputs the particle count data digitally via an RS-232 port at preselected time intervals. The RS-232 output is connected to a microcomputer that records the data.

4 Measurement Procedures and Results

This section presents the results of the environmental measurements performed between November 1990 and December 1991. Only a small portion of the building was occupied in November 1990, with full occupancy occurring in May 1991. Therefore, neither the thermal loads nor the HVAC operation were at their design levels until May 1991.

4.1 Building Ventilation

Building ventilation rates are being measured in the Overland Building using the automated tracer gas system described earlier. When the building ventilation system is operating, the measured air change rate is referred to as a ventilation rate and is equal to the sum of the rate of intentional air intake through the building air handlers plus the rate of uncontrolled air infiltration through leaks in the building envelope. An air change rate measured when the ventilation system is not operating is referred to as an infiltration rate. Infiltration rates are caused by weather-induced pressure differences across leaks in the building envelope. These pressures are induced by indoor-outdoor temperature differences and wind pressure on the exterior surfaces of the building. The tracer gas concentration decay procedure used to measure infiltration and ventilation rates are essentially identical, the only difference being the operation of the building ventilation systems during the ventilation rate measurements.

In these ventilation rate measurements, the automated measuring system injects tracer gas into all fifteen of the building air handlers every three hours. The tracer gas concentration decay is monitored at nineteen locations within the building and at an outdoor location. The sampling locations for the measurements described here include the return air streams on each floor of the building, the atrium return duct, a mixture of air samples from the same column location within the occupied space on levels 2 through 5, a location on the second level of the old building (same as the first level of the new building), a central occupied space location on each level of the new building, and an outdoor location on level 5. The return shaft locations only provide meaningful concentrations when the building ventilation system is operating. The concentrations from the sampling locations on the columns in the occupied space can be used regardless of fan operation, and it is these concentrations that are used to determine air infiltration rates. The infiltration rate measurements rely on the existence of a significant concentration of tracer gas remaining in the building when the air handling systems are turned off. In order for these measurements to be reliable, these concentrations must also be uniform throughout the building. Therefore, the ability to measure infiltration rates depends on the time since the last tracer gas injection and the distribution of tracer gas concentrations in the building when the fans are turned off. On some occasions, conditions are not appropriate for the reliable measurement of air infiltration rates.

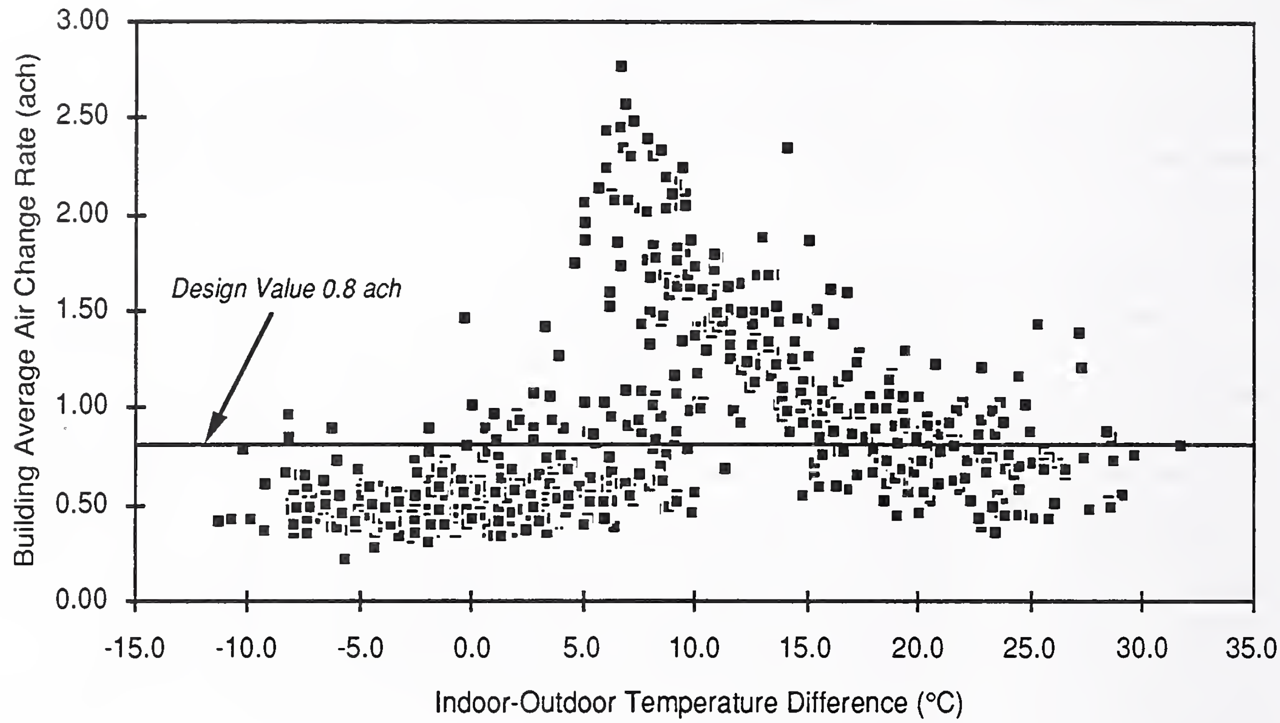


Figure 7: Building Air Change Rates

The results of the tracer gas decay measurements of ventilation between November 1990 and December 1991 are presented in Figure 7. These data indicate ventilation rates ranging from about 0.3 to 2.6 air changes per hour (ach), depending on the amount of outdoor air intake which in turn correlates with the indoor-outdoor temperature difference. This HVAC system utilizes an economizer cycle which controls the amount of outdoor air intake based on the indoor and outdoor air temperatures. When the outdoor air temperature is greater than a predetermined economizer shut-off temperature, the economizer reduces the outdoor air intake rate to a minimum by closing the outdoor air intake dampers to their minimum settings. This is done because it is more economical to cool the building return air than the hotter outdoor air. This trend is shown by the lower ventilation rates when the indoor-outdoor temperature difference is around 0°C and below. When the outdoor air temperature is below the economizer shut-off temperature, the economizer regulates the outdoor air intake dampers and the return air dampers to provide a mixture which yields the desired supply air temperature. This mode of operation is indicated by the higher air change rates at temperature differences above 5°C which decrease as the indoor-outdoor temperature difference increases. As the outdoor air gets cooler, less air is required to cool the building return air to the desired supply air temperature. When the outdoor air is below a certain temperature, the economizer returns to the minimum outdoor air intake condition to protect the HVAC equipment from freezing and to avoid the need to heat too much outdoor air. Not all of the variation in ventilation rate is due to the changing of damper positions; some of the variation is due to the maintenance of the supply static pressure requirement of the HVAC system. It is interesting to note that the minimum ventilation rate under cold outdoor conditions is higher than the minimum measured during warm weather. The exact cause for this difference has not been determined, but it may be due to increased air infiltration through the building envelope due to the larger stack-driven pressure differences during colder weather. Pressure testing of the building envelope showed that the building was quite leaky, supporting this explanation [Persily et al. 1991].

Some of the measured air change rates, particularly those during warm weather minimum outdoor air intake operation, are somewhat below the recommendation of 10 L/s (20 cfm) per person from ASHRAE Standard 62-1989, which as previously discussed corresponds to about 0.7 ach in an office building. As previously discussed, the building's minimum design ventilation rate is approximately 0.8 ach. Figure 7 shows that many of the lower ventilation rate measurements are also below the design minimum ventilation rate. In comparison to other office buildings, the range of ventilation rate data is similar to that obtained in other modern office buildings [Persily et al. 1989].

4.2 Radon

Radon levels were measured in the building in August 1990, June 1991 and January 1992 using charcoal canisters obtained from a private company that performs radon testing. The charcoal canisters are metal containers, about 100 mm (4 in) in diameter and 25 mm (1 in) deep, that contain activated charcoal. The design of the canister is similar to that developed at the U.S. Department of Energy. The canisters are opened at the sample location and set out for a period of about three days. Radon is collected on the charcoal during the sample period, at the end of which the canisters are sealed. The sealed canisters were returned to the commercial laboratory for analysis based on gamma ray detection of trapped radon progeny in equilibrium with radon in the canister. The laboratory participates in the EPA Radon/Radon Progeny Measurement Proficiency Program and closely follows procedures recommended by EPA for radon measurements with charcoal canisters. The minimum detectable radon concentration for these canisters is 0.4 pCi/L, and the accuracy of the measurements is about 20%.

Thirty canisters were used in each assessment, including duplicates and blanks. The canisters were deployed on all seven levels of the building, and the individual sample locations are given in Table 2. The column designations in the table refer to the building floor plans. One location on the second floor of the old building, the GSA Field Office (Room 2015), was also monitored. While radon generally enters a building through the soil, it is important to monitor radon concentrations at all levels of the building including the upper floors when assessing a multi-story building. Air and radon can move through a building through vertical shafts such as elevators and stairways as well as chases associated with the ventilation, plumbing and electrical systems. Particularly under heating conditions, it is possible for air to enter such shafts on lower floors and to flow from these shafts into the occupied space on upper floors. In addition to airflows induced by temperature differences, air can flow into and out of these shafts due to the effects of the operation of the mechanical ventilation system. Depending on the site at which radon enters a building, the proximity of such vertical shafts, and the magnitude and direction of the relevant pressure differences, radon concentrations could be higher on the upper levels of a building than on the lower levels. At the time of the August 1990 measurements the building was unoccupied, the air handlers were operating during the day with no outdoor air intake and were not operating at night. The tracer gas measuring system was not yet in operation, so the building air change rates are not available for this period. During the June

1991 measurements the building was almost fully occupied and the HVAC system was operating normally. Whole building ventilation rates for the periods of radon monitoring in June 1991 and January 1992 were on the order of 0.5 and 1.5 ach respectively. The lower concentrations measured in January 1992 can not be exclusively attributed to either a higher air change rate or a lower radon entry rate. Since the measurements conducted in January 1992 were made at lower outdoor air temperatures, the radon entry rate into the building could have been larger due to larger stack pressures. However, no independent assessment was made of the radon entry rate or the pressure across the subbasement floor.

Table 2 shows the measured radon concentrations for each of the locations tested for the three sample periods. Samples designated as BLANK were deployed at selected sample locations, but were not opened during the sampling period. Three such blanks were included in the thirty samples, and at six of the remaining locations duplicate samples were taken. The highest levels, between 1 and 2 pCi/L, were all on the B2 level for all three sets of measurements. All of the other measured concentrations were not significantly different from the minimum detectable level of 0.4 pCi/L. Those duplicates with measurable concentrations agreed within the expected range, and all blanks were below the minimum detectable level. The results of the first two tests were identical with the exception of a slightly lower concentration in the stairwell on level B2 during the June 1991 test period.

ASHRAE Standard 62-1989 gives a guideline radon concentration of 0.027 working levels, which is approximately equivalent to 5 pCi/L. The EPA action level for homes is 4 pCi/L, i.e., some action should be taken to reduce radon concentrations in homes with concentrations above 4 pCi/L. The measured radon concentrations in the Overland Building were low compared to both of the guidelines at the time of these measurements. It is possible that under other conditions of weather and ventilation system operation the radon concentrations could be different.

Sample Location	Level	Aug-90 (pCi/L)	Jun-91 (pCi/L)	Feb-91 (pCi/L)
Stairwell by Room B277	B2	1.9	0.8	0.4
Stairwell by Room B277	B2	1.7	0.6	0.6
Outside Freight Elevator	B2	1.4	1.6	0.4
Mechanical Room B277	B2	1.1	1	0.6
Mechanical Room B277	B2	0.8	1.4	<0.4
Mechanical Room B277 - BLANK	B2	<0.4	<0.4	<0.4
Column P7	B2	1.8	---	0.4
Column P12	B2	---	1.6	<0.4
Column N14	B1	<0.4	<0.4	<0.4
Outside Freight Elevator	B1	<0.4	<0.4	<0.4
Lounge, Room B153	B1	<0.4	<0.4	<0.4
Column W20	B1	<0.4	<0.4	0.4
Column W20	B1	<0.4	<0.4	<0.4
Meeting Hall A	1	<0.4	---	---
Hall outside of Architects Office	1	---	<0.4	<0.4
Outside Freight Elevator	1	<0.4	<0.4	<0.4
GSA Office in Old Building	1	<0.4	<0.4	<0.4
Guards' Desk	1	<0.4	<0.4	<0.4
Column G13	2	<0.4	<0.4	0.5
Column G13 - BLANK	2	<0.4	<0.4	<0.4
Outside West Mechanical Room	2	<0.4	<0.4	<0.4
Outside West Mechanical Room	2	<0.4	<0.4	<0.4
Room 373, Column G9	3	<0.4	<0.4	<0.4
Outside Freight Elevator	3	<0.4	<0.4	0.5
Outside Freight Elevator	4	<0.4	<0.4	<0.4
Outside East Mechanical Room	4	0.6	<0.4	<0.4
Column R22	4	<0.4	<0.4	0.4
Column K2	5	<0.4	<0.4	0.5
Column K2	5	0.6	<0.4	<0.4
Column K2 - BLANK	5	<0.4	<0.4	<0.4
East Mechanical Room	5	0.6	<0.4	<0.4
Column R22	5	<0.4	<0.4	0.4

Table 2 - Measured Radon Concentrations

4.3 Formaldehyde

Formaldehyde levels were measured in the building over six day periods in August 1990 and June 1991 using passive monitors. These monitors were obtained from a private company that also provided analysis of the monitors. The monitors consist of a capped glass vial with a sodium bisulfite-treated filter on the bottom. The cap is removed when the monitor is deployed at a sampling site and formaldehyde is absorbed by the treated filter over the test period of five to seven days, at the end of which the vial is recapped. The vial is returned to the laboratory for analysis of the formaldehyde concentration by the chromotropic acid colorimetric method. The minimum detection limit of the monitor, as given by the manufacturer, is 0.01 ppm, and the optimum range of exposure is 0.025 to 1.0 ppm with a precision of 15%. At the time of the August 1990 measurements the building was unoccupied and the air handlers were operating during the day with no outdoor air intake and were not operating at night. The tracer gas measuring system was not yet in operation at the time of these tests, so the building air change rates are not available for this set of measurements. At the time of these measurements, the building furnishings had been installed from one to four months. During the June 1991 measurements, the building was almost fully occupied and the HVAC system was operating on a full occupancy schedule, and building ventilation rates were on the order of 0.5 ach.

Twenty-nine monitors were used in the August 1990 assessment, including duplicates and blanks, and 30 were used in the June 1991 assessment. The monitors were deployed on all seven levels of the building, and the individual sample locations are given in Table 3 along with the measured concentrations in ppm. Several monitors were deployed in the building's conference rooms which contained a high loading of tables made from pressed-wood products. Samples designated as BLANK had monitors deployed at the particular sample location, but they were not opened during the sampling period. Three blanks were included in the twenty-nine samples, and at three or four of the remaining locations duplicate samples were taken. The concentrations of duplicates samples agreed within the stated precision, and no blanks were significantly different from a concentration of 0 ppm.

ASHRAE Standard 62-1989 does not provide a guideline formaldehyde concentration but in the appendix states that concentrations above 0.1 ppm have been identified as being of concern and concentrations below 0.05 ppm have been reported to be of limited or no concern. Therefore concentrations between 0.05 and 0.10 ppm can be interpreted as still being of some concern. Guidelines for industrial environments are 1 ppm or higher, but the applicability of these guidelines to office environments is not universally accepted.

For the August 1990 measurements, all of the measured formaldehyde concentrations were below 0.1 ppm and several are below 0.05 ppm. Therefore, the measured formaldehyde levels in this building were not above the level of concern contained in the appendices of ASHRAE Standard 62-1989, although the concentrations between 0.05 and 0.10 ppm can still be interpreted as being of some concern.

All of the concentrations measured in June 1991 were less than 0.05 ppm except for one. The June 1991 concentrations were lower than the previous measurements with only a few exceptions. These measurements seem to indicate that the operation of the building ventilation system with outdoor air intake generally reduced the formaldehyde levels in the building below the values reported during the preoccupancy period in August 1990. Also, aging of materials in the building between the two tests could have reduced emission rates. In both sets of measurements the formaldehyde concentrations in the conference rooms were not significantly different from the concentrations elsewhere in the building.

Sample Location	Level	Aug-90 (ppm)	Jun-91 (ppm)
Room 599 - Conference Room	5	0.07	0.03
Room 599 - Conference Room	5	0.07	0.02
Room 510 - Conference Room	5	0.07	0.02
Column G15	5	0.07	0.02
Column R22	5	0.07	0.02
Room 499 - Conference Room	4	0.06	0.04
Room 499 - BLANK	4	0.01	<0.01
Room 410 - Conference Room	4	0.06	0.04
Column J22	4	0.06	0.04
Room 399 - Conference Room	3	0.05	0.03
Room 310 - Conference Room	3	0.04	0.02
Room 310 - Conference Room	3	0.04	0.02
Column R22	3	0.07	0.03
Column G15	3	0.06	0.02
Room 210 - Conference Room	2	0.04	0.06
Room 210 - BLANK	2	0.01	<0.01
Column P22	2	0.03	0.04
Column G15	2	0.02	0.04
Meeting Hall B	1	0.04	0.03
Room 145 - Conference Room	1	0.03	0.03
Room 145 - Conference Room	1	0.03	0.03
Column P22	1	0.04	0.04
Column S17	B1	0.03	0.02
Column N14	B1	0.03	0.02
Column N14 - BLANK	B1	0.00	<0.01
Room 168	B1	0.03	0.02
Computer Room	B2	0.06	0.03
Column J22	B2	----	0.02
Column J22	B2	0.07	0.03
Hall by Column P7	B2	0.06	0.03

Table 3 - Measured Formaldehyde Concentrations

4.4 Carbon Dioxide and Carbon Monoxide

The indoor and outdoor concentrations of carbon dioxide (CO_2) and carbon monoxide (CO) were monitored in the building starting in November 1990; however, the building was not fully occupied until May 1991. CO_2 and CO concentrations were monitored continuously using an automated system that measured the CO_2 and CO concentrations at nine indoor locations and one outdoor location every 10 minutes. Initially the indoor sampling locations included the return air from each of the 7 levels, the atrium return, and a space average sample consisting of a mixture of air from one sample location on each of the four upper levels of the building. The outdoor air sample is located outside the fifth level of the building. At the end of August 1991, the return air samples of the two basement levels, the atrium and the space average were changed in order to monitor concentrations at individual space locations on the four upper levels of the building. All four space locations were located at column W15.

4.4.1 Carbon Dioxide

The major indoor source of CO_2 in this building is people; therefore, the data collected under partially occupied conditions were not particularly revealing. Daily maximum CO_2 concentrations were in the 400 to 500 ppm range during this period, with the higher concentrations on the partially occupied B1 and B2 levels. Starting early in December, people began moving into the upper levels of the building, and the daily maximum CO_2 concentrations ranged from 600 to as high as 800 ppm on some of the floors. During these measurements, the building ventilation system was being operated with outdoor air intake, though its operation may not reflect the design operation under full occupancy.

Figure 8 shows some of the CO_2 data collected under partial occupancy during December 1990. The middle graph shows the outdoor and indoor concentrations of CO_2. The vertical lines on the horizontal axis of the graphs correspond to midnight. Some spikes in the CO_2 concentration occurred in the evening, with these maxima occurring as late as midnight. The fact that these spikes occurred so late in the day argues against their being caused by evening rush hour motor vehicle exhaust. An examination of these data indicate a strong association between the peaks and the wind direction. The lower graph in Figure 8 contains the measured wind direction on the roof of the building. There is a strong association between the occurrence of these peaks and winds blowing from the north (360 degrees) to the northwest (315 degrees). Winds blowing from a more westerly direction, less than 315 degrees, are not associated with such spikes. The cause of these outdoor peaks is unknown, but a point source to the north-northwest of the building is suspected.

CO_2 measurements under full occupancy conditions revealed daily maximum values between 400 and 1100 ppm in the returns and between 400 and 1400 ppm in the space. These values are based on the highest single reading for each non-holiday weekday. Typically, instantaneous daily peak values in the returns ranged from 450 to 750 ppm with an average value of 600 ppm, and in the space they ranged from 500 to 850 ppm with an average value of 630 ppm. On a few isolated occasions the return concentrations were as high as 1100 ppm and the space as high as 1400 ppm. These relatively high concentrations occurred on days that the ventilation system was not operating according to design, i.e., not all of the air handlers were operating.

Hourly average CO_2 concentrations were also determined for each sample location.

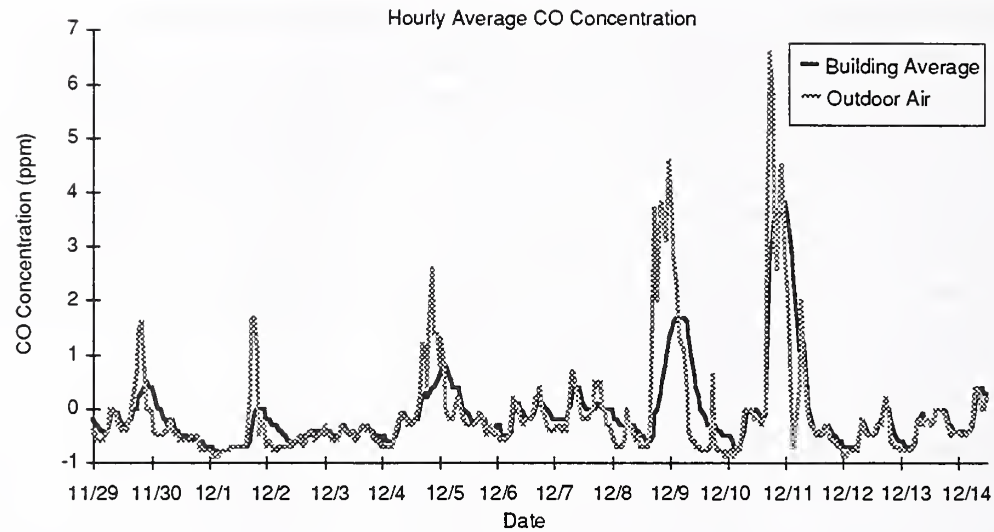
Daily maxima of the hourly average concentrations typically ranged from 450 to 700 ppm in the returns and from 500 to 800 ppm in the space. As was the case with the instantaneous measurements, there were a few isolated occasions when hourly average concentrations reached levels as high as 1000 ppm in a return and 1100 ppm at a space location.

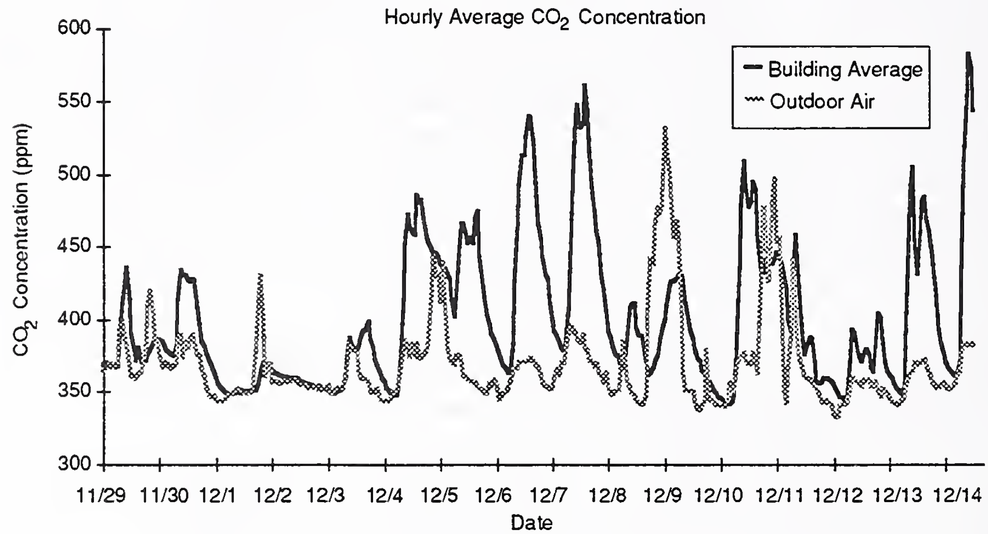
Figure 9 shows CO_2 data collected under full occupancy in July 1991. This data indicates a typical daily pattern in which peaks occur before and after the lunch break. There are also some outdoor spikes occurring around midnight, as observed during the early occupancy sampling period. The wind direction monitoring system was not working during this period so the correlation between these peaks and wind direction could not be made, although it is still suspected to exist.

4.4.2 Carbon Monoxide

There are no known sources of carbon monoxide in the building, e.g., an underground garage. The measurements to date indicate fairly low CO concentrations in the building during the daytime that essentially track the outdoor levels, generally in the range of 0 to 2 ppm. The National Ambient Air Quality Standards contain a maximum for an eight-hour average CO concentration of 9 ppm. ASHRAE Standard 62-1989 contains no recommendation for maximum CO levels, but reports that concentrations of 26 ppm have been suggested as a level of concern. Thus far the average indoor levels measured in The Federal Records Center are well below both of these recommendations

Figures 8 and 9 show data which were collected during two weeks of December 1990 and July 1991 respectively. The upper graphs show the hourly average outdoor and indoor CO concentrations. The measurement accuracy of these low CO concentrations is on the order of 1 ppm, leading to values below zero. The relative concentrations between indoors and outdoors are more accurate and of greater interest. The indoor CO concentration is based on a mixture of four air sample locations located within the occupied space on Levels 2 through 5. The outdoor levels generally follow a fairly typical pattern based on rush hour motor vehicle traffic; the maximum levels associated with traffic being on the order of 1 to 2 ppm. However, a number of outdoor CO spikes have been identified on selected evenings. These spikes are also associated with peaks in the outdoor CO_2 concentration ranging from 400 to 500 ppm. During the early occupancy period these evening spikes were as high as 10 ppm leading to indoor values of approximately 7 ppm, but so far during the full occupancy measurements the highest indoor and outdoor peaks have been around 3 ppm. The fact that these spikes occur late in the evening, with maxima occurring as late as midnight, argues against their being caused by evening rush hour motor vehicle exhaust. An examination of the early occupancy data indicates a strong association between the peaks and the wind direction. The lower graph in Figure 8 shows the wind direction as measured on the roof of the building. There is a strong association between the occurrence of these peaks and winds blowing from the north (360 degrees) to the northwest (315 degrees). Winds blowing from a more westerly direction, less than 315 degrees, are not associated with such spikes. The cause of these outdoor peaks is unknown, but a point source to the north-northwest of the building is suspected. As noted previously the wind direction monitoring system was not working during the full occupancy period so the correlation between these peaks and wind direction could not be made, although it is still suspected to exist.





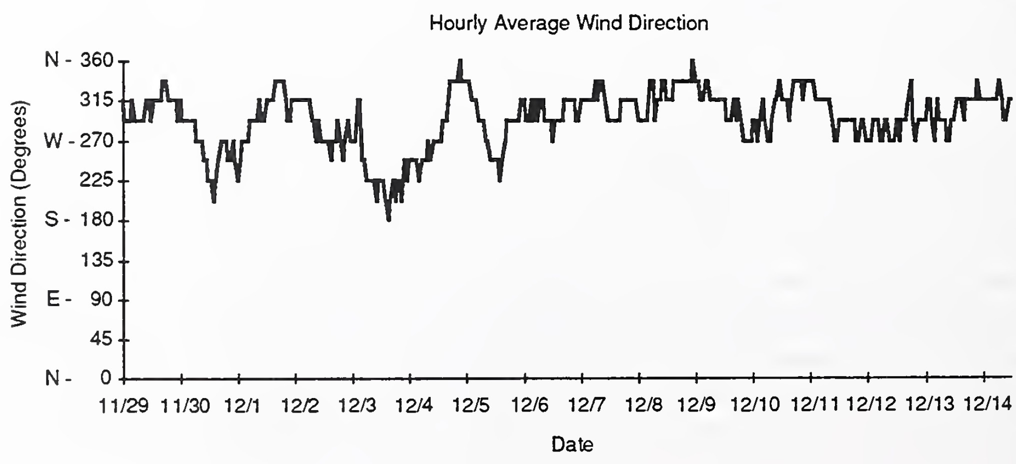


Figure 8 - CO, CO_2 and Wind Direction Data (partially occupied)

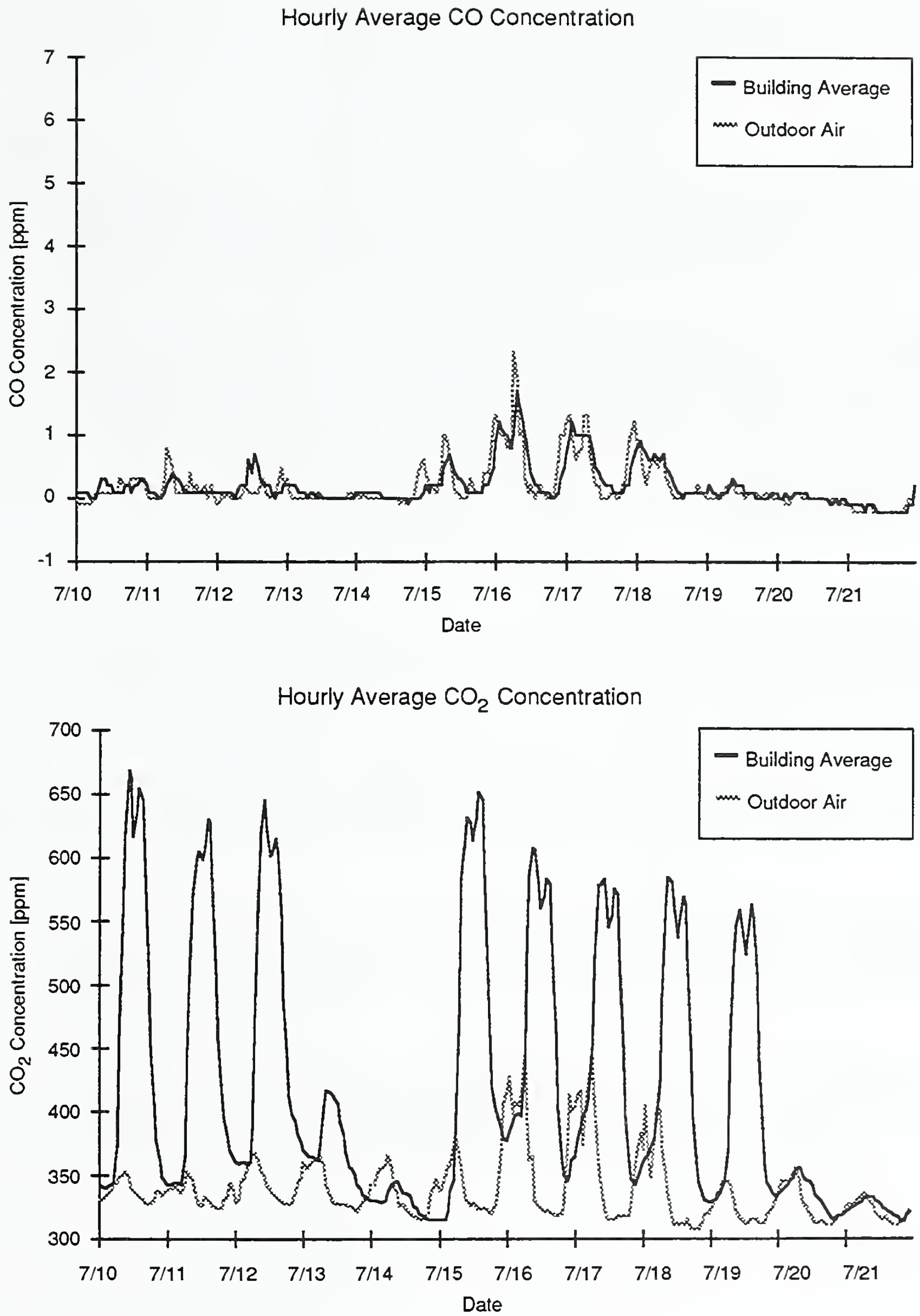


Figure 9 - CO and CO_2 Data (fully occupied)

5 Summary

This report has described the thermal and environmental evaluation program being conducted in the new Federal Records Center in Overland Missouri, including the results to date of the early occupancy testing. These results include the following findings. Building ventilation rates ranged from 0.3 to 2.6 ach depending on the inside-outside temperature difference. The minimum ventilation rates were generally about 0.5 ach which is below the 0.8 ach minimum design ventilation rate of this building. These minimum ventilation rates were also below the recommended minimum in ASHRAE Standard 62-1989 of 10 L/s (20 cfm) per person which is equivalent to about 0.7 ach. Radon measurements in the building revealed levels of 2 pCi/L or less on the B2 level, with concentrations less than or equal to 0.4 pCi/L on all other levels of the building. The formaldehyde measurements in the building ranged from 0.03 to 0.07 ppm, below 0.1 ppm but above some levels of concern. Daily peak CO_2 levels were typically between 500 and 800 ppm with a few instances of significantly higher concentrations when the ventilation system was not operating according to design, i.e. some of the air handlers were off. Several episodes have been observed when the outdoor levels of CO_2 and CO have increased significantly in the evening, raising the indoor levels as well.

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11. ABSTRACT (A 200-WORD OR LESS FACTUAL SUMMARY OF MOST SIGNIFICANT INFORMATION. IF DOCUMENT INCLUDES A SIGNIFICANT BIBLIOGRAPHY OR LITERATURE SURVEY, MENTION IT HERE.)

The National Institute of Standards and Technology (NIST) is studying the thermal and environmental performance of new federal office buildings for the Public Buildings Service of the General Services Administration (GSA). This project involves long-term performance monitoring starting before occupancy and extending into early occupancy in three new office buildings. The performance evaluation includes an assessment of the thermal integrity of the building envelope, long-term monitoring of ventilation system performance, and measurement of indoor levels of selected pollutants. This is the second report describing the study of the Federal Records Center in Overland, Missouri, and this report presents measurement results from preoccupancy to full occupancy. Ventilation rates ranged from 0.3 to 2.6 air changes per hour (ach) with the minimum levels being below both the building design value of 0.8 ach and the recommended minimum in ASHRAE Standard 62-1989. The measured radon concentrations were 2 pCi/L or less on the sub-basement level, and less than or equal to 0.4 pCi/L on the other levels. Formaldehyde concentrations ranged from 0.03 to 0.07 ppm. Daily peak levels of carbon dioxide in the building were typically between 500 and 800 ppm. Maximum carbon monoxide levels were typically on the order of 1 to 2 ppm, essentially tracking outdoor levels induced by automobile traffic. There have been some occasions of elevated carbon monoxide and carbon dioxide levels in the building associated with unexplained episodic increases in the outdoor levels.

12. KEY WORDS (6 TO 12 ENTRIES; ALPHABETICAL ORDER; CAPITALIZE ONLY PROPER NAMES; AND SEPARATE KEY WORDS BY SEMICOLONS)

carbon dioxide, carbon monoxide, formaldehyde, indoor air quality, office building, radon, ventilation

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