NISTIR 4634

Preliminary Results of the Environmental Evaluation of the Federal Records Center in Overland Missouri

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Research Laboratory
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Public Buildings Service
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Preliminary Results of the 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 both before occupancy and during 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 the measurement of indoor levels of selected pollutants. This report describes the effort being conducted in the second of the three buildings, the Federal Records Center in Overland Missouri, and presents preliminary measurement results from the building. The infrared thermographic inspection of the Overland Building did not reveal any significant thermal defects in the building envelope, though the existence of air leakage and thermal bridging was noted. The whole building pressurization test showed that the building is quite leaky compared to other modern office buildings. The measured radon concentrations were 2 pCi/L or less on the B2 level, and less than or equal to 0.5 pCi/L on the other levels. Formaldehyde concentrations ranged from 0.03 to 0.07 ppm, below the 0.1 ppm guideline but above some levels of concern. The measured levels of volatile organic compounds were similar to those observed in other new office buildings, and the impact of building furnishings and construction activities on the VOC levels were noted. The carbon dioxide levels in the building have generally been low, as would be expected in a building with low levels of occupancy.

Key words: building diagnostics; building performance; carbon dioxide; carbon monoxide; formaldehyde; indoor air quality; office building; radon; ventilation; volatile organic compounds

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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 with special emphasis on environmental control, building thermal performance and occupant productivity. These areas of interest have been pursued in the development of several new construction projects including the Portland East Federal Building in Portland, Oregon, the Federal Records Center in Overland, Missouri and the Long Beach Federal Building in California. The building systems and features within these structures are intended to offer enhanced capabilities over conventional construction. In order to verify the accomplishment of these performance objectives, the actual levels of performance in the buildings need to be quantified through diagnostic evaluations.

Previous studies of federal office buildings have shown the value of applying diagnostic techniques to assess building performance. These diagnostic evaluations have been initiated in buildings with excessive energy consumption, poor thermal comfort and indoor air quality complaints, and were generally successful in identifying the sources of these problems [Grot 1985 and 1989]. While building diagnostics are generally valuable in addressing such situations, their value is increased if applied early in a building project when the opportunity exists to correct some of these defects more easily. 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 (formerly the Center for Building Technology) at the National Institute of Standards and Technology to evaluate the thermal and environmental performance of the three office buildings referenced above. 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 1989] and is now being applied in the evaluation of the Overland and Long Beach Buildings.

The goals of the Overland Federal Records Center study are to evaluate the performance of the thermal envelope and the ventilation system and to conduct an assessment of air quality within the building. Indoor air quality can be of particular concern in new buildings due to pollutant emissions from new building materials, construction and move-in activities and inadequate performance of the mechanical ventilation systems as they are being "debugged." The actual air quality impacts of these issues have not yet been adequately studied in new buildings, and the long-term, intensive evaluation being conducted in the GSA advanced-technology office buildings is making significant contributions. It is of particular interest in the Overland Building that the building occupants will be moving from an existing facility that adjoins the new building. After the occupants move from the old building to the new building, the old building will be renovated, and the potential exists for deterioration of air quality of the new building due to these construction activities. The evaluation of the new Federal Records Center will enable the study of this issue and the effects of new construction materials and furnishings, occupant activities, outdoor air quality and ventilation system performance on the indoor air quality of the new building.

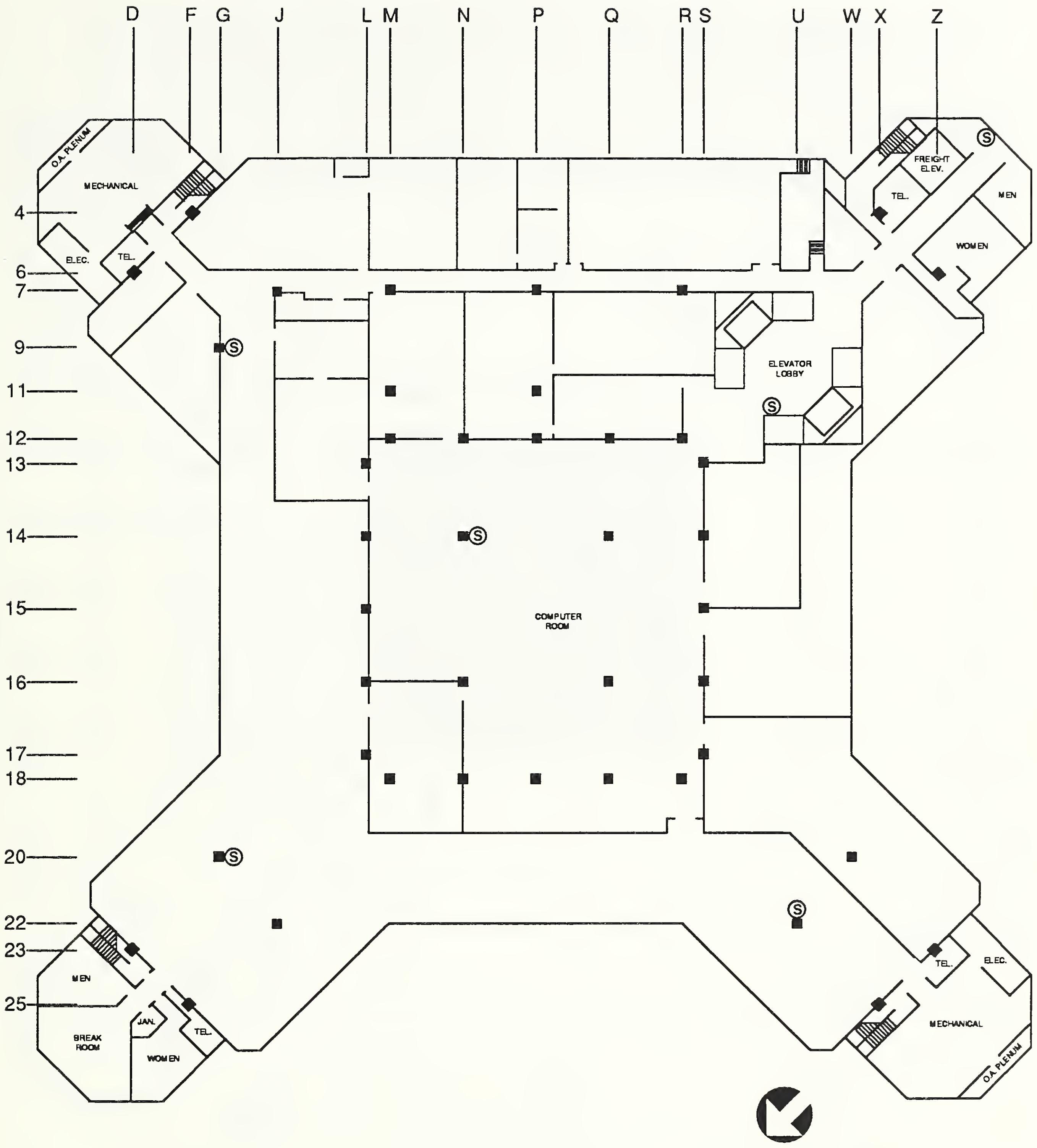
This report describes the diagnostic center installation in the Overland Federal Records Center and presents results of preoccupancy and early occupancy testing. These tests include the measurement of the indoor levels of radon, carbon dioxide, carbon monoxide, formaldehyde, and volatile organic compounds along with measurements of whole building air exchange rates and building envelope airtightness. An infrared inspection of the building was also conducted to evaluate the thermal integrity of the building envelope.

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 new FRC is shown in Figure 1. The building has a total floor area of approximately 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 large meeting hall that is two stories high, and there is a large computer facility located in the center of level B2. Floor plans for all seven floors are shown in Figures 2 through 8. The building is basically square, with a skylit atrium extending from the first floor to the roof. Stairwells are located in each corner of the building. Mechanical rooms are located in the east and west corners, and restrooms 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.

Figure 1 Photograph of Building

The building ventilation system is zoned horizontally with air handling equipment located in two mechanical rooms on each floor. There is no mechanical room in the west corner of the first floor where the main entrance to the building is located. The first floor west mechanical room is located on level B1 adjacent to the B1 west mechanical room. The mechanical room serving the atrium is also located on the B1 level as shown in the floor plan in Figure 3. A schematic of a typical mechanical room, located in the east and west corners, is shown in Figure 9. Each of these mechanical rooms 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 supply airflow rate capacity of 5.6 m^3/s (12,000 cfm), yielding a capacity of 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 for 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). In a typical mechanical room, 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 outdoor air 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 concerns 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 for spillage of supply air into the mechanical room.



Ⓢ = Sample Location

Figure 2 Level B2 Floor Plan

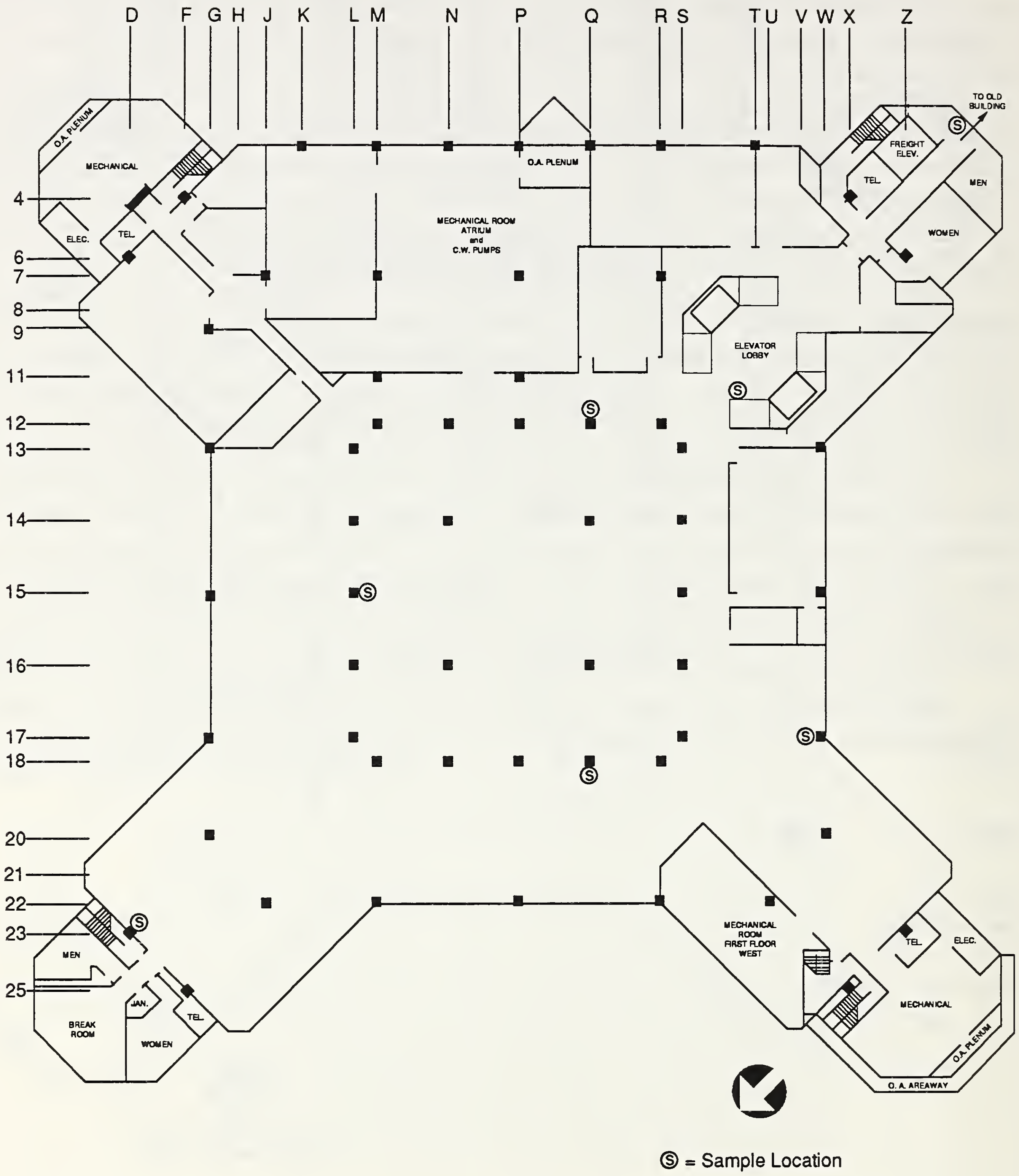


Figure 3 Level B1 Floor Plan

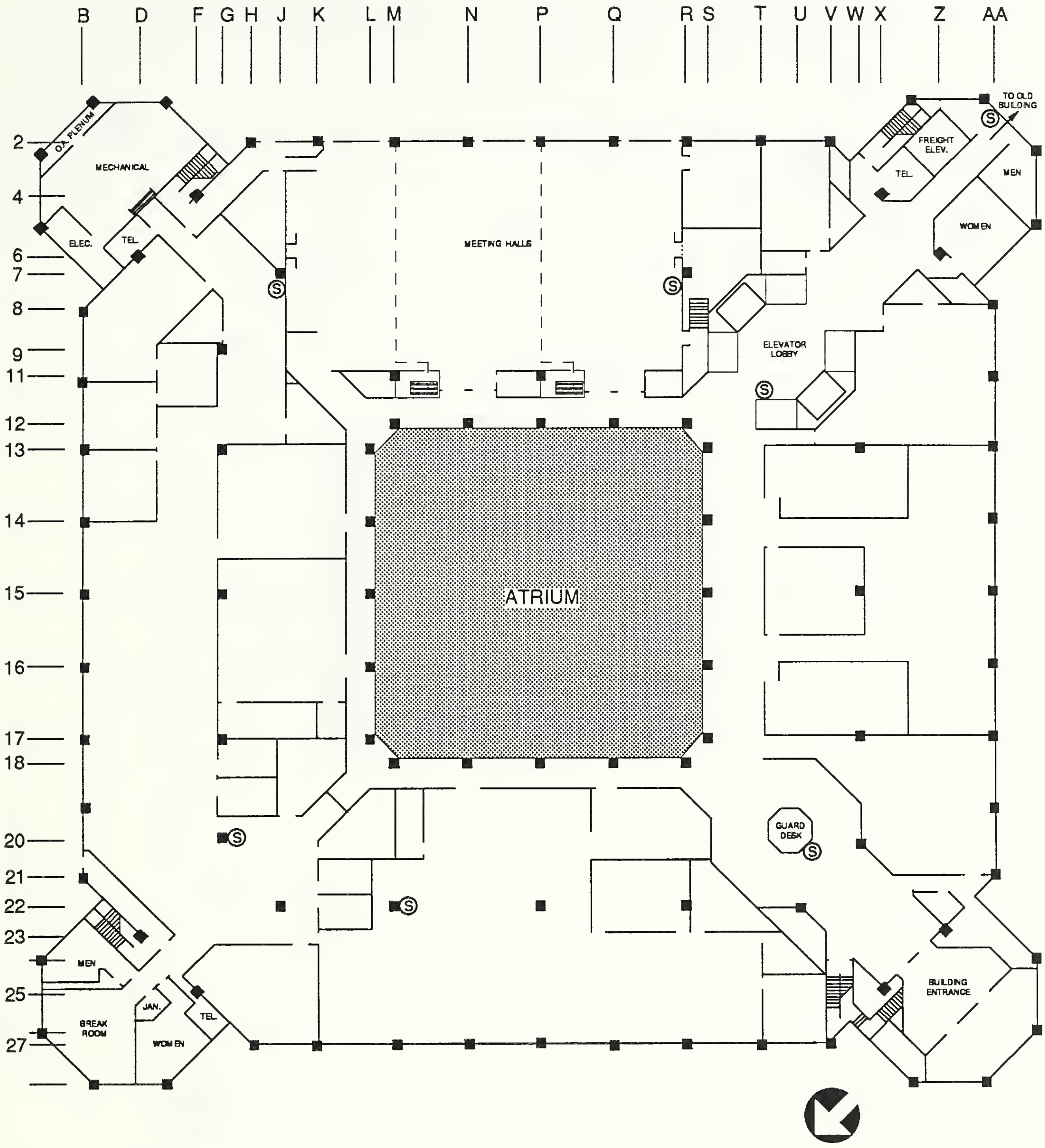


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Figure 4 Level 1 Floor Plan

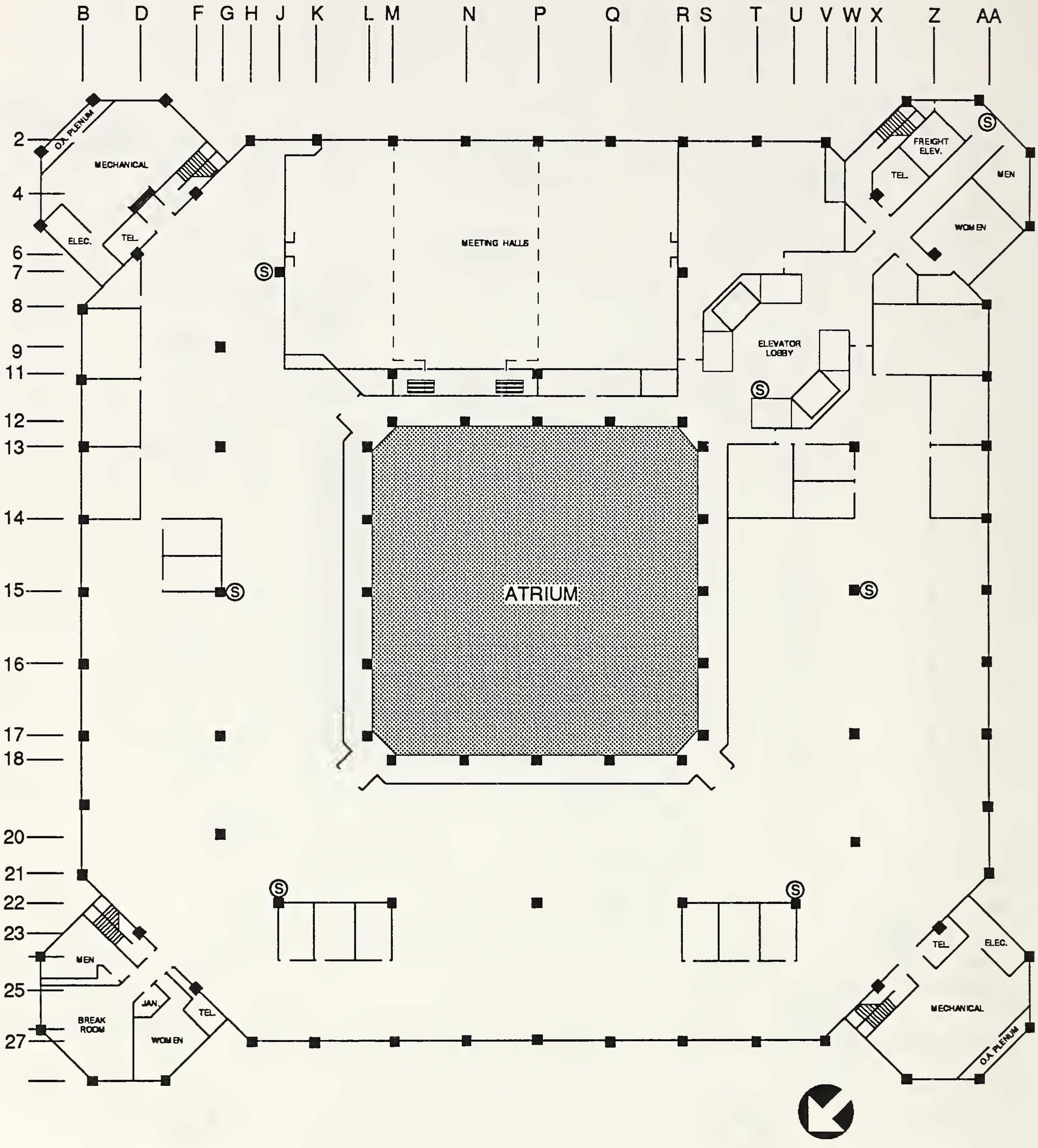

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Figure 5 Level 2 Floor Plan

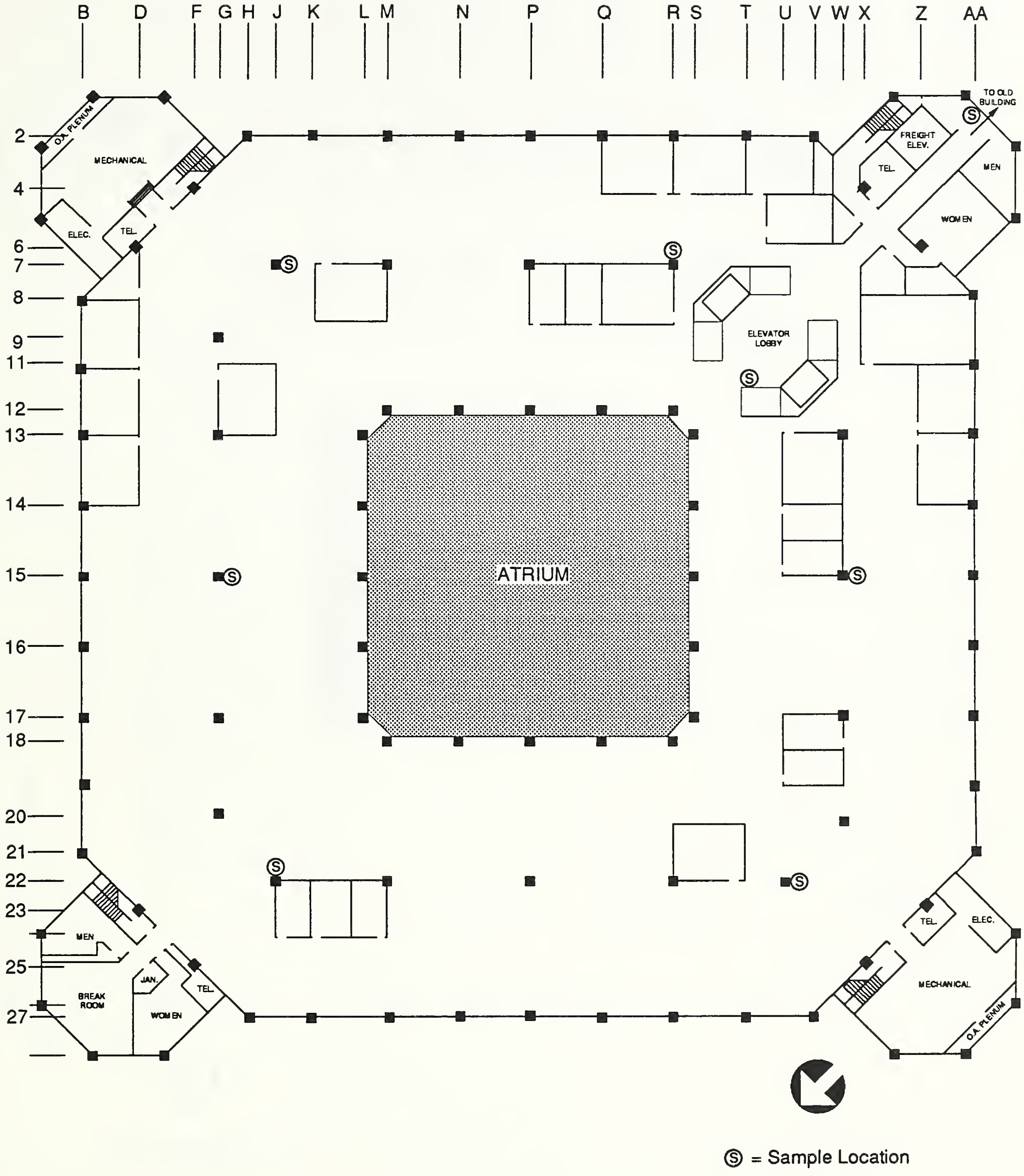


Figure 6 Level 3 Floor Plan

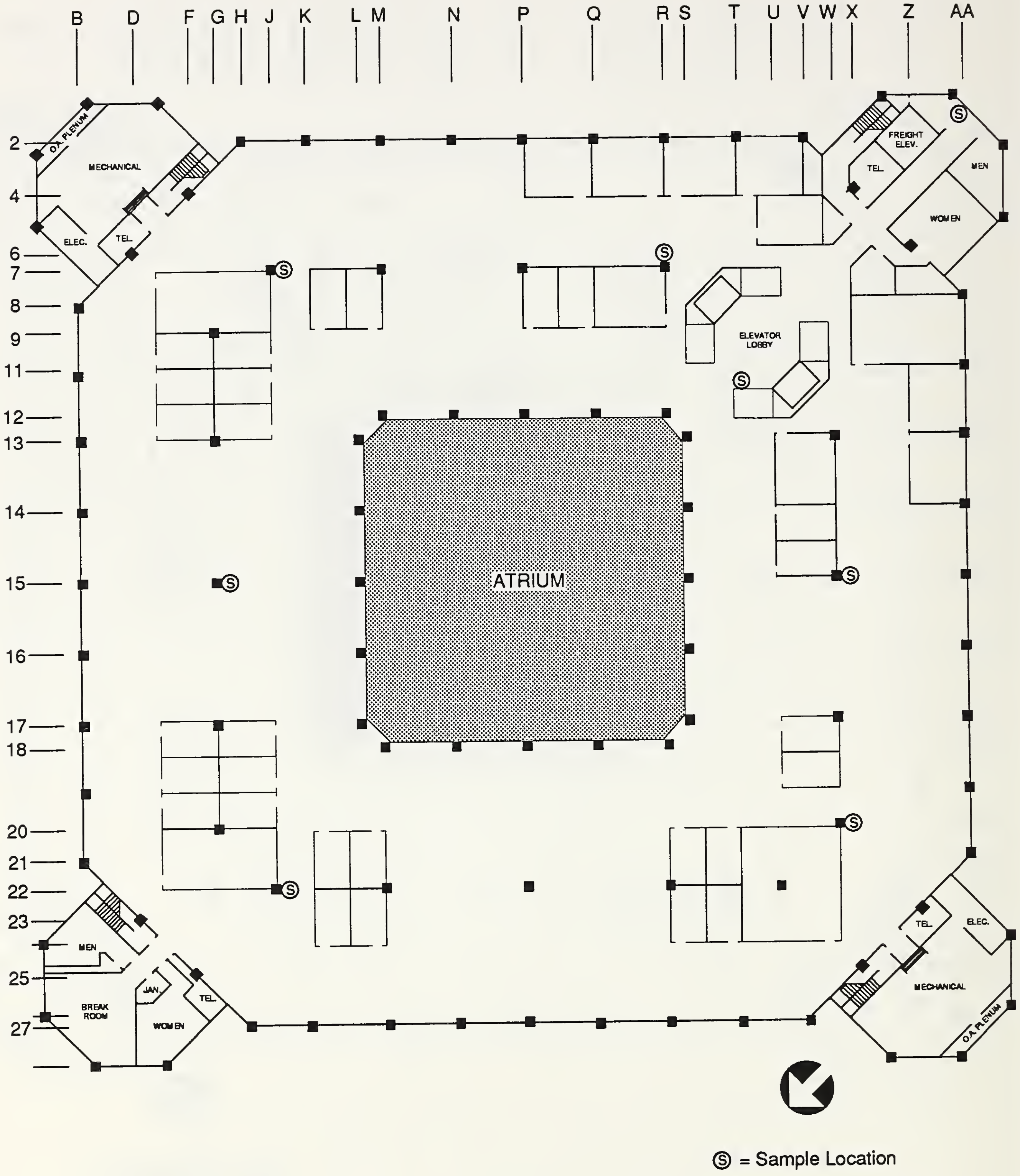
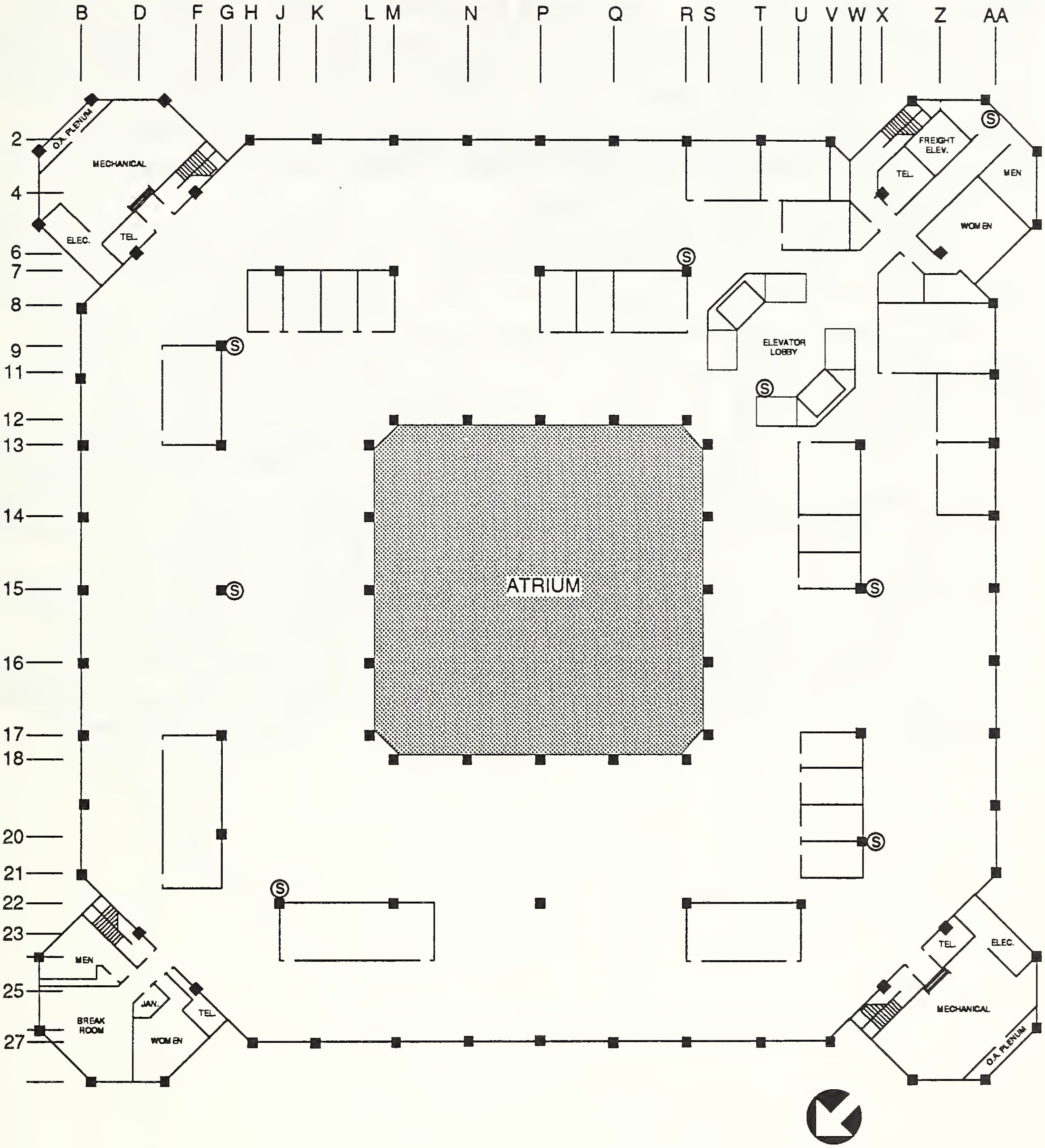


Figure 7 Level 4 Floor Plan



Ⓢ = Sample Location

Figure 8 Level 5 Floor Plan

The mechanical rooms serving the first floor west and the atrium are different from the typical mechanical rooms described previously. Both of these mechanical rooms are located on level B1. Schematics are shown in Figures 10 and 11. The air handling systems in these two mechanical rooms utilize return air fans to draw air from the occupied space through a return duct. Dampers modulate the return airflow rate to either the air handler or the relief air shaft. The atrium mechanical room has an additional air handler that brings in only outdoor air to be used in conjunction with the relief fans for smoke control in the event of a fire. There is also an exhaust fan to ventilate the atrium mechanical room itself.

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). The supply airflow rate capacity corresponds 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 occupancy density in the atrium is much lower than in office space, and therefore the ASHRAE recommendation would correspond to an air change rate that is well below 0.72 ach. Therefore, the minimum outdoor air intake rate specifications for all floors in the building are above the ASHRAE recommendation.

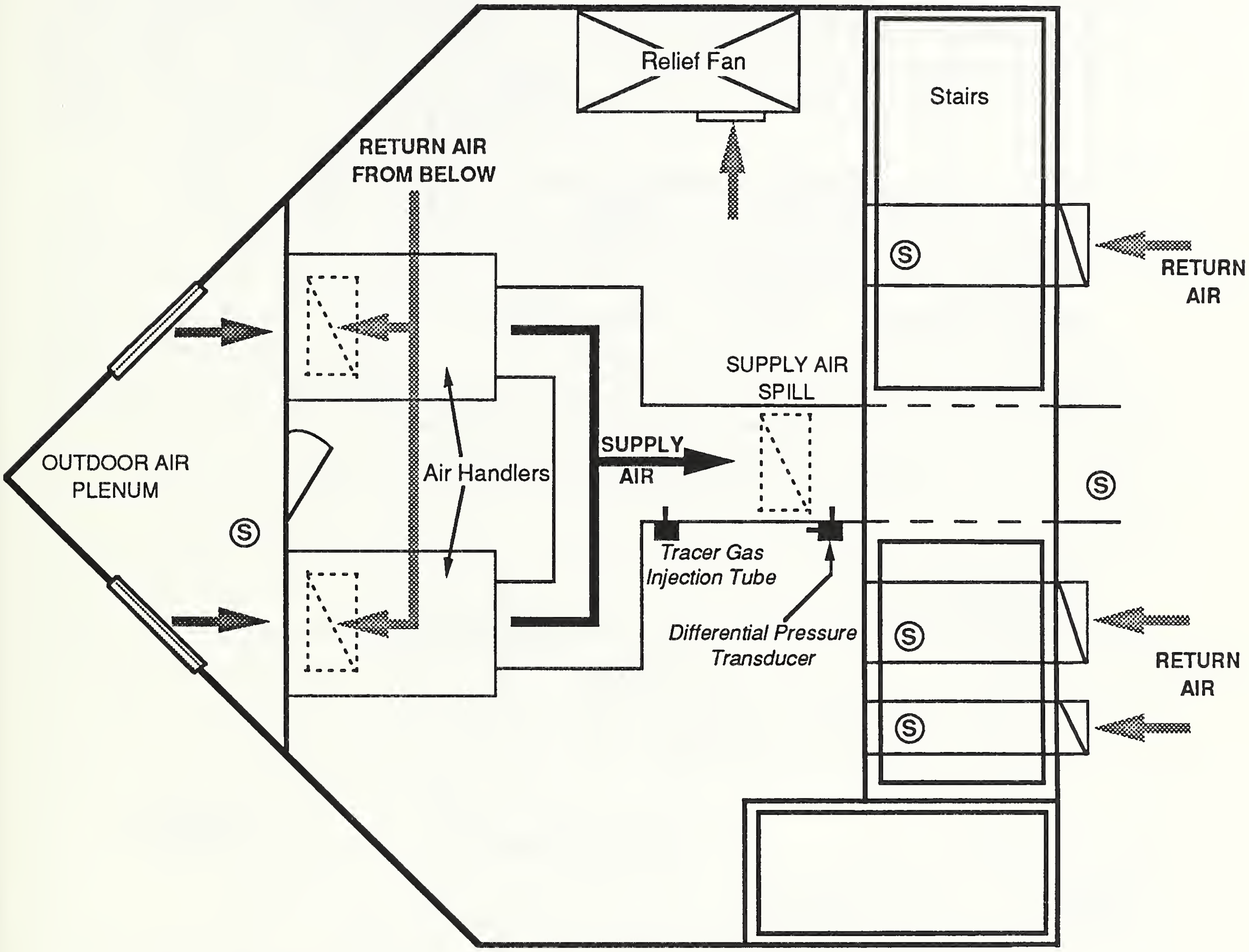


Figure 9 Schematic of Typical Mechanical Room

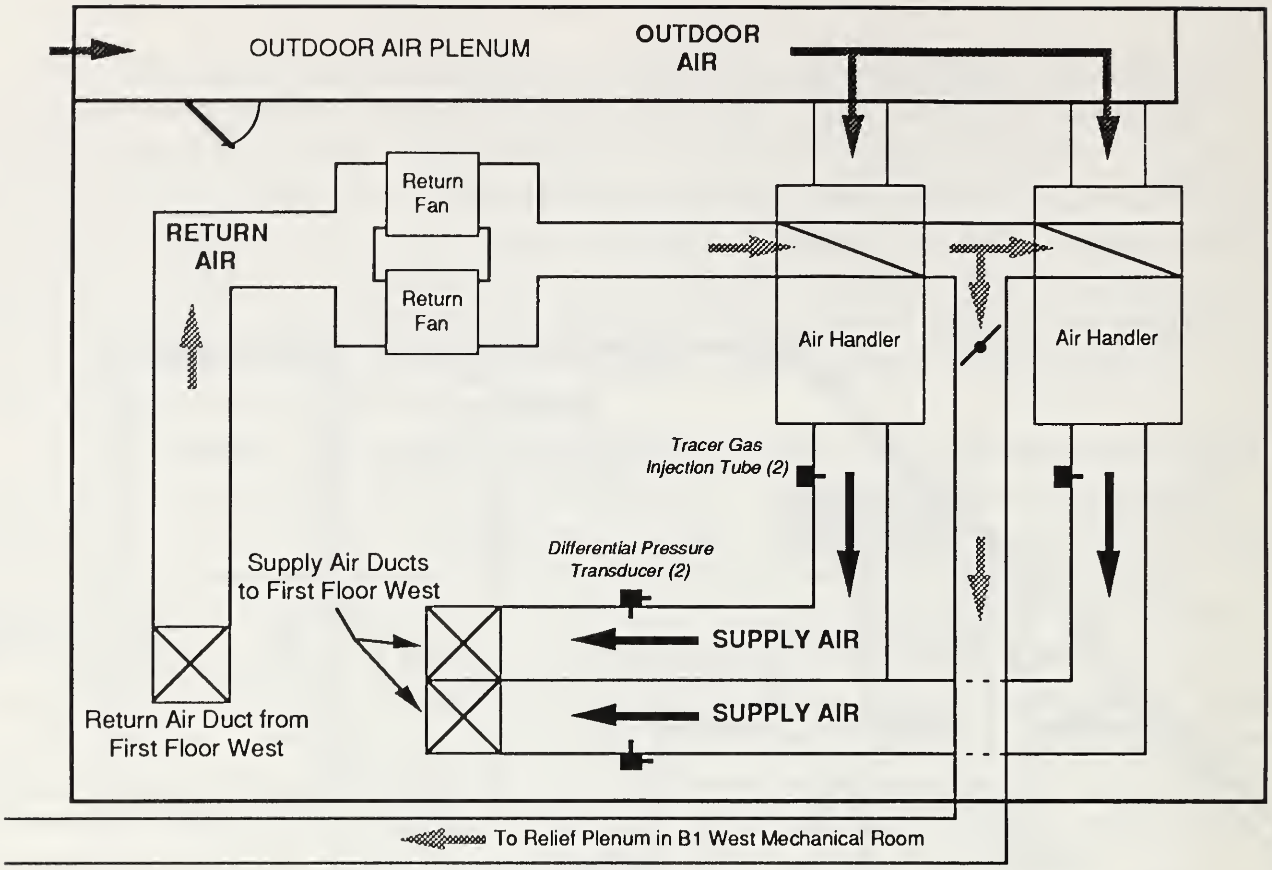


Figure 10 Schematic of Level 1 West Mechanical Room

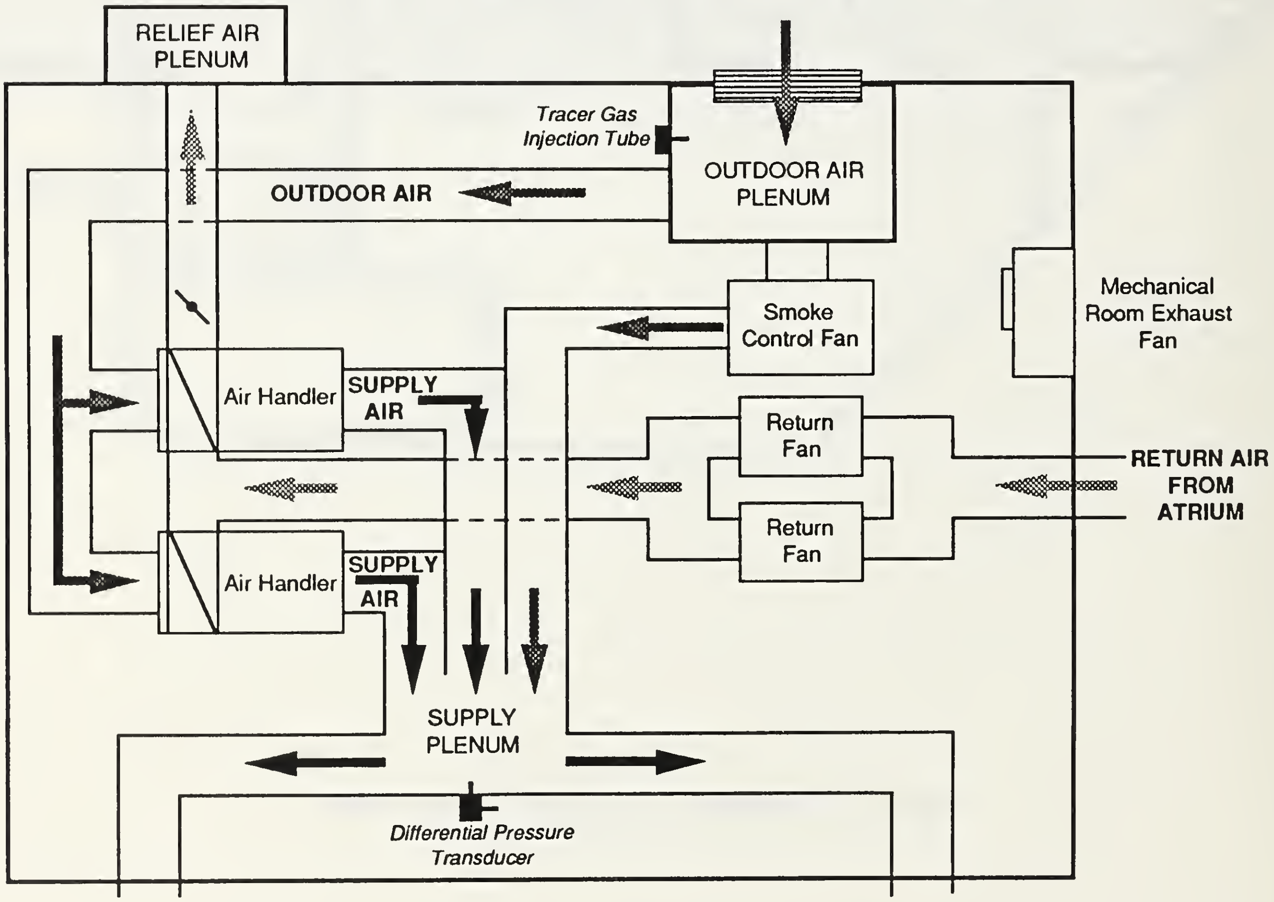


Figure 11 Schematic of Atrium Mechanical Room

3 Diagnostic Center Installation

This section of the report describes the diagnostic center used in the thermal and environmental evaluation of the building. This system 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. The monitoring systems employ a network of air sampling and tracer gas injection tubes and sensor wires running through the building and back to the diagnostic center (DC), where the majority of the monitoring and control equipment is located. A schematic of the DC is shown in Figure 12, and a photograph of the equipment in the DC is shown in Figure 13.

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 as shown in Figures 2 through 8. The sample points in the occupied space are located on the designated columns about 1.5 m (5 ft) above the floor and are covered by vented thermostat covers as shown in the photograph in Figure 14. One sample location on each floor employs a soft copper tube used for sampling particulates and volatile organic compounds. The return air sample points are located inside the mechanical rooms where the return air flows into the room (see Figure 9). 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 fan ducts come together. Outdoor air samples are taken through a tube that runs through the outdoor air intake plenum and extends approximately one foot 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 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 pumps run continuously at an airflow rate of about 0.03 m^3/s (0.5 cfm) 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 selected 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.

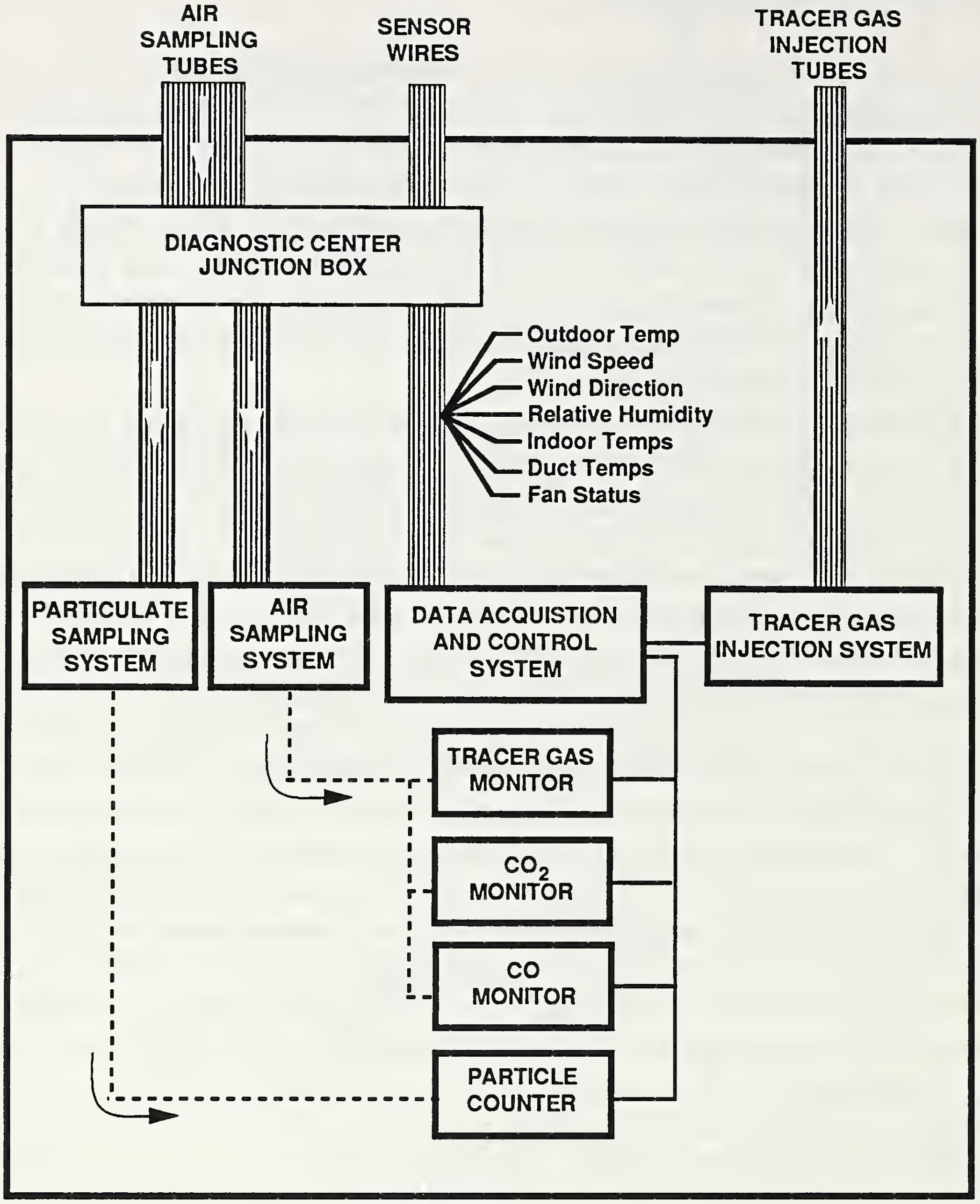


Figure 12 Schematic of Diagnostic Center

Figure 13 Photograph of Diagnostic Center Monitoring Equipment

Figure 14 Photograph of Occupied Space Air Sampling 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
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 Air Sample Locations

The diagnostic system monitors selected environmental conditions including up to 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% of the reading. 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 employing 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. 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 airstreams from the two air handlers come together (see Figure 9). Therefore, only one fan is required to be running to 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 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 split off into 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) OD nylon tube runs from the outlet of each flow meter to the supply air duct inside of each mechanical room as indicated in Figures 9 through 11. Two-conductor wires from the fan status pressures switches are wired to the injection panel such that tracer gas is injected into a supply duct only when an air handler in that mechanical room is running.

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 respirable particle counter.

The building air exchange rate is measured using the tracer gas decay technique [ASTM 1990], employing two automated air infiltration rate measurement systems and SF_6 as the tracer gas. Each system consists of a microcomputer-based data acquisition and control system and a gas chromatograph (GC) equipped with an electron capture detector capable of determining SF_6 concentrations over a range of about 5 to 300 parts per billion (ppb) with an accuracy of roughly 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 in order to obtain a uniform tracer gas 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 exchange 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 is operating are all 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 0.1 ppm. 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 via an RS-232 port at preselected time intervals. The RS-232 output is recorded by a microcomputer.

4 Measurement Techniques and Results

This section presents the measurement techniques used in the thermal envelope and indoor air quality evaluations in the Overland Building, as well as preliminary results. The thermal envelope evaluation has included an infrared thermographic inspection to qualitatively evaluate the thermal integrity of the building envelope, a whole building pressurization test to measure the envelope airtightness and tracer gas measurements of building air infiltration rates. The indoor air quality evaluation has included measurements of the concentrations of radon, formaldehyde, carbon dioxide, carbon monoxide, and volatile organic compounds and tracer gas measurements of building ventilation rates. The measurements reported on below were conducted before the building was fully occupied and before the building ventilation system was being operated as designed.

4.1 Thermal Envelope

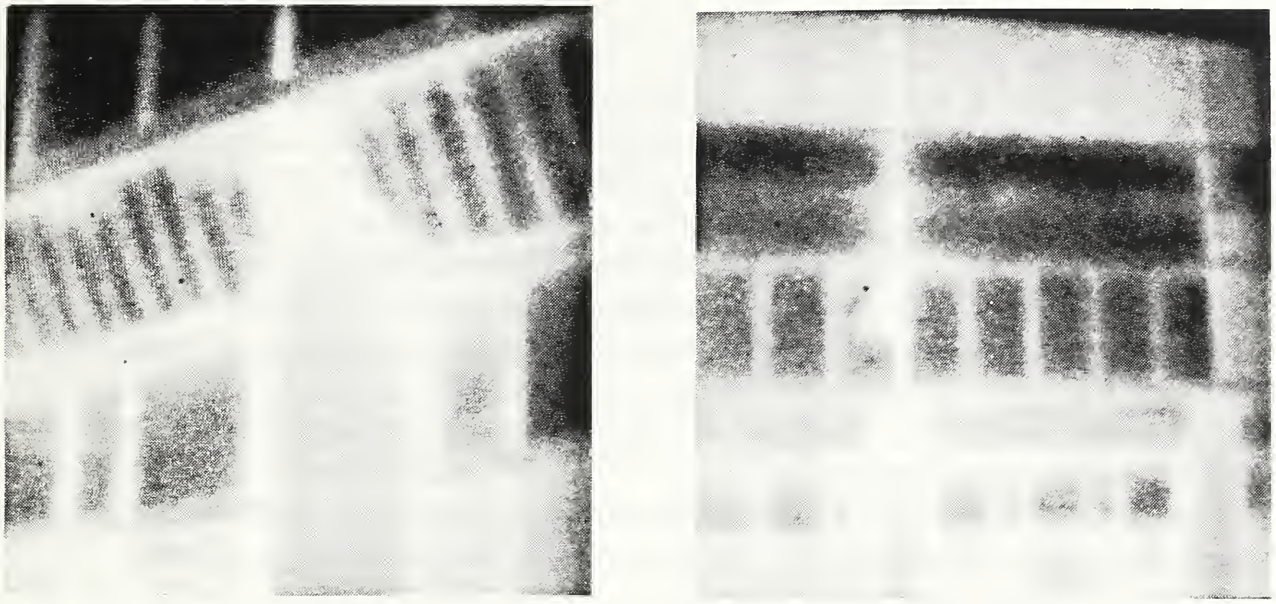
The thermal envelope evaluation is intended to determine the thermal performance of the envelope as constructed and to identify the extent of thermal defects such as thermal bridges, insulation system defects and air leakage. This thermal evaluation includes three evaluation procedures: infrared thermography, whole building pressurization testing, and tracer gas measurements of air infiltration rates.

4.1.1 Infrared Thermography

Infrared thermography is a procedure for qualitatively evaluating the heat transfer performance of the thermal envelope by obtaining an image of the envelope surface temperature distribution. Areas on the thermal envelope with higher heat transmission rates will be at a temperature that is closer to the opposite side of the envelope than areas with lower heat transmission rates. Therefore, under heating conditions, exterior surfaces associated with poor thermal performance will be warmer than those associated with better performance, and interior surfaces will be colder . Infrared thermography can be conducted from either inside or outside a building as long as there is a significant temperature difference across the envelope. An inspection requires a trained individual to operate the equipment and interpret the thermographic images. Several standards exist for conducting these evaluations [ASTM 1986, ISO 1983].

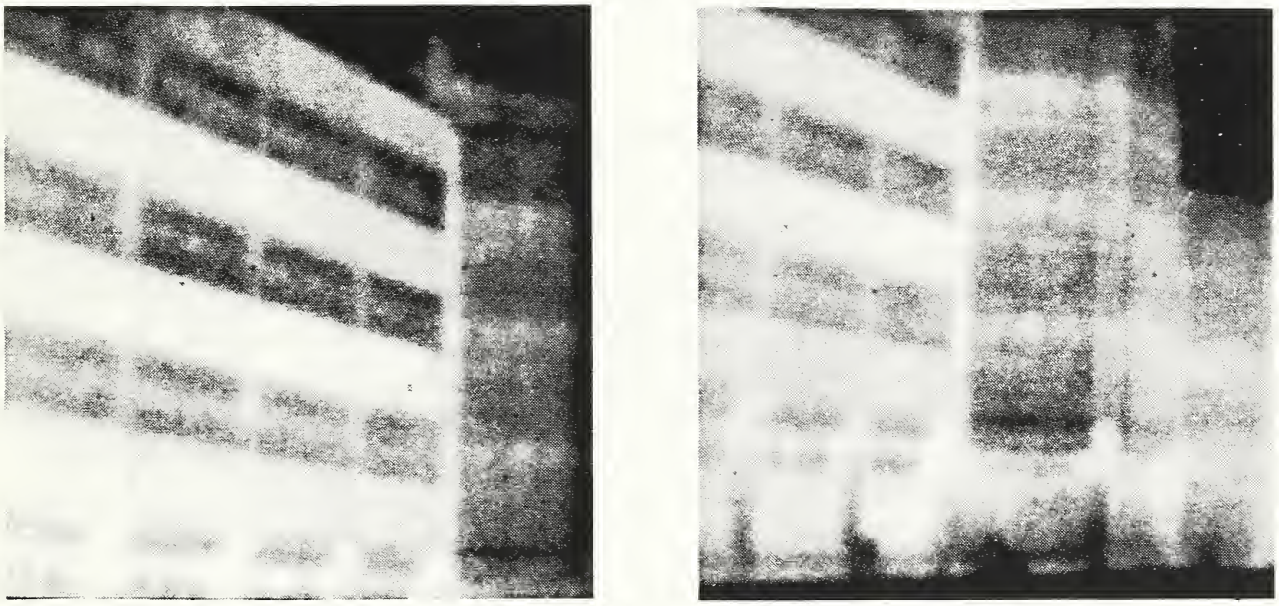
Infrared thermography can be used to locate and assess heat loss paths in building envelopes including uninsulated areas, gaps in the insulation, excessive heat loss at envelope component connections, thermal bridges, moisture damage to insulation, air leakage sites, and air penetration into envelope cavities [Chang 1987]. Previous experience has shown the existence of such thermal defects in building envelopes, resulting in significantly increased energy consumption and diminished interior comfort [Grot 1985]. An infrared inspection was conducted on the Overland Building in March 1990 to assess the overall thermal integrity of the building envelope and to identify the existence of thermal defects. At the time of the inspection the building was unoccupied, but it was heated.

The infrared inspection did not reveal any dramatic thermal defects such as large areas of missing insulation or extensive air leakage. The thermal defects that were identified are shown in the exterior thermograms in Figure 15. The first thermogram is of a ground level column where it meets a diagonal overhang outside of the first floor meeting halls. There are hot spots at the top of all these columns and along the upper edge of the overhang. These two apparent defects may be caused by air leakage at the top of the columns and a lack of thermal insulation integrity where the diagonal overhang intersects with the vertical wall. The second thermogram is a more distant view of the same area showing a hot spot a few feet up on the vertical wall, which appears to be caused by an air leak. The third thermogram shows several floors of the exterior wall and a portion of one corner of the building. In the long portion of the wall the horizontal, white areas are the windows and the dark areas are the opaque wall. Thermal bridging at the floor slab intersections and the facade supports are evident in these images. Similar bridging at the floor slabs are seen in the corner section, a close-up of which is shown in the fourth thermogram. In this image the floor-wall intersection shows up more strongly, suggesting the presence of more severe bridging and perhaps air leakage. Therefore, the infrared inspection of the thermal envelope integrity of this building revealed no large-area thermal defects. Several air leakage sites are apparent at floor-wall intersections and at the tops of the ground level columns. Thermal bridging also appears to be occurring at the floor-wall intersections and facade supports.



a. Thermogram of Ground Level Column

b. Thermogram of Ground Level



c. Thermogram of Exterior Wall

d. Thermogram of Corner

Figure 15 Infrared Thermograms of Building Exterior

4.1.2 Whole Building Pressurization

The envelope airtightness of the Overland Building was measured using a whole building pressurization test in November 1990. This test involved using the building air handlers to induce a series of pressure differences across the building envelope and measuring the outdoor airflow rates required to maintain these indoor-outdoor pressure differences [Persily 1986]. The airflow rate required to induce a specific pressure difference serves as a measure of the airtightness of the building shell. Although the test conditions differ considerably from those that normally induce air infiltration across the building envelope, pressurization testing provides a quantitative measure of envelope airtightness. It is not a measure of the building air change rate induced by the weather or ventilation system operation.

In the Overland Building pressurization test, the outdoor airflow rate through each air handler was measured with the integral pulse tracer gas technique [Persily 1990]. A small volume of tracer gas v_t was injected into the outdoor airstream flowing into the air handler. At the same time an air sample container was slowly filled downstream of the injection point to determine the average tracer gas concentration $\overline{c}$ starting several minutes before the injection and continuing until all of the tracer gas has passed the sampling point. The airflow rate through the air handler q is determined by where Δt is the time interval over which the average concentration air sample is determined.

$$q=v_t/(\overline{c}\Delta t)$$

The test was conducted with all building exhaust fans off, all relief fans off and sealed, and the air handlers operating with 100% outdoor air intake. Therefore, all air entering the building was brought in through the air handlers and could leave only through leaks in the building envelope. The sum of the all of the airflow rates measured through the air handlers using the integral pulse technique is equal to the total airflow rate into the building, i.e., the total airflow rate out through envelope leaks. The pressurization test was conducted on a Sunday when the building was unoccupied in order to avoid problems of maintaining the indoor-outdoor pressure difference due to door openings. All stairwell doors were left open during the test in order to facilitate achieving a uniform interior pressure. Four indoor-outdoor pressure differences were induced during the test, 21.5, 32.4, 54.0 and 76.4 Pa (0.086, 0.130, 0.217 and 0.307 inches of water). Six of the building's fifteen air handling systems were used to achieve the lowest pressure difference and thirteen were used to induce the highest pressure difference. At each test point, the supply airflow rates of the air handlers in operation were set at a constant rate and the indoor-outdoor air pressure difference was measured at each floor. The airflow rates through each air handler were then measured using the integral pulse technique described above. After the airflow rate measurements, the pressure differences were measured again. The data collected at each test point consists of the average envelope pressure difference Δp and the airflow rate out of the building Q, equal to the sum of the airflow rates measured at each air handler in operation. The four data points were fit to a curve of the form

$$Q = C\,\Delta p^n$$

where C and n are empirical constants determined from the curve fit. In order to enable comparison of the test results to airtightness measurements made in other buildings, Q_{25}, the value of Q at a pressure difference of 25 Pa (0.1 inches of water) was determined using the above equation. The calculated airflow rate Q_{25} is normalized by the building volume 129,000 m^3 (4.57 x 10^6 ft^3) and the building envelope area 11,900 m^2 (129,000 ft^2). This analysis of the Overland pressurization test data results in a calculated value of Q_{25} of 254,000 m^3/hr (150,000 cfm) corresponding to 1.96 air changes per hour and 21.2 m^3/hr-m^2 of envelope area (1.16 cfm/ft^2). The values of C and n in the above equation are 42,500 m^3/hr-$(Pa)^n$ (538,000 cfm/(inches of water)^n) and 0.556 respectively. Comparing these to measurements made in seven other new office buildings, the Overland building envelope is leakier than any of the other buildings [Persily 1986]. The airflow rate Q_{25} in the other buildings ranged from 0.45 to 1.45 air changes per hour, and from 1.9 to 9.2 m^3/hr-m^2 of envelope area (0.10 to 0.50 cfm/ ft^2). A detailed analysis of the test data revealed some inconsistencies in the airflow rates associated with individual air handlers between the test points. While the airflow rate through any given air handlers throughout the test is not expected to be exactly constant, the observed variations were larger than expected and may be due to experimental error. The data were reanalyzed in an attempt to account for these inconsistencies and the results obtained are as follows:

C = 22,100 m^3/hr-$(Pa)^n$ (280,000 cfm/(inches of water)^n)
n = 0.685
Q_{25} = 201,000 m^3/hr (118,000 cfm)
1.55 ach
16.7 m^3/hr-m^2 (0.92 cfm/ft^2)

These modified results are still high compared to the previous measurements in other buildings. It is not clear whether the test results are reliable given the inconsistencies observed in the data. When the building air infiltration rates have been well characterized, it will be possible to evaluate whether the relationship between the pressurization test results and the measured air infiltration rates in this building is consistent with the relationship observed in other buildings. Unless a repeat pressurization test reveals otherwise, it appears that the building envelope in the Federal Records Center is quite leaky compared to the small number of available measurements in other office buildings.

4.1.3 Air Infiltration Rate

Building air infiltration rates are being measured in the Overland Building using the automated tracer gas system described in Section 3. When the building ventilation system is being operated, the measured air exchange 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 exchange rate measured when the ventilation system is not being operated 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 temperature differences between indoors and outdoors and wind pressures on the exterior surfaces of the building. The procedure used to measure infiltration and ventilation rates in the Overland Building are essentially identical, the only difference being in the operation of the building ventilation systems during the ventilation rate measurements. The infiltration rates serve as a measure of the building envelope airtightness, with leakier buildings having higher air infiltration rates under similar weather conditions.

The tracer gas decay technique is being used to measure the building infiltration rates [ASTM 1990]. In these measurements, the automated measuring system injects tracer gas into all fifteen of the building air handlers every three hours. The injection rate is sized to attain an initial tracer gas concentration in the building of 150 parts per billion (ppb). After a period of about 20 minutes to allow the tracer gas to mix with the interior air, the tracer gas concentration decay is monitored at nineteen locations within the building. An outdoor location is also monitored. The concentration at each location is monitored once every 10 minutes and the measured concentrations are recorded by the measuring system. The sampling locations within the building will be varied during the building evaluation, but the initial group of sampling locations include the return airstreams 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 in 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 building air infiltration rates. The infiltration rate measurements rely on 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 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 may not be appropriate for the reliable measurement of air infiltration rates.

Only limited tracer gas decay measurements have been made in the building to date, and these data indicate building air infiltration rates on the order of 0.2 ach . More reliable measurements of the infiltration rates will be available once the tracer gas injection rates to the various zones of the building have been adjusted properly, an inevitable part of the tracer gas measurement procedure. When this adjustment procedure is completed, additional data obtained under a range of weather conditions will be used to thoroughly characterize air infiltration in the building.

4.2 Indoor Air Quality

Several aspects of the Overland Building's indoor air quality performance were monitored prior to building occupancy, and this monitoring will continue into occupancy. These include the concentrations of radon, formaldehyde, volatile organic compounds, carbon dioxide and carbon monoxide, as well as building ventilation rates.

4.2.1 Radon

Radon levels were measured in the building over a three day period in August 1990 using charcoal canisters obtained from a private company that does 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 this 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 floor plans in Figures 2 through 8. 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 common for air to enter such shafts on lower floors and to flow out 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 these 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 it is impossible to report on the building air exchange rates during the measurements.

Table 2 shows the measured radon concentrations for each of the locations tested. 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. All of the other measured concentrations were not significantly different from the minimum detectable level. Those duplicates with measurable concentrations agreed within the expected range, and all blanks were below the minimum detectable level. 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 will be higher. These measurements will be repeated when the ventilation system is operating normally and during colder weather.

Sample Location	Level	Concentration (pCi/l)
Stairwell by Room B277	B2	1.9
Stairwell by Room B277	B2	1.7
Outside Freight Elevator	B2	1.4
Mechanical Room B277	B2	1.1
Mechanical Room B277	B2	0.8
Mechanical Room B277 - BLANK	B2	<0.4
Column P7	B2	1.8
Column N14	B1	<0.4
Outside Freight Elevator	B1	<0.4
Lounge, Room B153	B1	<0.4
Column W20	B1	<0.4
Column W20	B1	<0.4
Meeting Hall A	1	<0.4
Outside Freight Elevator	1	<0.4
GSA Office in Old Building	1	<0.4
Guards' Desk	1	<0.4
Column G13	2	<0.4
Column G13 - BLANK	2	<0.4
Outside Mechanical Room	2	<0.4
Outside Mechanical Room	2	<0.4
Room 373, Column G9	3	<0.4
Outside Freight Elevator	3	<0.4
Outside Freight Elevator	4	<0.4
Mechanical Room	4	0.6
Column R22	4	<0.4
Column K2	5	<0.4
Column K2	5	0.6
Column K2 - BLANK	5	<0.4
Mechanical Room	5	0.6
Column R22	5	<0.4

Table 2 Radon Measurement Results (August 1990)

4.2.2 Formaldehyde

Formaldehyde levels were measured in the building over a six day period in August 1990 using passive monitors. These monitors, obtained from a private company, 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. The vial is recapped and returned to the laboratory for analysis of the formaldehyde concentration by the chromotropic acid colorimetric method. The minimum detection limit of the monitor 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 these 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 at the time of these tests, so it is impossible to report on the building air exchange rates during the measurements. At the time of these measurements, the building furnishings had been installed from one to four months.

Twenty-nine monitors were used in this assessment, including duplicates and blanks. 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. The column designations in the table refer to the floor plans in Figures 2 through 8. Several monitors were deployed in the building's conference rooms which contained a high loading of tables made from pressed-wood products. It was thought that if there were high formaldehyde levels in the building, they would probably be in these rooms. 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 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, Ventilation for Acceptable Indoor Air Quality, 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. All of the measured formaldehyde concentrations are 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, but concentrations between 0.05 and 0.10 ppm can still be interpreted as being of some concern. The formaldehyde concentrations in the conference rooms were not significantly different from the concentrations elsewhere in the building. These measurements will be repeated when the ventilation system is operating normally. These future measurements may enable a determination of whether the formaldehyde emission rates from the furnishings are decreasing.

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

Table 3 Formaldehyde Measurement Results (August 1990)

4.2.3 Volatile Organic Compounds

Measurements of volatile organic compounds (VOCs) were made in the building on two occasions, 7 June and 19 July 1990. These measurements were intended to identify and quantify the individual VOCs during the preoccupancy period and to study their relationship to sources including outdoor air, building materials, furnishings, and construction and move-in activities.

Measurement Procedure

The VOC measurements were made using active sampling on a sorbent followed by analysis with a gas chromatograph connected to a mass spectrometer (GCMS) with a mass selective detector (MSD). The samples were collected on sample tubes (traps) packed with 0.5 g of 35/60 mesh porous polymer, 2,6-diphenyloxide. Before sampling, the traps were cleaned of residual contaminants using a thermal conditioner operating at 280 °C (540 °F) for a period of 8 hours while purging them with ultra high purity (UHP) helium at a nominal flow rate of 100 ml/min (0.2 scfh). The samples were collected on the traps with an adjustable, continuous flow sampling pump that operated over a range of flow rates from 50 to 300 ml/min (0.1 to 0.6 scfh). The sampling air flow rate was measured with an electronic volumetric bubble flow rate calibrator that was accurate to within 0.5% of scale. The sample tubes were filled at nominal flow rates of 50 and 100 ml/min (0.1 to 0.2 scfh) at the test site. The volume of air drawn across the traps ranged from 0.5 to 2.0 liters. Triplicate samples were taken at each location; one sample was used for identification and two for quantification. Shipping and field blanks were sent to the test site along with the sample tubes to insure the samples were not contaminated in the shipping or sampling processes. All shipping blanks, field blanks, and samples were transported back to NIST and stored at -30°C (-22 °F) prior to analysis. A thermal desorber was used to remove the sample from the tubes and introduce it to the gas chromatograph (GC), which was equipped with a 25 m x 0.32 mm x 1.05 mm film thickness (cross-linked 5% phenyl methyl silicone) capillary column.

One of the three samples from each location was analyzed with the GCMS in the scan mode to identify the compounds in the building air. A total ion chromatograph (TIC) of the sample was compiled and a search of the NBS library Revision 3.1 (NBS/NIH/EPA/MSDC data base) was performed to provide tentative identification of the compounds. These results provided the basis for the selection of components for the gas standard mixture on which positive identification and later quantification was based. Neat solutions of the selected compounds were injected into a static dilution bottle to create the gas calibration standard. A new calibration standard was prepared for each of the two tests, with the standard for the first test containing 32 compounds and the second containing 41. The complete analytical system, consisting of the desorber, the GCMS and the sample tubes, was calibrated together by placing known amounts of the gas standard mixture on a series of traps, desorbing the traps, analyzing them with the GCMS, and producing calibration curves. A three-point calibration was made with the MSD in the scan mode to enable the determination of total VOC (TVOC) concentrations in the building air at each sampling location from the TICs. The system was also calibrated with the MSD in the selected ion (SIM) mode to enable quantification of the individual compounds. Five to seven point calibration curves were generated for each individual compound. After calibration, one of the quantification traps from each location was analyzed. If there was any reason to suspect improper analysis, the second quantification trap for that location was also analyzed.

On both sampling occasions, the building ventilation system was operating with no outdoor air intake. The building was unoccupied except for a portion of the first floor used as classrooms and the main entrance of the building which was being used as an entrance to the old building. Furniture and communication cable installation was in progress during the measurements. During both tests one air sample was taken on each level (except B2) and the outdoors. Equipment set-up, air sampling and data recording took approximately one hour per sample location, and therefore the sample times were not identical at the individual locations.

Results and Discussion

The shipping and field blanks from both tests showed no significant peaks, indicating that no contamination was introduced in the field samples during sampling and transportation. As a result of both tests, 95 VOCs were tentatively identified in the building air, most of which have been identified in other office building studies [Hodgson 1989, Berglund 1990]. The positively identified and quantified components for each test are listed in Tables 4 and 5. These VOCs are categorized into four major VOC groups: oxygenated hydrocarbons, chlorinated hydrocarbons, alkanes and cycloalkanes, and aromatic hydrocarbons. These tables also show the concentrations of the individual compounds on each floor and outdoors, the average building concentration for each component present in at least five of the building locations, the sum of the individually quantified VOC concentrations for each floor and the outdoors, the sum of the concentrations of the VOCs common to both tests, and the TVOC concentrations for each floor and the outdoor air. Table 6 records the status of each floor at the time of each test. Table 7 presents a classification of the individual compounds as "outdoor", "building", or "activity/furnishing" related, based on the measurement results discussed below.

The outdoor measurements on 19 July show higher concentrations of some VOCs compared to the 7 June measurements. Among them, 2-propanone and cyclopentanone have the highest levels (greater than 100 $\mu g/m^3$). The outdoor concentrations of the light hydrocarbons (boiling points less than 80 °C) are also significantly higher during the second test. These elevated outdoor concentrations may be due to the fact that the outdoor sampling location for the second test was near the main entrance of the building, where indoor air may have been flowing out of the building and influencing the outdoor sample. The outdoor sample location for the first test was on the roof of the building.

Concentrations of the individually quantified compounds are well below the Occupational Safety and Health Administration (OSHA) promulgated "transitional" Permissible Exposure Limits (PELs), and "final rule" Time Weighted Averages (TWAs), Short Term Exposure Limits (STELs) and ceiling limits [OSHA 1989]. They are also

	COMPOUND NAME	CONCENTRATION (µg/m³)							
		Out	B1	1st	2nd	3rd	4th	5th	Avg
Oxygenated	Ethanol	8	24	21	21	12	18	19	19
	2-Propanone	14	245	62	32	26	22	59	74
	2-Propanol*	21	119	57	41	25	30	48	53
	2-Butanone	13	15	12	14	14	17	24	16
Chlorinated	1,1,2-Trichlorotrifloroethane		25	15					
	Dichloromethane		389	268					
	1,1,1-Trichloroethane	9	76	38	14	7	7	14	26
	Trichloroethene	8	42	17	5	3	4	7	13
	Tetrachloroethene**	9	6	3	7	6	2	5	5
Alkane + Cycloalkane	2-Methylbutane	6	6	7	6	5	7	19	8
	2-Methylpentane	2	4	3	3	3	2	6	3
	2,3-Dimethylpentane	14	25	13	18	15	16	31	20
	3-Methylhexane	3	4	3	4	5	4	9	5
	2,2,4-Trimethylpentane**	9	10	7	9	8	8		8
	Methylcyclohexane		2	2	2	2	2	4	2
	n-Nonane		104	39	10	8		21	36
	2,6-Dimethyloctane**		63	25	7	5	6	15	20
	n-Decane	12	173	91		17		123	
	n-Undecane	1	61	25	21	26	30	168	55
Aromatic	Benzene	9	7	8	10	6	8	11	8
	Toluene	14	248	130	32	37	25	68	90
	Ethylbenzene	7	17	19	23	20	19	40	23
	1,2-Dimethylbenzene	7	18	17	20	17	16	33	20
	1,3- ,1,4-Dimethylbenzene	15	33	40	47	39	42	80	47
	Methylethylbenzene		17	5	4	5	5	8	7
	Propylbenzene	1	9	4	8	7	3	14	7
	3-Ethyltoluene	13	73	38	37	32	26	58	44
	1,3,5-Trimethylbenzene	6	33	19	19	15	13	29	21
	2-Ethyltoluene	5	21	11	14	11	11	21	15
	1,2,4-Trimethylbenzene	10	8	4	51	35	44	50	32
	1,2,3-Trimethylbenzene	8	17	12	14	13	11	25	15
TOTALS	Sum of Individual VOC	223	1,895	1,014	492	421	398	1,006	871
	Sum of Common VOC	202	1,776	958	452	397	368	959	818
	TVOC (calculated)	620	5,020	2,310	520	1,090	840	2,980	2,127

* Compounds not in gas standard for test 2

** Compounds not detected in building air during test 2

Table 4 Results of Test #1 (7 June)

well below the Threshold Limit Values (TLVs) and STELs of the American Conference of Governmental Industrial Hygienists [ACGIH 1990]. The applicability of these industrial standards to non-industrial environments, including office buildings, is a matter of much discussion. No VOC standards specific to office buildings exist; however, some guideline values have been discussed in the literature. According to Molhave [1984], subjective complaints occur at TVOC levels greater than 2 mg/m^3 while eye and nose irritation occurs at 5 mg/m^3. A guideline value of 1 mg/m^3 has been suggested by Tucker [1988]. Four of the TVOC values determined in this study exceed the 1 mg/m^3 level on 7 June: 5.0, 2.3, 1.1 and 3.0 mg/m^3 for levels B1, 1, 3 and 5 respectively. None are above 1 mg/m^3 on 19 July. TVOC levels are not available for the 19 July measurements. These values of TVOC are not unusual and are similar to other TVOC measurements in new European buildings ranging from 0.5 to 19 mg/m^3 [Molhave 1984].

The 7 June TVOC concentrations in Table 4 were calculated using an average

	COMPOUND NAME	CONCENTRATION (μg/m³)							
		Out	B1	1st	2nd	3rd	4th	5th	Avg
Oxygenated	Ethanol	39	35	35	53	67	113	48	58
	2-Propanone	165	177	158	208	184	197	231	192
	3-Butene-2-one*	51	34	35	50	33	43	44	40
	2-Butanone	24	34	25	36	34	40	46	36
	1-Butanol*	20	26	11	28	25	42	48	30
	Cyclopentanone*	174	118	67	64	47	49	32	63
	Hexanal*	54	97	62	79	85	123	180	104
Chlorinated	1,1,2-Trichlorotrifloroethane		138					57	
	Dichloromethane	7		98	11	8	16	3	27
	1,1,1-Trichloroethane		26	48	19	25	44	91	42
	Trichloroethene	2	12			3	3		
Alkane + Cycloalkane	2-Methylbutane	17	44	32	37	46	57	124	56
	Pentane*		6	3		12	22	13	11
	2-Methylpentane						5	10	
	2,3-Dimethylpentane			1					
	3-Methylhexane			1				1	
	Methylcyclohexane			4			1	1	
	n-Nonane		11	11	12	11	11	11	11
	n-Decane	20						21	
	n-Undecane	13	14	14	15	16	16	16	15
Aromatic	Benzene	58		33	37	31	32	38	34
	Toluene	5	13	11	156	16	14	22	39
	Ethylbenzene		10	9	14	13	12	15	12
	1,2-Dimethylbenzene	6	10	9	13	13	11	13	11
	1,3-,1,4-Dimethylbenzene	5	16	15	26	24	21	28	22
	Methylethylbenzene			5	5				
	a-Pinene*		31		22	27	40	49	34
	Propylbenzene				8	8	6	8	
	3-Ethyltoluene		9	9	15	13	11	12	11
	1,3,5-Trimethylbenzene		7	7	10	9	8	8	8
	2-Ethyltoluene			6	15	11	10	10	10
	1,2,4-Trimethylbenzene		16	16	25	23	21	20	20
	3-Carene*		19	9	13	14	20	22	16
	1,2,3-Trimethylbenzene			8	10	10	9	9	9
TOTALS	Sum of Individual VOC	661	902	740	980	805	998	1,229	942
	Sum of Common VOC	361	571	552	725	564	659	841	652

*** Compounds added to gas standard for test 2**

Table 5 Results of Test #2 (19 July)

calibration curve of all 31 quantified VOCs. Excluding level 2, the TVOC concentrations of each floor are twice the sums of the concentrations of the individual VOCs. This compares well with the ratios of TVOC to VOC concentration sums in a study of a new office building in Portland, Oregon [Hodgson 1989].

Considering the data from both tests, 35 of the 38 quantified compounds were classified according to suspected source into three groups: “outdoor”, “building”, and “activity/furnishing” (Table 7). Outdoor substances are those that are in the outdoor sample at approximately the same concentrations as in the building samples. Building related substances are those with concentrations that tend to be relatively constant throughout the building, but well above the outdoor levels suggesting an indoor source that is relatively uniform throughout the building. The concentrations of activity/furnishing related substances vary among floors, are generally elevated when there is construction activity occurring on these floors, and when these substances are detected

FLOOR	STATUS	
	7 June 1990	19 July 1990
B1	• No cubicles installed • 20 rolls of communication cable • 3 workers stripping cable	• All cubicles installed • 13 cloth, 24 plastic and 35 vinyl chairs stored in breakroom • 102 cloth chairs and 30 tables stored by elevator lobby • Mold smell outside mechanical room near column N16
1	• No cubicles installed • Occupied class rooms • People walking from entrance to old building	• No cubicles installed • Occupied class rooms • People walking from entrance to old building • 40 plastic chairs and 2 tables in breakroom • 12 cloth chairs and 2 tables in classroom • 100 cloth chairs and 50 tables in classrooms
2	• No cubicles installed • Stacks of steel framed tack boards in boxes on 1/4 of floor • Stacks of office partitions on 1/4 of floor	• No cubicles installed • Installation of communication cable in progress
3	• No cubicles installed • 30 rolls of communication cable	• No cubicles installed • 76 cloth covered chairs and10 tables stored in rooms near elevators
4	• No cubicles installed • 30 rolls of communication cable • 15 cloth chairs in stacks	• Cubicles partially installed • 8 workers installing shelves in cubicles • Cubicle desks stacked in boxes
5	• 1/2 of cubicles installed • 6 workers installing cubicles • Stacks of partitions on 1/4 of floor	• All cubicles installed

Table 6 Status of Floors During VOC Measurements

their concentrations are typically higher than those of the outdoor and building related substances. Figure 16 shows the concentration profiles of a representative compound in each classification.

Although some of the compounds clearly fit into only one category, the behavior of others are not so distinct. As shown in Table 7, seven of the 35 classified compounds are categorized as outdoor related substances. Most of the outdoor related substances have low concentrations, belong to the alkane group and are typical gasoline by-products [Supelco 1989]. Eighteen of the compounds have been characterized as building related compounds. Of these compounds, the concentrations of individual components on levels 2, 3, and 4 are roughly twice the outdoor concentrations. No chlorinated hydrocarbons are included in the building related group. Thirty of the compounds are classified as activity/furnishing related compounds, and they include members of all four major VOC chemical groups. The results of this compound classification have been compared with those of an air quality study in a large library building in Sweden [Berglund 1990]. The compound classifications of the 10 VOCs common to both studies does not match well for outdoor and building related substances. This may be due to differences in outdoor air contaminants as well as to different building materials and furnishings.

The activity/furnishing related compounds have been examined relative to the worker activities and new furniture installations occurring on the sampling dates listed in Table 6. These components are seen where construction was in progress. The alkanes (n-decane and n-undecane), the aromatic hydrocarbons (toluene and 3-ethyltoluene), the oxygenated compounds (ethanol and 2-propanone) and the chlorinated compounds (1,1,2-trichlorotrifluoroethane, dichloromethane and 1,1,1-trichloroethane) have relatively high concentrations on these floors. Most of them are often used in solvents, paints or glues. The relatively high concentrations of toluene (156 and 248 $\mu g/m^3$) are associated with the installation of communication cable in this building.

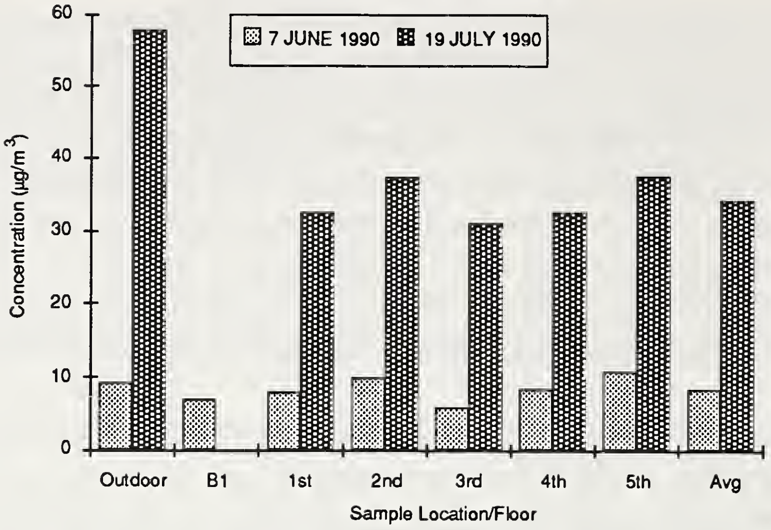
As mentioned in the previous section, the sum of the concentrations of 30 VOCs common to both tests are listed in Tables 4 and 5 for all the floors and the outdoor air. On 7 June, the sums of the common-VOC concentrations vary from 397 to 1776 $\mu g/m^3$. The sums of the individual VOC concentrations on levels 2, 3 and 4 are similar, and their average is around 400 $\mu g/m^3$. This is relatively low compared to the other floors and twice the outdoor concentration sum. No construction activity or new furnishings were noted on these floors during the sampling period; therefore, this level may be considered the building's background concentration for that day. Conversely, levels B1, 1 and 5 show higher VOC concentration sums that are correlated with worker activity and new furnishings, such as the installation of communication cable and partitions. On 19 July the sums of the common-VOC concentrations are more uniform, varying from 552 to 841 $\mu g/m^3$. On this date, the levels 2, 4 and 5 present the highest sums of individual VOC levels. As in the earlier test, these higher concentrations correspond to worker activities and newly installed systems furniture.

A headspace analysis of carpet squares from the building was performed at NIST in which the carpet was placed in a sealed container for a period of time after which the air in the container was sampled. Although the loading rate in these tests (i.e. the ratio of carpet area to volume of air in the container) was approximately 10 times that in the building, no significant VOC emissions were detected after 91 hours. This indicates the carpet material itself is not a substantial source of the VOC concentrations in the building. The carpet adhesive has not been tested yet.

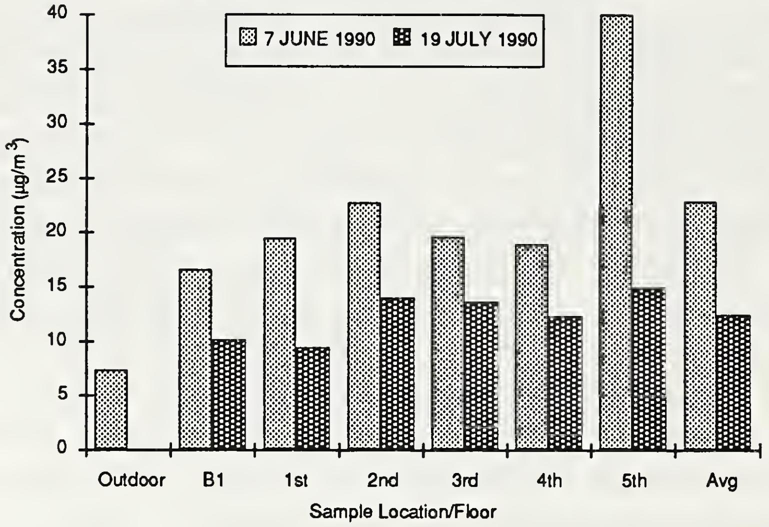
Conclusions

Identification and quantification of VOCs was performed in the building on two occasions, and the compounds identified are typical of those found in indoor air. They have been classified according to suspected source as "outdoor", "building" and "activity/furnishing" related compounds; the last group including the most numerous VOCs and highest concentrations. The levels of all these compounds are at least three orders of magnitude below the OSHA PELs and the ACGIH TLVs for the industrial workplace. Molhave's study suggests that these industrial standards are well above levels known to cause building occupant discomfort. Additional tests are planned after all the office furniture and partitions are installed and the building is occupied to examine the influence of occupant activity and ventilation rate on VOCs.

Outdoor Related Compound (Benzene)



Building Related Compound (Ethylbenzene)



Activity Related Compound (1,1,1-Trichloroethane)

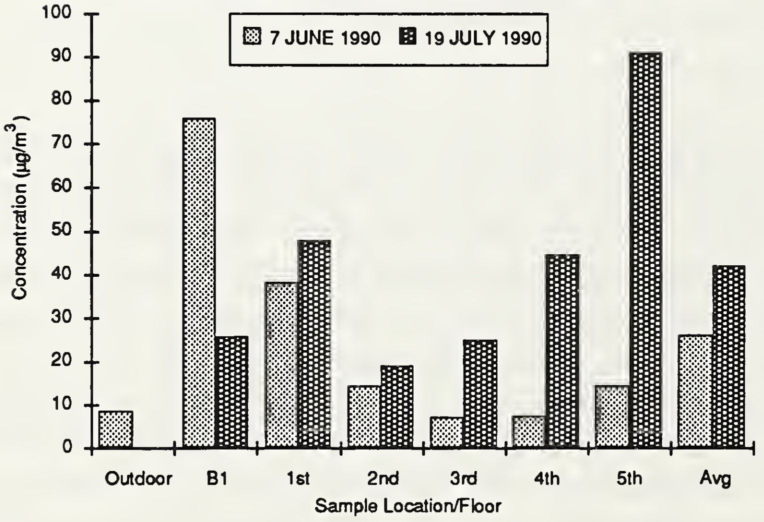


Figure 16 Concentration Profiles of Three Representative VOCs

Name of compound [Number of compounds]	**Outside** [7]	**Building** [18]	**Activity** [30]	**Not Classified** [3]
Ethanol		X	X	
Butane, 2-methyl-	X	X	X	
2-Propanone		X	X	
Pentane			X	
2-Propanol			X	
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-			X	
Methane, dichloro-			X	
Pentane, 2-methyl-	X		X	
3-Buten-2-one (Methyl vinyl ketone)				X
2-Butanone (Methyl ethyl ketone)		X	X	
Ethane, 1,1,1-trichloro-			X	
Benzene	X			
1-Butanol				X
Pentane, 2,3-dimethyl-	X		X	
Hexane, 3-methyl-	X			
Pentane, 2,2,4-trimethyl-	X			
Ethene, trichloro-			X	
Cyclohexane, methyl-		X	X	
Benzene, methyl-			X	
Cyclopentanone				X
Hexanal		X	X	
Ethene, tetrachloro-	X			
Benzene, ethyl-		X	X	
Benzene, 1,3 & 1,4-dimethyl-		X	X	
Benzene, 1,2-dimethyl-		X	X	
Nonane		X	X	
Benzene, (1-methylethyl)- (Cumene)		X	X	
Octane, 2,6-dimethyl-			X	
a-Pinene			X	
Benzene, propyl-			X	
Benzene, 1-ethyl-3-methyl-		X	X	
Benzene, 1,3,5-trimethyl- (Mesitylene)		X	X	
Benzene, 1-ethyl-2-methyl-		X	X	
Benzene, 1,2,4-trimethyl-		X	X	
Decane			X	
3-Carene		X		
Benzene, 1,2,3-trimethyl- (Hemellitene)		X	X	
Undecane		X	X	

Compounds listed in order of retention time.

Table 7 Classification of VOCs by Source

4.2.4 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 using the equipment described in Section 3 of this report. These concentrations are monitored continuously using an automated system that measures the CO_2 and CO concentrations at nine indoor locations and one outdoor location every 10 minutes. The indoor sampling locations include the return air samples from each of the 7 levels, the atrium return, and a mixture of air from four sample locations on each of the four upper levels of the building. The outdoor air sample is located on the fifth level of the building.

The major indoor source of CO_2 is people, and therefore the preoccupancy data is not particularly revealing. Daily maximum CO_2 concentrations are 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 operation that will be occurring once the building is fully occupied. ASHRAE Standard 62-1989 recommends a maximum CO_2 concentration of 1000 ppm. While these measurements are all below this recommended value, daily maximums of 800 ppm are close to the ASHRAE guideline and these concentrations will be monitored closely once the building is fully occupied.

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 that essentially track the outdoor levels. 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 ppm. However, a number of outdoor CO spikes have been identified on selected evenings. These spikes are also associated with increases in the outdoor CO_2 concentration ranging from 400 to 500 ppm. Figure 17 shows some of these data collected during the first two weeks of December 1990. The upper graph shows 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 middle graph shows the outdoor and indoor concentrations of CO_2. The vertical lines on the horizontal axis of the graphs correspond to midnight. The fact that these spikes occur 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 these data indicate a strong association between the peaks and the wind direction. The lower graph in Figure 17 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

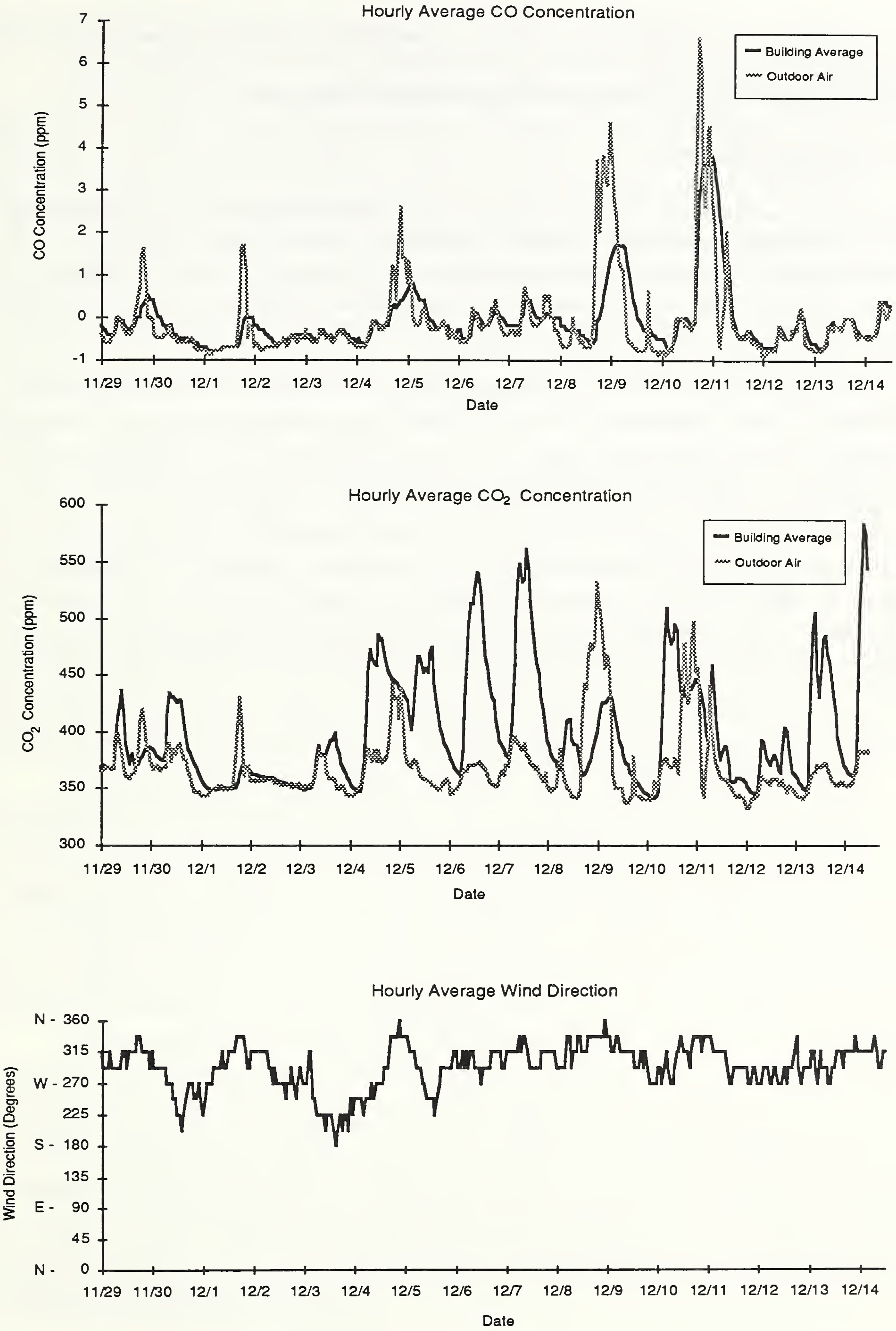


Figure 17 Carbon Monoxide and Carbon Dioxide Data

peaks is still being investigated, but a point source to the north-northwest of the building is suspected. As in the case of the CO_2 concentrations, the CO monitoring in the building will also continue during the early occupancy evaluation.

4.2.5 Building Ventilation

Building ventilation rates are being measured in the Overland Building using the automated tracer gas system described in Section 3 and the tracer gas decay procedure used to monitor infiltration rates described in Section 4.1.4. The building ventilation rate is the air change rate when the ventilation system is operating and is equal to the outdoor air intake rate through the air handling systems plus the rate of infiltration through leaks in the building envelope.

Only limited tracer gas decay measurements of ventilation have been made in the building to date. These data indicate ventilation rates ranging from about 0.5 to 1.5 air changes per hour (ach), depending on the amount of outdoor air intake. These data are preliminary, and as additional data are collected, it will be possible to more thoroughly characterize the building ventilation rate as a function of outdoor temperature, humidity and time of day. The rates that have been measured are somewhat below the recommendation of 20 cfm (10 L/s) per person from ASHRAE Standard 62-1989, which as previously discussed corresponds to about 0.7 ach in an office building. In comparison to other office buildings, the range of preliminary ventilation rate data is similar to that obtained in other modern office buildings [Persily 1989].

5 Discussion and Future Testing

This report has described the thermal and environmental evaluation program being conducted in the new Federal Records Center in Overland Missouri, including the results of the preoccupancy testing. These results include the following findings on the buildings performance. The infrared thermographic inspection did not reveal any significant thermal defects in the building envelope, though the existence of air leakage and thermal bridging was noted. The whole building pressurization test showed that the building is quite leaky compared to other modern office buildings. The infiltration measurements being conducted in the building will serve to verify the building's leakiness. The infiltration and ventilation rate monitoring has begun in the building, but only preliminary results are available at this time. Radon measurements in the building revealed levels of 2 pCi/L or less on the B2 level, with concentrations less than or equal to 0.5 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 [ASHRAE 1989]. The levels of volatile organic compounds in the building were evaluated, and while the levels were not unusual relative to measurements in other new office buildings, the relationship between these levels and occupant health and comfort is not known. The levels of total VOCs ranged from about 0.5 to 1 mg/m^3 on floors with carpet and no furniture or construction activity. Once furniture was installed, or when construction was in progress, the VOC levels increased. The CO_2 levels in the building have generally been low, but this is to be expected in a building with such low levels of occupancy. Several episodes have been observed when the outdoor levels of CO_2 and CO have increased dramatically in the evening, raising the indoor levels as well. The cause of these evening spikes has not yet been determined, but is being investigated.

The monitoring of the building will continue approximately one year into occupancy, through the spring of 1991. This monitoring will provide a complete characterization of the building's infiltration and ventilation rates as they vary with season and outdoor weather. Continued monitoring of CO_2 and CO will enable further investigation of the outdoor spikes and the impact of occupancy on CO_2 levels. The preoccupancy measurements of respirable particulates will be studied, and these measurements will continue into occupancy. Finally, additional measurements of VOCs will be conducted with the building occupied to study the impact of occupant activities, the aging of building materials and ventilation rate on indoor VOC levels.

No serious indoor air quality problems have yet been observed in the building. However, several issues merit further attention. The outdoor CO/CO_2 spikes need to be better understood as to their source and their impact on indoor levels. Another issue concerns the fact that the building mechanical rooms are part of the return air system. There is no inherent problem with this design, but special attention must be given to the cleanliness of these rooms. They must not be used for storage of any substances of potential hazard to the building occupants. Finally, after the new building is occupied and the renovation of the old building begins, the potential will exist for migration of contaminants from the old building to the new. This situation will be monitored as part of the early occupancy evaluation.

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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 both before occupancy and during 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 the measurement of indoor levels of selected pollutants. This report describes the effort being conducted in the second of the three buildings, the Federal Records Center in Overland Missouri, and presents preliminary measurement results from the building. The infrared thermographic inspection of the Overland Building did not reveal any significant thermal defects in the building envelope, though the existence of air leakage and thermal bridging was noted. The whole building pressurization test showed that the building is quite leaky compared to other modern office buildings. The measured radon concentrations were 2 pCi/L or less on the B2 level, and less than or equal to 0.5 pCi/L on the other levels. Formaldehyde concentrations ranged from 0.03 to 0.07 ppm, below the 0.1 ppm guideline but above some levels of concern. The measured levels of volatile organic compounds were similar to those observed in other new office buildings, and the impact of building furnishings and construction activities on the VOC levels were noted. The carbon dioxide levels in the building have generally been low, as would be expected in a building with low levels of occupancy.

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

building diagnostics; building performance; carbon dioxide; carbon monoxide; formaldehyde; indoor air quality; office building; radon; ventilation; volatile organic compounds

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