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# Specifications for Thermal and Environmental Evaluations of Advanced-Technology Office Buildings

Andrew K. Persily

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
Center for Building Technology
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Prepared for
**Office of Real Property Development**
**Public Buildings Service**
**General Services Administration**
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U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, *Secretary*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

## ABSTRACT

Specifications for conducting a thermal and environmental evaluation program for advanced technology office buildings are presented. This program is to be used by the General Services Administration (GSA) in designing and assessing the performance of these new federal office buildings. The evaluations include quantification of the building envelope thermal integrity in terms of thermal resistance, insulation quality and airtightness, and the environmental performance in terms of outside air intake rates, air distribution system performance and indoor pollutant levels. These specifications cover the installation of sensors in the building and a "diagnostic center" that will contain measurement equipment and serve as a terminal point for wires and tubes from the sensor locations.

This document consists of three basic sections: (1) programing directives - a description of requirements regarding the diagnostic center and associated items, and quantitative architectural performance standards, to be used in the building design process; (2) construction specifications - detailed specifications regarding the procurement and installation of sensors and equipment for use in the evaluations, written in the Masterspec format developed by the Construction Specifications Institute; (3) work statements - detailed descriptions of each of the thermal and environmental evaluations for use in procuring the services of individuals or organizations to perform the tests. The three sections are intended for use by GSA in the design and procurement processes, and are therefore presented in formats appropriate to GSA's needs.

Key words: advanced-technology buildings, building design, building diagnostics, building thermal performance, design, whole building performance

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## Table of Contents

## List of Figures

## List of Tables

## INTRODUCTION

The design and construction of modern, advanced-technology buildings places more stringent requirements on the buildings' thermal and environmental performance. A better understanding of the thermal, environmental and operational characteristics of advanced-technology buildings is essential to avoid design, construction and operation errors that may result in buildings being unsuited to their occupants or having excessive operating costs. The inability to meet energy consumption, thermal comfort and air quality criteria in buildings is due to improper selection of building materials, poor building design, poor construction quality, and improper operation of building equipment. Various diagnostic test methods exist to evaluate a building's performance with respect to these criteria.

Previous studies have shown the value of diagnostic techniques in assessing building thermal envelope performance, and have revealed the existence of several types of problems.* These problems include excessive envelope air leakage leading to degraded insulation performance, increased space conditioning loads, decreased thermal comfort, and potential material damage to the building envelope. Improper installation of insulation was another common defect encountered in the buildings studied. Inadequate outside air intake levels, along with poor air distribution, also occured and has implications for thermal comfort and indoor air quality. Finally, the building envelope designs led to the existence of "thermal bridges" where highly conductive building components penetrate the wall insulation, leading to significant heat transfer even though the building is constructed as designed.

In order to avoid these and other problems in the more demanding environment of advanced-technology buildings, one may employ existing diagnostic techniques early in the construction and occupancy of a building as a matter of course. The present document provides the information necessary to accomplish this in new, advanced-technology buildings being planned and constructed by the General Services Administration (GSA). The evaluations include the following:

- Thermographic inspection of the building envelope
- In-situ measurements of envelope thermal resistance
- Pressurization testing of envelope airtightness
- Tracer gas measurement of airtightness and ventilation system performance
- Indoor pollutant concentration measurement

In order to facilitate these diagnostic evaluations, the building design and construction program will include the installation of sensors and measurement equipment and a central "diagnostic center" for locating this equipment and coordinating the various tests.

This document is to be used by the General Services Administration in designing advanced-technology office buildings and conducting the tests, and it is therefore presented in a format specific to the needs of GSA.

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* Grot, Persily, Chang, Fang, Petersen, Galowin, "Evaluation of the Thermal Integrity of Eight Federal Office Buildings," NBSIR 85-3147, National Bureau of Standards, 1985.

The first section contains "programing directives" to be used in the building design process. These directives present a general description of the requirements of the diagnostic evaluation program in terms of physical space (the diagnostic center), materials, equipment and HVAC control commands. The programing directives also provide architectural performance standards, i.e. requirements regarding the quantitative results of the thermal and environmental performance evaluations.

The second section of this document contains construction specifications, which are detailed specifications concerning the procurement and installation of sensors and equipment to be used in the evaluations. The specifications are written in the Masterspec format developed by the Construction Specifications Institute.

The final section of this document contains work statements describing the diagnostic evaluations in detail, including how the tests are to be conducted, how the data are to be analyzed and how the results are to be presented. These work statements are intended for use in procuring the testing and evaluation services.

The details of the application of an evaluation program to a specific building depend on the building being studied and the measurement equipment that is used. The size, layout and zoning of a building will determine the number and location of the various sensors required for the tests. While several types and brands of sensors and measurement equipment meet the specifications that are described in this document, the specific devices that are used will determine other material and logistic requirements. For example, the type of device used to measure tracer gas concentration will affect compressed gas requirements. The information in this document is not written for any specific building and is general in terms of the sensors and measurement equipment. Therefore, in order to use this information in an actual building, additional detail regarding the specific building is necessary. For example, the construction specifications require a list of sensor locations for the procurement and installation of the sensors. The specifications for the required sensors and measurement equipment are provided, but specific manufacturers are not given. The work statements describing the evaluations to be conducted depend on the details of the building and the installed equipment, and other information to be contained in the construction specifications. Therefore, these work statements must also be made more detailed for actual use. The work statements in this document are written to be consistent with the construction specifications in the second section. If different construction specifications are used, the work statements must be modified accordingly. Finally, the term "contractor" refers to the general construction contractor (builder) and any of the builder's subcontractors. The term "testing agent" refers to those individuals or groups conducting the tests that are described in the work statements.

PART I

# DESIGN PROGRAMING DIRECTIVES

DATE:
HANDBOOK: Design Programing for Federal Buildings (PBS P 3430.2)
SUBJECT: Diagnostic Center

1. General: Provide a diagnostic center (DC) within the building for use in various thermal and environmental evaluations of the building. The DC shall contain several pieces of scientific equipment, and shall serve as a terminal point for sensor wires and air sampling lines and a source of tracer gas injection lines. The attached schematic diagram in figure 1 provides a general description of the DC. Most of the scientific equipment shall be provided during the building construction stage, with the remainder being brought to the building by testing agents for use in specific tests. Details on the sensors, materials, and equipment to be provided and/or installed by the contractor are described in detail in the construction specifications. A general outline of the facility along with other programming directives related to the thermal and environmental tests are given below.

2. Facility Support: The DC shall be located near the building automation system (BAS) control room and the security office. A floor area of about 200 $ft^2$ is required, and the space shall be in a separate, lockable room or part of a larger, lockable room. The space must be accessible 24 hours a day, seven days a week. There must be a double-doorway entrance at least 5 ft wide. The DC shall be furnished with at least three tabletops (roughly 3 ft by 6 ft), a lockable tool cabinet (about 6 ft tall), two upright cabinet racks, three chairs, and a compressed gas cylinder rack. The space shall have a telephone, 24 hour computer grade space conditioning, a compressed air supply, a vacuum line, and at least ten 15 amp outlets of 115 VAC, UPS/filtered power. Space shall also be provided within the building for the storage of at least 12 unused compressed gas cylinders.

3. Pollutant and Tracer Gas Monitors: The contractor shall provide equipment to measure the concentration of a tracer gas (sulfur hexafluoride, $SF_6$), carbon dioxide ($CO_2$), carbon monoxide (CO), formaldehyde (HCHO), and particulates in air. This equipment is described in the construction specifications.

4. Air Sampling: There shall be air sample tubes from various locations in the building which will terminate in the DC, as shown in figure 1. Each line shall be compatible with the inlets of air sampling pumps used to draw air from the sampling locations. These air sampling pumps shall be mounted in a rack and the pump outlet tubes shall run to a common location within the DC.

5. Tracer Injection: There shall be tracer gas injection tubes running from an injection system to various locations within the building, as shown in figure 1. Each injection line, corresponding to a different injection location, shall be associated with a solenoid valve to turn the tracer flow on or off and with a flowmeter to monitor and control the tracer gas injection rate. The solenoid valves' wires will run to a common location within the DC, as will the tubes from the solenoid outlets.

6. Sensor Wires: There will be various sensor wires terminating in the DC for use in the testing, as shown in figure 1. These sensors shall be provided

and installed by the contractor and shall include thermistors for measuring temperatures in ducts, the building interior and outside, an anemometer for measuring wind speed and direction, differential pressure transducers for measuring the pressure difference across the exterior walls, and fan switches (relays) for providing a switch closure when individual air handlers are on.

7. Compressed Gas: Several different compressed gases are required and the gas cylinders shall be securely mounted on a wall of the DC. There must be room for ten size #1A cylinders and four size #3 cylinders. Besides the tracer gas, there shall be carrier gas required for the gas chromatograph used to measure the tracer gas concentration, $CO_2$ free air and ultra zero air for use in calibrating gas concentration measuring devices, 1 ppm $SF_6$ in air for calibrating the gas chromatograph, 250 ppm and 750 ppm $CO_2$ in air for calibrating the $CO_2$ monitor, 5 ppm and 20 ppm CO in air for calibrating the CO monitor, and other calibration gases for the other pollutant monitoring equipment.

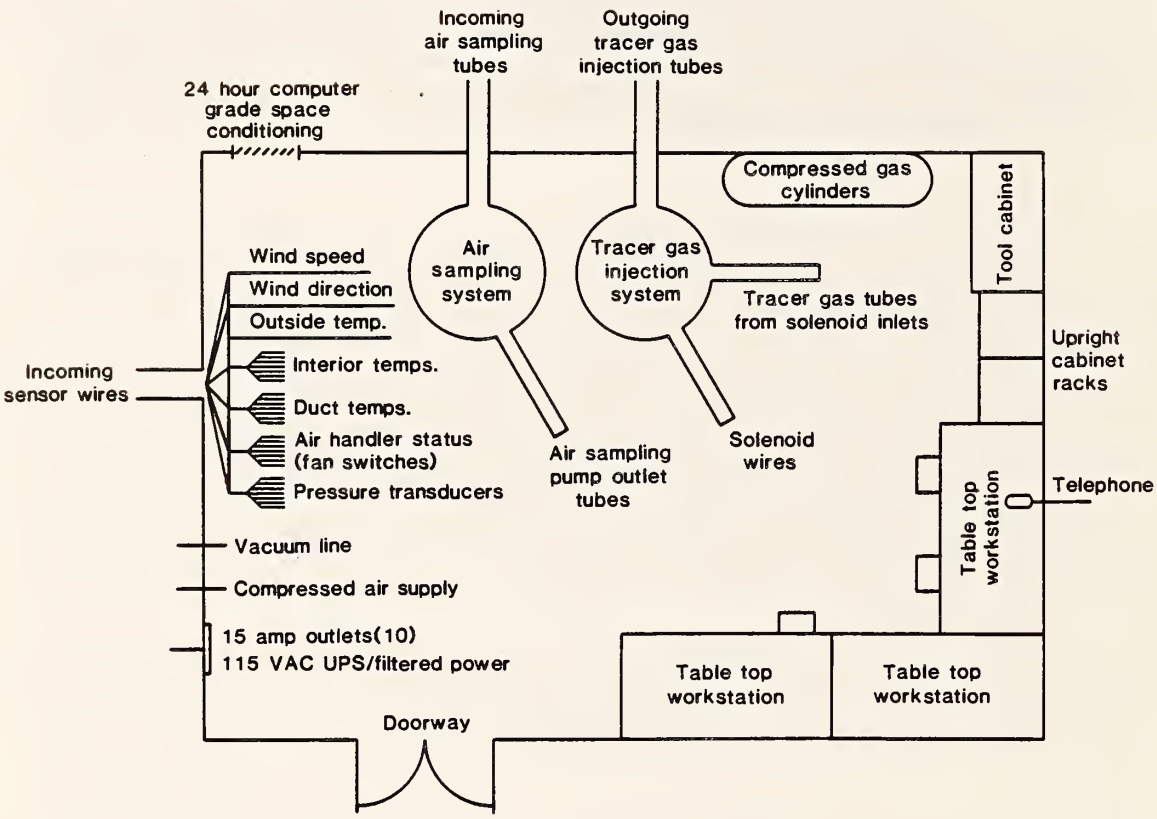


Figure 1 Schematic of Diagnostic Center

RELATED DIRECTIVES:

1. Building Automation System (BAS): The diagnostic tests require several HVAC control commands to be programmed into the BAS. The control commands include:

   a. "Pressurization"
      All return, exhaust and spill dampers closed
      All return and exhaust fans off
      Supply and intake dampers open and adjustable remotely
      Main supply fan(s) ready to be turned on and controlled individually using appropriate controls

   b. "Depressurization"
      All supply and intake dampers closed
      All supply and intake fans off
      Main spill/exhaust dampers open and adjustable remotely
      Main return fan(s) ready to be turned on and controlled individually using appropriate controls

   c. "Infiltration"
      Close all intake and spill dampers, including minimum outside air intake dampers
      All noncritical exhaust fans and dampers off/closed
      All supply and return fans on
      Override to normal controls if early morning heating or cooling are called for
      Override to fire control mode in event of fire alarm

2. Architectural Performance Statements: A series of thermal and environmental tests of the building will be conducted to evaluate the performance of the building and its systems. The results of each test must comply with the following performance specifications.

   a. Infrared Thermographic Inspection
      The building envelope will be inspected using infrared thermography, according to ASHRAE Standard 101-81. The percent of exterior wall area (excluding windows) having thermal defects must be less than 10%.

   b. R-Value
      The R-value of the exterior walls will be measured in at least three locations for each exterior wall type, where the wall is judged to be properly insulated according to the infrared thermographic inspection. If thermal defects are detected, then there shall be three R-value measurements for each type of defect. The measured R-values for the properly insulated walls must be no less than 90% of the calculated values based on the building design and standard ASHRAE handbook procedures.

   c. Whole Building Airtightness
      The airtightness of the building envelope will be measured using the fan pressurization method according to ASTM E 779-81. The airflow rate required to maintain the interior air pressure 0.1 in. $H_2O$ below the exterior pressure will be measured, as well as the airflow rate

required to maintain the interior air pressure 0.1 in. $H_2O$ above the exterior. The average of these two airflow rates divided by the building volume must be less than 0.75. This average airflow rate divided by the total exterior building envelope area (including windows, roof, etc.) must be less than 0.25 cfm/ft$^2$.

d. Component Airtightness
The airtightness of a sample of the windows and doors will be measured in accordance with ASTM E 783. The measured tightness must be in compliance with ASHRAE Standard 90-80, i.e. window leakage must be less than 0.50 cfm per foot of crack at 0.3 in. $H_2O$ and door leakage must be less than 11 cfm per foot of crack at 0.3 in. $H_2O$.

e. Air Infiltration
The whole building air infiltration rate will be measured with the air handlers operating at 0% outside air intake using the tracer gas decay technique according to ASTM Standard E 741-83. The average infiltration rate for an inside-outside temperature difference between 10 and 30 degrees F and wind speeds less than 5 mph must be less than 0.20 air changes per hour. The infiltration rate for a temperature difference greater than 40 degrees F and wind speeds greater than 10 mph must be less than 0.40 air changes per hour.

f. Ventilation
The whole building ventilation rate will also be measured using the tracer gas decay technique (ASTM E 741-83) under normal-occupancy operating conditions of the outside air intake control system. The measured ventilation rates (under conditions of minimum outside air intake) must be greater than the ventilation requirement calculated as follows. The ventilation requirement in air change per hour (V) depends on the specified requirement for outside air per person (q) in cfm, the floor area per person (A) in ft$^2$ and the office ceiling height (H) in ft, according to $V = qx60/AxH$. For example, if one requires 10 cfm per person with 140 ft$^2$ of floor area per person and a ceiling height of 10 ft, then the ventilation requirement is approximately 0.43 air changes per hour. The maximum ventilation rate under conditions of minimum outside air intake must be less than 1.5 times this minimum.

g. Indoor Pollutant Levels
The indoor concentrations of carbon monoxide, carbon dioxide, formaldehyde, oxides of nitrogen, ozone, radon, sulfur dioxide, respirable particulates, volatile organic compounds, and asbestos will be measured. The concentrations of carbon monoxide, nitrogen dioxide, sulfur dioxide, and particulates must be in compliance with the National Ambient Air Quality Standards listed in Table 1 of ASHRAE Standard 62-1981 for the noted time periods, i.e. CO - 35 ppm for 1 hour and 9 ppm for 8 hours; $NO_2$ - 0.05 ppm for 8 hours; $SO_2$ - 0.03 ppm for 8 hours; respirable particulates - 260 $\mu g/m^3$ 8 hour average for total suspended particulates. The hourly average concentrations of carbon dioxide, formaldehyde, ozone and radon must be in compliance with Table 4 of ASHRAE Standard 62-1981, i.e. $CO_2$ - 2500 ppm; HCHO - 0.1 ppm; $O_3$ - 0.05 ppm; radon - 0.01 working levels. Volatile organic compounds are variable in composition and generally exhibit low concentrations in office buildings. While no standards exists

specific to the nonindustrial indoor environment, the concentrations of these substances will be measured and compared to those levels measured in other buildings. Unusually high concentrations of total or specific volatile organic compounds will be investigated further. Although GSA design policies preclude the use of asbestos in the construction of buildings, an asbestos survey will be conducted, including sampling of the interior air, to verify that asbestos hazards do not exist within the building.

## REFERENCES


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## ORIGINATOR

National Bureau of Standards, for the Office of Real Property Development, Public Building Service

# PART II

# CONSTRUCTION SPECIFICATIONS

## SECTION 00000 - THERMAL AND ENVIRONMENTAL PERFORMANCE SENSORS

THIS SECTION COVERS THE PROCUREMENT AND INSTALLATION OF SENSORS AND EQUIPMENT USED IN BUILDING THERMAL AND ENVIRONMENTAL PERFORMANCE EVALUATION INCLUDING THE CONNECTION OF THE SENSORS TO A CENTRAL DIAGNOSTIC CENTER REFERRED TO AS THE "DC."

### PART 1 - GENERAL

1.01 DESCRIPTION OF WORK:

A. Extent of this section includes all work necessary for the procurement and installation of sensors and equipment for use in building thermal and environmental performance evaluations. It covers sensor and equipment specifications, installation, connection to the Diagnostic Center (DC), and testing.

B. Types of sensors and equipment in this section include the following:

1. Environmental: sensors for use in a variety of the diagnostic tests.

   a. Anemometer: wind speed and direction.

   b. Outside temperature thermistors.

   c. Inside temperature thermistors.

   d. Supply and return duct temperature thermistors.

2. Infiltration/Pressurization: equipment for use in measurements of building airtightness and ventilation rates.

   a. Tubing: For tracer gas injection, air sampling, and pressure difference measurement.

   b. Tracer injection system: Flowmeters, tubing, solenoid valves and wires for the injection of tracer gas.

   c. Air sampling system: Pumps for drawing air to the DC from sampling locations and tubing for connection of the pumps to measurement instruments.

   d. Fan switches: To provide switch closures indicating when individual air handlers are on.

   e. Tracer gas concentration measurement equipment: Gas chromatograph equipped with an electron capture detector for measuring tracer gas concentration.

f. Differential pressure transducers: To measure the pressure difference across the exterior walls.

3. Pollutant Monitors: For measuring concentrations of various indoor pollutants.

a. Carbon Dioxide ($CO_2$) monitor.

b. Carbon Monoxide (CO) monitor.

c. Particulate monitor.

d. Formaldehyde (HCHO) monitor.

4. General Supplies:

a. Compressed gas: Tracer gas (sulfur hexafluoride, $SF_6$), carrier gas for gas chromatograph, calibration gases for tracer gas and pollutant concentration measuring equipment.

b. Compressed gas regulators and tube fittings.

c. Compressed air pump and supply lines.

d. Vacuum pump and vacuum line.

e. Upright cabinet racks for mounting scientific equipment.

f. Air sample bags and personal exposure pumps.

g. Environmental Stations (ES): vented boxes in occupied space for interior thermistors and air sampling.

h. Wiring to connect sensors to the DC.

i. Spare materials: tubing, wire, thermistors, flowmeters, solenoid valves, pumps, pump repair kits, fan switches, etc.

1.02 QUALITY ASSURANCE:

A. Contractor Qualifications: Installation shall be provided by a speciality contractor of established reputation (or if newly organized, whose personnel have previously established a reputation in the same field), which is regularly engaged in, and which maintains a regular force of personnel skilled in the installation of building thermal sensors and long lengths of tubing and wiring, and shall have performed this work on previous projects.

1.03 SUBMITTALS:

A. Product Data: Submit manufacturer's technical data and installation instructions on all sensors and equipment including anemometer, thermistors, fan switches, flowmeters, solenoid valves, pumps, gas chromatograph/electron capture detector, differential pressure transducers, pollutant monitors, compressed air pump, and vacuum pump.

B. List of Label Names: Submit a list of all sensor wire and tube label names including the associated sensor type and location, as in the following example: (See list of sensor locations for locations and label names)

| Label Name | Type | Location |
|---|---|---|
| WSP | Wind Speed | -- |
| WDIR | Wind Direction | -- |
| TOUT | Outside Temp | -- |
| T/R/RF1 | Return Temp | Return Fan RF1 |
| T/R/RF2 | " " | " " RF2 |
| T/1 E/A-10 | Interior " | 1st Floor East Col.A-10 |
| T/1 E/B-15 | " " | " " " Col.B-15 |
| S/R/RF1 | Air Sample | Return Fan RF1 |
| S/1 E/A-10 | " " | 1st Floor East Col.A-10 |
| I/SF 1 | Injection | Supply Fan SF1 |
| I/SF 2 | " | " " SF2 |
| DP/1 E/A-10 | Pressure Diff | 1st Floor East Col.A-10 |
| DP/1 E/B-15 | " " | " " " Col.B-15 |
| F/SF 1 | Fan Switch | Supply Fan SF 1 |
| F/SF 2 | " " | " " SF 2 |

1.04 SEQUENCING/SCHEDULING:

A. Pre-Interior Finishing: Install equipment within DC. Install anemometer, outside thermistors, return and supply duct thermistors, differential pressure transducers, fan switches and all associated wiring to the DC including the wiring from the ES's. Install the tracer gas injection and air sampling tubing. Install the compressed air and vacuum pumps and lines. Test anemometer, outside and duct thermistor wires, differential pressure transducers, fan switches, and compressed air and vacuum systems for proper operation. Test all tubing for continuity.

B. During Interior Finishing: Install all ES's and interior thermistors, and test the associated wiring for proper operation.

PART 2 - PRODUCTS

2.01 MATERIALS AND SUPPLIES:

A. Sensor wires: For connecting the thermistors, anemometer, differential pressure transducers, and fan switches to the DC. All conductors within cables shall be 22 gauge, stranded tinned copper, color-coded, vinyl plastic insulated with jacket overall, voltage rating 200 V.

1. Thermistors and Fan Switches: 2-conductor, nominal OD = 0.175 in.

2. Differential Pressure Transducers: 4-conductor, 2 shielded pairs, nominal OD = 0.165 in.

3. Anemometer: 5-conductor, nominal OD = 0.194 in.

4. Quantity: As necessary for all connections such that they are continuous from sensor to DC. Supply an additional 500 ft of 2-conductor, 500 ft of 4-conductor, and 250 ft of 5-conductor. All from same manufacturer.

B. Tubing: For connection between DC and air sampling locations, and between DC and tracer gas injection locations.

1. Material: Nylon, high flexibility, low friction.

2. Air Sampling: OD = 0.375 in., ID = 0.295 in.

3. Tracer gas injection: OD = 0.125 in., ID = 0.095 in.

4. Quantity: As necessary for all connections such that they are continuous from each sampling and injection location to the DC, and as necessary for air sampling and tracer gas injection systems. Supply an additional 1000 ft of the air sampling and 500 ft of the tracer gas injection tubing. All from same manufacturer.

C. Pressure Transducer Tubing: For connecting the differential pressure transducers to the outside pressure taps.

1. Material: Flexible polyethylene tubing, capable of achieving a leak-proof seal with friction-fit hose fittings.

2. Size: ID = 0.1875 in., OD = 0.3125 in.

3. Quantity: As necessary for all the differential pressure transducers such that the lines are continuous from the outside pressure tap to the pressure transducer. Supply an additional 200 ft. All from same manufacturer.

D. Compressed Gas Cylinders:

1. Carrier gas: For tracer gas concentration measurement equipment.

a. Specifications: As specified by manufacturer of gas chromatograph/electron capture detector.

b. Quantity: 4 size #1A cylinders.

2. Sulfur Hexafluoride: Tracer gas.

a. Specifications: Commercial purity, 99.8% minimum.

b. Quantity: 3 size #1A cylinders (at least 100 lb each), and 3 size #3 cylinders (at least 10 lb each).

3. Sulfur Hexafluoride Calibration Gas: For calibrating gas chromatograph/electron capture detector.

a. Specifications: Primary standard, 1 ppm $SF_6$ in dry air.

b. Quantity: 1 size #1A cylinder (at least 200 $ft^3$).

4. Ultra Zero Air: For calibrating pollutant monitors.

a. Specifications: Certified, THC as $CH_4 < 0.1$ ppm.

b. Quantity: 2 size #1A cylinders (at least 200 $ft^3$ each).

5. Carbon Dioxide Free Air: For calibrating $CO_2$ monitor.

a. Specifications: Certified, total $CO_2$ equivalent < 5 ppm.

b. Quantity: 2 size #1A cylinders (at least 200 $ft^3$ each).

6. Carbon Dioxide Calibration Gases: For calibrating $CO_2$ monitor.

a. Specifications: Primary standard, in dry air, 250 ppm and 750 ppm.

b. Quantity: 1 size #1A cylinder of 250 ppm (at least 200 $ft^3$) and 1 size #1A cylinder of 750 ppm (at least 200 $ft^3$).

7. Carbon Monoxide Calibration Gases: For calibrating CO monitor.

a. Specifications: Primary standard, in dry air, 5 ppm and 20 ppm.

b. Quantity: 1 size #1A cylinder of 5 ppm (at least 100 $ft^3$) and 1 size #1A cylinder of 20 ppm (at least 100 $ft^3$).

E. Compressed Gas Regulators:

1. Description: 2-stage, all brass body.

2. Requirements:

a. Cylinder valve outlet CGA No.590, delivery pressure 4-50 psig, quantity 5 (for $SF_6$).

b. Cylinder valve outlet CGA No.590, delivery pressure 4-100 psig, quantity 5 (for ultra zero air, $CO_2$ free air, and CO calibration gas).

c. Cylinder valve outlet CGA No.320, delivery pressure 4-100 psig, quantity 2 (for $CO_2$ calibration gas).

d. Cylinder valve outlet appropriate to carrier gas, quantity 2.

F. Fittings: For nylon air sample and tracer injection tubes.

1. Description: Brass tube fittings, providing leak-proof and torque-free seal, requiring no special tools for installation. All from same manufacturer.

2. Requirements:

a. As necessary to connect regulators, flowmeters, solenoid valves, and calibration gas generators to 1/8 in. OD nylon tubing, and to connect air sample pumps and pollutant monitors to 3/8 in. OD nylon tubing.

b. Additional fittings: 50 each of 1/8 in. OD tubing tees, 3/8 in. OD tubing tees, 1/8 in. OD tubing unions, 3/8 in. OD tubing unions, male connectors (1/8 in. OD tubing to 1/4 in. male pipe), male connectors (1/8 in. OD tubing to 1/8 in. male pipe), and tees (1/8 in. OD tubing, 1/8 in. OD tubing, 1/8 in. male pipe).

G. Air Sample Bags: For collecting air samples within the building space for ventilation system performance and pollutant concentration measurements.

1. Specifications: 10 liter capacity, 3/16 in. ID hose-fit on/off valve, does not absorb $SF_6$.

2. Quantity: 100.

H. Personal Exposure Pumps: Small, battery operated pumps for filling air sample bags.

1. Specifications: 3/16 in. ID hose connections on inlet and outlet, adjustable flow rate between 1 and 80 liters/hour, flow constant within ± 5%, battery operated, minimum battery life of 10 hours at 1 liter/hour, low noise level compatible with office use.

2. Quantity: 20 pumps, all from same manufacturer.

2.02 EQUIPMENT:

A. Anemometer: For measurement of wind speed and direction on the building roof. The device shall combine both measurements and be mounted on a mast.

1. Wind speed: Cup anemometer employing a DC generator, linear DCV output, sensitivity approximately 4 V at 100 mph, accuracy ±1 mph, threshold maximum of 1 mph.

2. Wind direction: Transmitter vane employing a 1000 Ohm potentiometer, linear relation between 0-360° direction and 0-1000 Ohm potentiometer resistance, constant DC input voltage no greater than 12 V, 3 wire connection (supply voltage, ground, output voltage), accuracy ±5%, threshold maximum of 0.7 mph, linearity ±0.5%.

3. Additional Equipment:

a. Cross Arm: For mounting cup anemometer and direction vane, and subsequent mounting on mast.

b. Mast: For mounting cross arm, at least 20 ft tall, such as 1.5 ID water pipe. Must be compatible with cross arm.

c. Extra Anemometer Cups: At least 3, must be compatible with cup anemometer.

B. Thermistors: For air temperature measurement in ducts, interior space, and outside.

1. Description: Interchangeable, linear air temperature probes with a 0.1% precision resistor pair. All from same manufacturer.

2. Specifications:

a. Thermistor Probes: Interchangeable, stainless steel cage around an epoxy encapsulated thermistor, accuracy of ±0.15 °C in range of -30 to 100 °C, with standard 1/4 in. 3-conductor phone plug on end of 10 ft cable.

b. Resistor Pairs: 0.1% metal film resistors, resistance as specified by manufacturer for interior and duct temperature range (approximately 30 to 100 °F) and exterior temperature range (-30 to 120 °F). One resistor ($R_2$) for connection to probe, and other resistor ($R_1$) for connection to thermistor reading equipment.

3. Preparation: All $R_1$ resistors must be securely packaged for use by testing agent in data acquistion system. All $R_2$ resistors must be wired with probe as shown in figure 2.

4. Quantity: Inside type, one for each interior and duct location, plus 10 extra. Outside type, one for each outside location plus 2 extra.

C. Differential Pressure Transducers: To measure pressure difference across exterior walls.

1. Description: Low range differential pressure transducers with electronic output, compatible power supply and signal conditioner. Rack mountable case for power supply and signal conditioner. All from same manufacturer.

2. Transducer Specifications: Range approximately ±0.50 in. $H_2O$, accuracy and linearity of ±0.5% of full scale, temperature compensated from 0 to 160 degress F, pressure connection 3/16 in. ID hose.

3. Power Supply Specifications: Must be compatible with transducer, power input 115 VAC, capable of handling up to 50 channels of pressure difference measurement.

4. Signal Conditioner Specifications: Must be compatible with transducers and power supply, output voltage ±10 VDC, front-panel zero and span adjustments.

5. Mounting Case for Power Supply and Signal Conditioner: Rack mountable case capable of handling up to 50 transducer channels, compatible with power supply and signal conditioners.

6. Quantity: One transducer for each differential pressure location, plus six extra. Sufficient numbers of power supplies, signal conditioners, and mounting cases to accomodate all the transducers.

D. Fan Switches: To provide a switch closure as a signal of air handler status. Requires relay and socket pair.

1. Relay Specifications: General purpose relays, enclosed in clear, poly-carbonate dust cover, action - triple pole, double throw, input voltage 115 VAC, standard 11-pin octal type plug.

2. Socket Specifications: 11-pin octal type socket, must be compatible with the relay.

3. Quantity: One relay/socket pair for each tracer gas injection location, plus six extra. All from same manufacturer.

E. Environmental Stations (ES): Vented boxes for installation of interior thermistors and air sampling tubes.

1. Specifications: Lockable, vented, lightweight boxes, such as thermostat covers. At least 7 in. by 3.5 in. by 3 in.. A single key shall be able to open all the ES's in the building, and six copies of the key shall be provided.

2. Quantity: One for each interior sampling location, plus 6 extra. All from same manufacturer.

F. Solenoid Valves: For controlling tracer gas injection.

1. Description: Solenoid operated pnuematic valve, directional 2-way type, normally closed, zero leakage.

2. Specifications: Maximum pressure 100 psi, power input 110 VAC, power consumption 10 Watts maximum, room temperature gas, pipe thread inlet and outlet.

3. Preparation: Provide and install fittings to connect pipe thread valve inlet and outlet to 1/8 in. OD nylon tube.

4. Quantity: One valve for each tracer gas injection location, plus 12 extra. 24 extra pipe-to-tube fittings. All from same manufacturer.

G. Flowmeters: For measuring and controlling tracer gas injection rates. To be installed in tracer gas injection system.

1. Description: Rotameter type flowmeters with manual valve for controlling flow rate. Each meter held in manufacturer's rack mountable case or holder, containing an appropriately sized control valve and 1/8 in. OD tube fittings on the inlet and outlet. All from same manufacturer.

2. Specifications: Calibrated by manufacturer for $SF_6$ at 30 psig within meter and 20 °C. Accuracy of ±2% of full scale or better. High accuracy needle valve for controlling flow rate.

3. Sizing: For each tracer gas injection location, determine tracer gas flow rate that will yield a concentration of 100 ppb in the interior volume corresponding to that location after a 5 minute injection. This injection rate should be approximately 50% of full-scale on the flowmeter for that injection location.

4. Quantity: One for each tracer gas injection location plus one extra of each scale provided.

H. Air Sample Pumps: For pumping air from air sample locations, through 3/8 in. OD nylon tubing, to the DC. To be installed in air sampling system.

1. Description: Dual-headed pumps, rated for continuous duty. Motor must be service free, totally enclosed, brushless, with sealed ball bearings, and with thermal overload protection.

2. Specifications: Capacity 900 $in^3$/min per head in free air, maximum pressure 18 psig, power 115 VAC, class B motor, 1/25 hp motor at 1550 rpm, less than 2 amp. All from same manufacturer.

3. Connections: Provide and install fittings on inlet and outlet of each pump head for connection of 3/8 in. OD nylon tubes.

4. Other Materials: Spare parts, including diaphragms, valves, valve retainers, cams, pump-to-tube fittings, etc.

5. Quantity: 30 dual-headed pumps, plus 5 extra. 2 sets of spare parts for each dual headed pump.

I. Compressed Air Equipment: Pump and pressure lines to provide compressed air supply to the DC.

1. Description: Oil-less pump, rated for continuous duty, with storage tank to provide pulseless flow, filtered inlet to remove liquids, water vapor and particles, including appropriately rated lines to connect inlet to the outdoors and outlet to the DC.

2. Pump Specifications: Maximum pressure of 100 psi, free-air capacity of 4 scfm, power requirement of 115 VAC, motor protected for overload.

3. Other Materials: All fittings necessary for pressure lines and appropriate filters.

4. Quantity: One ready for operation, fully accessorized with all required spare parts.

J. Vacuum Equipment: Pump and pressure lines to provide vacuum to the DC.

1. Description: Oil-less pump, rated for continuous duty, including appropriately rated lines and fittings to connect pump inlet to the DC and outlet to the outdoors.

2. Pump Specifications: Free-air capacity at least 2 scfm, maximum vacuum 15 in. Hg, maximum pressure 60 psig continuous, power requirement of 115 VAC.

3. Other Materials: All fittings necessary for pressure lines.

4. Quantity: One ready for operation, fully accessorized with all required spare parts.

K. Carbon Dioxide Monitor: For measuring $CO_2$ concentrations of air samples.

1. Description: Real-time monitor based on non-dispersive infrared measurement or an electrochemical sensor.

2. Specifications: Range 100 to 3000 ppm, response time of one minute, accuracy of $\pm$ 5 ppm, linearity of $\pm$ 1%, minimal interference from water vapor and carbon monoxide, internal air pump, calibrated by manufacturer in above concentration range, output DC volts.

3. Connections: Provide and install fittings on inlet and outlet for connection to 3/8 in. OD nylon tubing.

4. Quantity: One ready for operation, fully accessorized with all required spare parts and attachments including filters.

L. Carbon Monoxide Monitor: For measuring CO concentrations of air samples.

1. Description: Real-time monitor based on non-dispersive infrared measurement or an electrochemical sensor.

2. Specifications: Range 1 to 50 ppm, response time of one minute, accuracy of $\pm$ 0.2 ppm, linearity of $\pm$ 1%, minimal interference from water vapor or carbon dioxide, internal air pump, calibrated by manufacturer in above concentration range, output DC volts.

3. Connections: Provide and install fittings on inlet and outlet for connection to 3/8 in. OD nylon tubing.

4. Quantity: One ready for operation, fully accessorized with all required spare parts and attachments including filters.

M. Particulate Monitor: For measuring particulate concentrations of air samples.

1. Description: Field portable, real-time, airborne particle counter based on optical scattering. With real time clock, LCD display, mass flow sample metering, on-board thermal printer, automatic self-calibration, RS232C interface, relative humidity and temperature measurements, low noise level under operation.

2. Specifications: Sample airflow rate roughly 1 scfm; sample duration variable from 5 seconds to 60 minutes; particle size ranges of 0.3, 0.5, 0.7, 1.0, 5.0 and 10.0 microns; automatic field calibration; weight less than 30 pounds.

3. Quantity: One ready for operation, fully accessorized with all required spare parts and attachments.

N. Formaldehyde Monitor: For measuring HCHO concentrations of air samples, plus required calibration equipment.

1. Description: Portable, real-time HCHO detector, no interference from water vapor or other aldehydes.

2. Specifications: Initially factory calibrated for HCHO, 0-10 ppm full-scale, detection limit of 5 to 10 ppb, accuracy and reproducibility better than 5%.

3. Quantity: One, plus all required attachments, expendible supplies, and spare parts such as pumps, tubing, sample cells, and reference cells.

4. Calibration Equipment: For on-site calibration of HCHO monitor in range of interest.

   a. Gas Standards Generator: 5 liter/min flowmeter, temperature setpoints of 25, 80 and 100 $^{\circ}$C.

b. HCHO Permeation Tubes: Permeation tubes certified at 80 and 100 $^{o}C$.

O. Tracer Gas Concentration Measurement Equipment: For measuring sulfur hexafluoride ($SF_6$) concentration in air samples.

1. Description: Real-time monitor based on gas chromatography and electron capture detection.

2. Specifications: Range from 1 to 250 ppb, accuracy of ± 2% of reading, internal air pump, maximum analysis time of one minute.

P. Upright Cabinet Racks

1. Description: Steel cabinet for installing scientific equipment.

2. Specifications: 70 in. high, 24 in. outside width, 32 in. outside depth, 29 in. clear inside depth, to be compatible with "rack mountable" equipment. Welded 14 gauge steel frame, 16 gauge panel mounting rail supports, 18 gauge sides and top. Front and rear panel mounting tapped 10-32 on E.I.A. universal spacing.

3. Quantity: Two.

## PART 3 - EXECUTION

### 3.01 PREPARATION:

A. Study Building Plans: From building plans, mechanical equipment specifications and on-site inspection, develop familiarity with the building, the number and location of air handlers, the zones which they serve, and the location of the DC.

B. Study Sensor Locations: Examine building plans and list of sensor locations for thermistor, air sampling,fan switch, differential pressure gauge, and tracer gas injection locations.

1. Environmental Stations (ES): At least one per floor as specified in the building interior air sampling locations in the list of sensor locations, in central locations at least 10 ft from windows, doors and heavy office equipment (e.g. copying machines), and at a height of roughly 4 ft off floor.

ON EACH FLOOR

i. If the floor is served by different air handlers, a minimum of one for each air handler, with an additional location for each additional 5000 $ft^2$ of floor area.

OR

ii. If entire floor is served by the same air handler, one for each 5000 $ft^2$ of floor area.

2. Thermistors:

   a. Outside: Two locations on the roof and two on the ground floor as specified in the exterior sampling locations in the list of sensor locations, out of direct sunlight, clear of any building exhaust vents and that will not interfere with regular maintainance activities.

   b. Floor Returns: One location where the ceiling return plenum connects with each vertical return air shaft as specified in the floor return air sampling locations in the list of sensor locations, upstream of the shaft and any dampers.

   c. Return Fans: One location for each return fan as specified in the main supply fan air sampling locations in the list of sensor locations, upstream of the fan and downstream of the merger of all lesser ducts into the main return duct.

   d. Supply Fans: One location for each supply fan as specified in the main supply fan air sampling locations in the list of sensor locations, downstream of the fan at least 10 duct diameters from the air handler.

3. Air Sampling:

   a. ES: One for each ES (corresponding to the locations in section 3.01.B.1).

   b. Outside: One for each outside thermistor location (corresponding to the locations in section 3.01.B.2.a).

   c. Floor Returns: One location at each point where the ceiling return air plenum connects with vertical return air shaft (corresponding to the locations in section 3.01.B.2.b).

   d. Return Fans: One location for each main return fan (corresponding to the locations in section 3.01.B.2.c).

   e. Supply Fans: Two locations in each main supply duct. One immediately upstream of the supply fan and tracer gas injection location, and the other (corresponding to the locations in section 3.01.B.2.d) downstream of the fan at least 10 duct diameters from the air handler.

4. Tracer Injection Locations: One location for each fan as specified in the list of sensor locations, immediately upstream of the fan.

5. Pressure Transducer Locations: As noted on drawings and list of sensor locations. At least three per exterior wall, located at or near ground level, mid-height, and highest occupied floor. Elevation above ground level of each transducer must be noted in list referred to in section 1.03.B.

6. Fan Switches: One location for each supply fan as specified in the list of sensor locations, located near a 120 VAC source which is

activated if and only if the fan is on.

## 3.02 INSTALLATION:

A. Sensors:

1. Anemometers: Mount securely on a 20 ft mast and locate mast on the highest point of the building. Secure mast with guide wires. Ground mast for lightning according to local building codes.

2. Environmental Stations: Mount on interior walls or interior columns at a height of roughly 4 ft above the floor according to the manufacturer's instructions. All ES keys shall be stored within the DC tool cabinet.

3. Thermistors:

   a. Outside: Secure probe with cable ties such that it will not move under extreme winds or with time, nor interfere with any regular maintainance activities. Secure phone jack and associated wiring in immediate vicinity of probe.

   b. Interior: Secure probe with cable tie in each environmental station (ES) such that it is suspended at least 1 in from any surface. Secure phone jack and associated wiring in suspended ceiling or raised access floor, directly above or below the ES, depending on the route used to run the thermistor wire from the ES to the DC.

   c. Duct: Secure probe with cable ties in center of duct, at least 3 ft from any moving parts such as dampers, heating or cooling coils or replacable air filters. Secure phone jack and associated wiring in immediate vicinity of probe.

4. Differential Pressure Transducers:

   a. Transducers: Mount securely near the outside pressure tap, away from any source of supply air.

   b. Pressure Tap: Smooth, circular hole in building skin, lined with 2 in. long, 5/16 in. ID tube. Outside end of tube should be flush with exterior surface. Tube should be sealed into the hole with an appropriate material to prevent water or air intrusion.

   c. Pressure Lines: Connect outside pressure tap to high pressure side of transducer. Friction fit plastic pressure line 1 in. inside pressure tap and seal connection with appropriate sealant to prevent air leakage. Leave low pressure side of transducer open to interior air.

5. Fan Switches: Since these devices are connected to 120 VAC power, they must not be exposed. They may be installed within the electric boxes which contain the fan on/off switches. They must be secured with a permanent adhesive, or other fasteners, to prevent their moving or falling.

B. Tubing and Wiring: All tubing and wiring must be unobtrusive in terms of damper operation and other moving parts. Interior installations must be contained in fireproof chases. Chases used for other purposes are adequate. All tubing and wiring must be labeled at the DC end with pressure sensitive adhesive labels. Extreme care must be taken to avoid "kinking" or collapsing of the tubing during installation. All tubing must be capped immediately after installation to avoid intrusion of dust and dirt. The installed tubing must also be mechanically protected from puncture, kinking, and constriction.

1. Outside Thermistor Wiring: Run 2-conductor wire from thermistor locations to the DC. Connect banana plugs to DC end of wire and label DC end with the thermistor location. Wire exposed to the outdoors must be secured every 3 ft with cable ties and must not be exposed to any moving parts or in the paths of any service personnel on the building roof.

2. Interior Thermistor Wiring: Run 2-conductor wire from each ES location to the DC. Connect banana plugs to DC end of wire and label DC end with the thermistor location. Any exposed wiring within the occupied space must be secured every 1 ft and painted to the color of the interior finish.

3. Floor Return and Fan Thermistor Wiring: Run 2-conductor wire from each duct location to the DC. Connect banana plugs to DC end of wire and label DC end with the thermistor location. Any wire within the air handler must be secured every 2 ft with cable ties and must not pass through any dampers or near any other moving parts. Wire passing through mechanical equipment rooms must be secured with cable ties every 4 ft and must not extend across any walkways.

4. Fan Switch Wiring: Run 2-conductor wire from each fan switch location to the DC. Connect 2-conductor standard 1/8 in. phone plugs to DC end of wire and label DC end with the fan switch location. Wire passing through mechanical equipment rooms must be secured with cable ties every 4 ft and must not extend across any walkways.

5. Anemometer Wiring: Run 5-conductor wire from anemometer location to the DC. Connect banana plugs to DC end of wire and label DC end with the appropriate labels. Wire exposed to the outdoors must be secured every 3 ft with cable ties and must not be exposed to any moving parts or in the paths of any service personnel on the building roof.

6. Pressure Transducer Wiring: Run 4-conductor wire from each transducer to the DC. Label DC end with the pressure transducer location and attach to pressure transducer electronics according to manufacturer's instructions. Any exposed wiring within occupied space must be secured every 1 ft and painted to the color of the interior finish.

7. Interior Air Sample Tubing: Run 3/8 in. OD tubing from each ES location to the air sampling system in the DC. Expose 1 1/2 in. of tubing within the ES and secure within ES with cable ties. Any exposed tubing within the occupied space must be secured every 1 ft and painted to the color of the interior finish. Label DC end of tube with air sample location.

8. Floor Return Air Sample Tubing: Run 3/8 in. OD tubing from each floor return location to the air sampling system in the DC. These locations are all within dropped ceiling return air plenums and must be secured with cable ties. The tubing must not obstruct any return air or fire dampers. Label DC end of tube with air sample location.

9. Exterior Air Sample Tubing: Run 3/8 in. OD tubing from each exterior location to the air sampling system in the DC. Expose 1 1/2 in. of tubing to the outdoors and secure to the exterior of the building every 3 ft. Label DC end of tube with air sample location.

10. Fan Sample Tubing: Run 3/8 in. OD tubing from each fan location to the air sampling system in the DC. Fan end should be in center of duct, at least 3 ft from any moving parts, and secured with a cable tie. Tubing within air handler must be secured every 2 ft with cable ties and must not pass through any dampers or near other moving parts. Tubing running through mechanical equipment rooms must be secured with cable ties every 4 ft and must not run across any walkways. Label DC end of tube with air sample location.

11. Fan Tracer Injection Tubing: Run 1/8 in. OD tubing from each fan location to the tracer gas injection system in the DC. Locate within center of duct and secure with cable ties at least 3 ft from any moving parts. Tubing within the air handler must be secured every 2 ft with cable ties and must not pass near other moving parts. Tubing running through mechanical equipment rooms must be secured with cable ties every 4 ft and must not run across any walkways. Label DC end of tube with tracer gas injection location.

C. Equipment

1. Tracer Injection System: Each injection tube is connected to a flowmeter, which is then connected to a solenoid valve. (See figure 3) A labelled wire runs from each solenoid valve to a common location in the DC.

a. Injection Tubing: Each injection tube from an injection site must be labelled and connected to the outlet of an appropriately sized flowmeter.

b. Flowmeters: For each injection line, a flowmeter must be installed in a rack, according to the manufacturers instructions. The outlet is connected to the tracer injection tube and the inlet is connected to a solenoid.

c. Solenoids: The tube from each flowmeter inlet runs to a solenoid outlet. All the solenoids are mounted in a rack according to the manufacturers instructions. A 10 ft length of 1/8 in. OD tubing runs from the solenoid inlet and is labelled as appropriate for its injection site. The tube end must be cut cleanly. A 10 ft length of 2-conductor wire, rated for 115 VAC, 1 amp is connected to the solenoid and is labelled accordingly.

d. Rack for Solenoids and Flowmeters: A rack must be provided for mounting the solenoids and flowmeters securely, and must fit in the upright cabinet racks (see section 2.02.P). The design of the flowmeter rack will depend on the specific flowmeters and solenoid valves that are used. Provision must be made for accessibility to fittings and flowmeter valves, and the flowmeter scale must be visible.

e. Labelling: The label names on the injection tube from the building, on the injection tube from the solenoid, and on the solenoid wire must all be the same for each injection location, and must correspond to the label names provided in the list of sensor locations and in the list referred to in section 1.03.B.

2. Air Sampling System: The air sampling tubes are to be compatible with the inlets of the air sampling pumps. Separate tubes must run from each pump outlet to a common location in the DC.

a. Air Sampling Tubing: Each air sample tube must be labelled and prepared for connection to the inlet of an air sampling pump.

b. Air Sampling Pumps: Thirty dual-headed air sampling pumps must be mounted on a shelf according to the manufacturers instructions.

c. Shelf for Air Sampling Pumps: A shelf must be provided for mounting the pumps securely. The design of the shelf will depend on the specific pumps that are used, but the shelf must be compatible with the upright cabinet racks (see section 2.02.P). Provisions must be made for accessibility to pump fittings and for pump repair.

d. Air Sampling Outlet Lines: A labelled, 20 ft length of 3/8 in. OD tubing must run from each pump to a common location in the DC. Each tube must be cut cleanly at the open end. The tube bundle must be secured with cable ties and not obstruct the interior space of the DC.

e. Labelling: The label names on the tubes from the air sampling locations must correspond to the label names in the list of sensor locations and in the list referred to in section 1.03.B. Separate label names for the air sampling pump outlet tubes must be on both ends of these tubes, and on the pumps.

3. Compressed Air System: A 100 psi compressed air supply must be available in the DC. The pump can be located anywhere in the building where pump noise will not be a problem, but the pump must be accessible for repair. An on/off switch for the pump must be located in the DC. The inlet line to the pump must be located outside of the building, far from any building exhaust vents. The compressed air line in the DC must be securely mounted on a wall, equipped with an on/off valve and 1/8 in. OD tube fittings.

4. Vacuum System: A vacuum line must be available in the DC. The pump can be located anywhere in the building where pump noise will not be a problem, but the pump must be accessible for repair. An on/off switch for the pump must be located in the DC. The outlet from the pump must be located outside of the building, far from any building inlet vents. The vacuum line in the DC must be equipped with a valve and 1/8 in. OD tube fittings.

5. Compressed Gas Cylinders: There must be a rack for securing ten size #1A compressed gas cylinders and four size #3 cylinders in the DC. The rack should contain the following compressed gases: carrier gas for the tracer gas equipment, sulfur hexafluoride, sulfur hexafluoride calibration gas, ultra zero air, carbon dioxide free air, carbon dioxide calibration gases (2), carbon monoxide calibration gases (2). All remaining cylinders are to be held in storage.

6. Differential Pressure Transducer Electronics: Mount pressure transducer power supply and signal conditioning equipment into the mounting case according to the manufacturers instructions. Connect all required wiring among components according to the manufacturer's instructions. Install mounting case in upright cabinet racks according to manufacturer's instructions.

7. Tracer Gas and Pollutant Monitoring Equipment: This equipment is extremely sensitive and requires special expertise for check-out, set-up, and operation. These devices are to remain unopened and stored in the DC.

8. Additional Materials: All of the following items are to be stored as received in the DC tool cabinet:
   - Compressed gas regulators
   - Air sampling bags
   - Personal exposure pumps
   - Spare tube fittings
   - Spare sensors: thermistors, pressure transducers, fan switches, flowmeters, solenoids, air sampling pumps, anemometer cups
   - Spare parts for all equipment
   - Spare tubing and wiring

3.03 TESTING:

A. Anemometer:

1. Wind speed: Measure voltage at DC end of wind speed wire and convert to mph according to manufacturers calibration. Compare a five minute average to a reading from a nearby weather station. Test must be under nonzero wind speed conditions.

2. Wind direction: Measure voltage at DC end of wind direction wire and convert to direction according to manufacturers calibration. Compare a five minute average to a reading from a nearby weather station. Test must be under nonzero wind speed conditions.

B. Thermistor Wiring: Before installing thermistors, apply roughly 2 VDC to the sensor end of the thermsitor wire. Measure voltage at the DC end of the wire to verify label name and to check for continuity.

C. Tubing: The continuity and integrity of the tubing must be verified soon after installation. Once this has been accomplished for a tube, the open ends must be securely capped to prevent the intrusion of liquids or particles.

1. Tracer injection: Connect small pump at DC end of each injection tube, upsteam of the flowmeter, and draw air through tube at a rate of at least 1 scfh. Check other end of tube with flowmeter to verify DC label and check for existence of blockage within the tube.

2. Air sampling: Connect DC end of each air sampling tube to an air sample pump, turn on pump and measure airflow output of pump. Check other end of tube with flowmeter to verify DC label and check for existence of blockage within the tube.

D. Differential Pressure Gauges: Calibrate each transducer after installation using a portable differential pressure gauge. Compare the calibration gauge reading to the transducer reading obtained in the DC with the transducer electronics.

E. Fan Switches: Measure line continuity at DC end of each fan switch wire. The circuit should be closed when the corresponding fan is on and open when the fan is off.

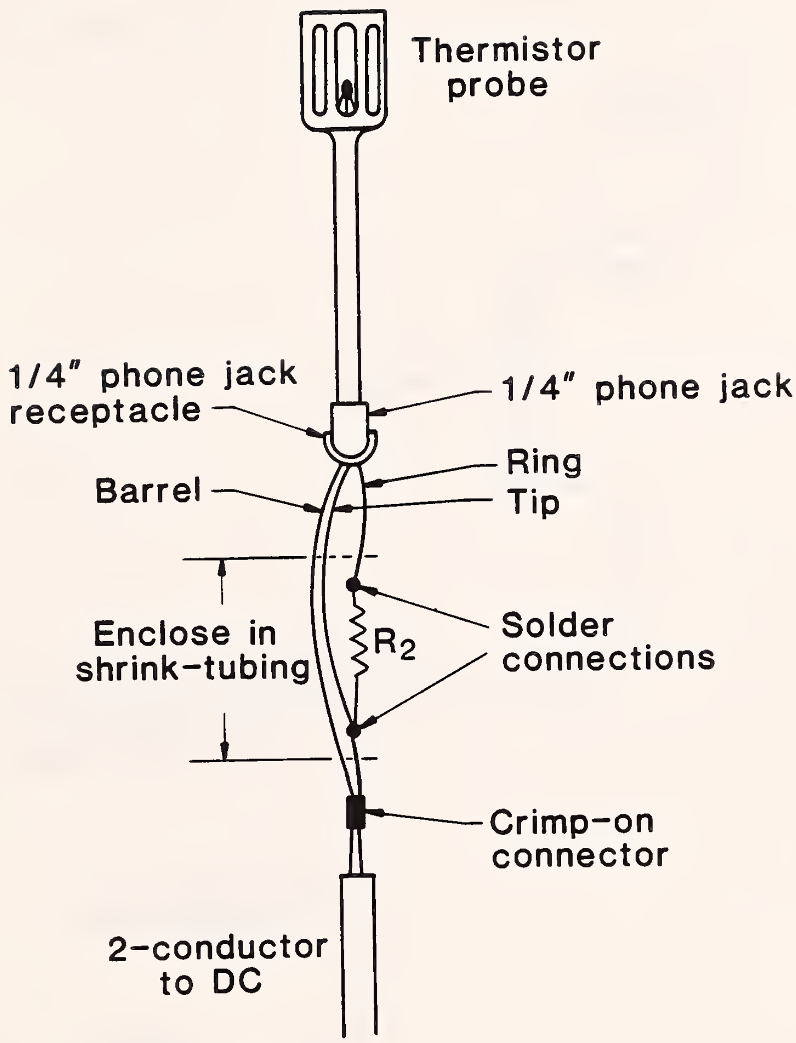



Figure 2 Thermistor Wiring Diagram

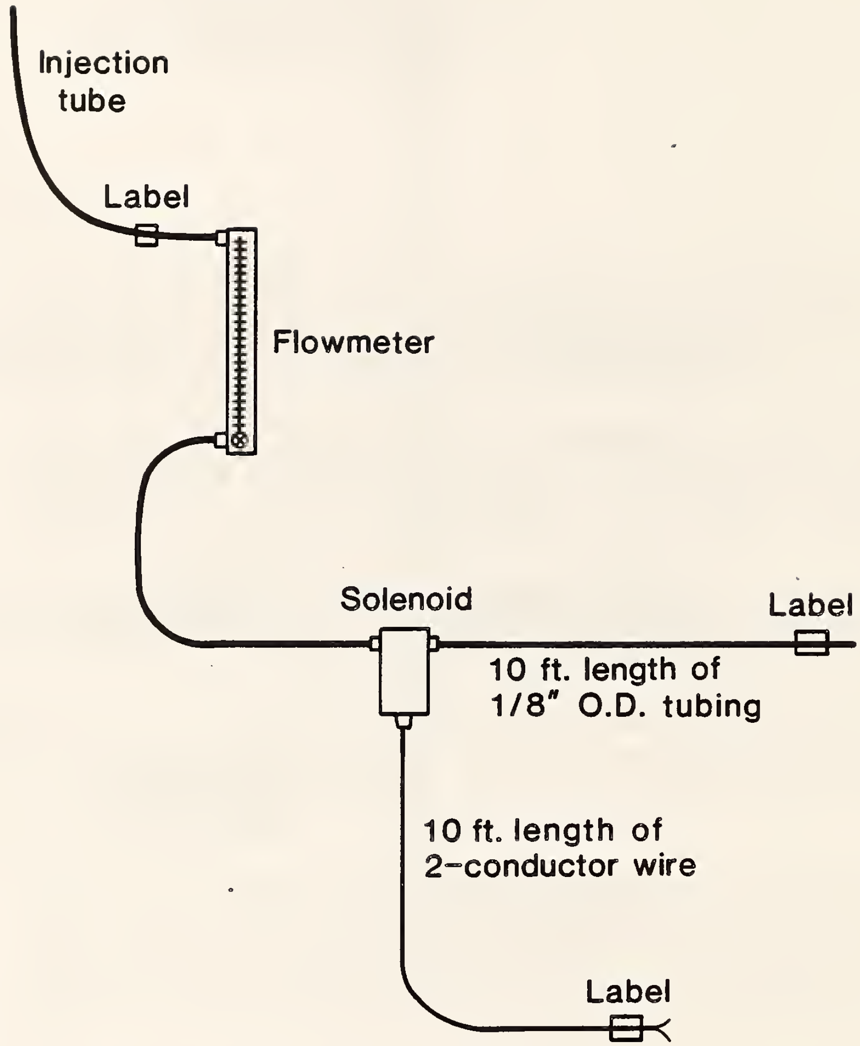



Figure 3 Tracer Gas Injection System Schematic

# PART III

# WORK STATEMENTS FOR BUILDING TESTS

In order to evaluate the thermal and environmental performance of the building, a series of tests will be conducted. This section contains work statements describing how each test is to be carried out, for use in procuring contract services of testing agents to perform the measurements. Some of the tests will employ sensors and measurement equipment that are already installed in the building. Sensor wires and tubing will terminate in a central location within the building, referred to as the diagnositc center or DC, which will also contain some of the measurement equipment. Details on the equipment, the sensor locations, and the DC will be provided to the testing agent. The work statements are divided into those covering tests that are to be conducted before the installation of interior furnishings and occupancy, and those tests that are to be conducted both before and after occupancy.

Pre-Occupancy: The following tests are to be performed before the building interior is furnished, but after the building envelope is completed and the HVAC system is operational. These tests are intended to evaluate the thermal envelope integrity early enough in the construction process such that defects can be identified and corrected.

1. Infrared Thermographic Inspection

2. R-Value Measurement

3. Whole Building Pressurization

4. Component Pressurization

Pre- and Post-Occupancy: The following tests evaluate aspects of the building's performance that need to be examined both before and after the building interior is furnished and occupied.

5. Tracer Gas Measurement of Air Infiltration

6. Tracer Gas Measurement of Ventilation

7. Indoor Pollutant Concentration Measurement

All testing shall be coordinated with the government's facility manager to assure minimum disruption to normal business routine and to avoid compromising the building's fire safety features. In some instances, the tests must be done at night or during unoccupied weekend hours.

1. <u>Infrared Thermographic Inspection</u> - To locate thermal defects in the building envelope, using an infrared imaging system, as described in ASHRAE Standard 101-1981, Application of Infrared Sensing Devices to the Assessment of Building Heat Loss Characteristics. The inspection involves assessing the heat loss characteristics of the building envelope from both inside and outside the building through a thermal image of the envelope surface.

Test Conditions: At the time of the infrared inspection, the exterior envelope of the building must be completed and the building must be heated to a constant, interior temperature (±2 °F). The inside inspections shall be conducted, if possible, before the suspended ceiling is installed and before interior furnishings such as curtains, furniture and pictures are installed. The outside temperature must be low enough to meet the inside-outside temperature difference requirements for the test that are specified in the ASHRAE standard.

Equipment: The test requires a thermal imaging system and equipment for measuring environmental conditions during the test. The specifications for the thermal imaging system are given in detail in the ASHRAE standard. The thermal imaging system for the exterior survey must be of Class A as described in section 5.D of the standard. The thermal imaging system in a Class A survey shall be able to recognize insulation voids and air leakage sites. For such a Class A survey, the instrument sensitivity expressed in Minimum Resolvable Temperature Difference (MRTD) shall be sufficient to distinguish a region with an R-value of 5 from an R-15 region for the wind speed and inside-outside temperature difference conditions during the inspection. The spatial resolution shall be sufficient to detect a 4 in. by 4 in. thermal anomaly. The thermal imaging system for the interior survey shall be of Class A as described in section 5.E of the ASHRAE standard. A Class A survey shall be able to identify the probable cause of a thermal anomaly, for example distinguish between insualtion voids and air leakage sites. The MRTD of the thermal imaging system must be able to resolve anomalies of 1.5 in. by 1.5 in. when the temperature difference between the anomaly and the background is the same as the interior wall surface temperature difference between an R-10 and R-15 wall area. For both exterior and interior surveys, the thermal imaging system shall be capable of producing hard copy records of the thermal image, or thermograms.

Additional equipment is required to measure the environmental conditions during the test including inside and outside air temperature, outside relative humidity, and wind speed.

Procedure: During the infrared inspection, relatively stable heat transfer conditions through the exterior envelope must exist. All exterior surveys shall be conducted at least 3 hours after sunset and before sunrise. Interior surveys may be conducted during any time of the day, except for solar loaded walls, as long as the minimum inside-outside temperature difference conditions given in table 6.1E of the ASHRAE standard exist for at least 2 hours prior to the survey. Exterior surveys shall not be conducted when the wind speed exceeds 15 mph, when the viewed building surfaces are not clear of water, snow and/or ice, or when fog is present.

The infrared inspection must include the observation and recording of environmental conditions including wind speed, precipitation, inside and outside air temperature, and outside relative humidity. Site factors such as shading, sun loading, unusual thermal radiation or reflection, and highly reflective exterior surface finishes on the building shall also be observed and recorded. Inside surveys require preparation of the building interior through the elimination of conditions that may interfere with the inspection, such as moving furniture, curtains or pictures from the surfaces to be inspected, and turning off perimeter heat approximately 1 hour before the survey. Conducting the interior survey before these interior furnishings are installed will expedite this preparation.

The exterior inspection involves producing a complete, two-dimensional map of the apparent temperature of the building's exterior envelope using the thermal imaging system. Thermal images of the building envelope, or thermograms, shall be recorded as photographs or video tapes. As much of the exterior envelope shall be inspected as is possible. The interior surveys also involve recording thermograms of the interior surfaces of the building envelope. Photographs in the visible spectrum of all inspected regions of the building envelope shall also be obtained. Additional information shall be recorded to locate the area of each thermogram within the building.

Data Interpretation: While the survey results do not lend themselves to quantitative determination of the envelope thermal resistance, a qualitative interpretation of the thermograms must be made. Based on the observations made during the inspection and consideration of the recorded thermograms, all thermal defects must be identified and sorted according to type. The generic defect types include insulation voids, thermal bridges, and air leakage sites. All specific instances of each defect type must be identified. A table of all defect types must be prepared, including a detailed description of all occurences of each defect in the building. The percent of wall area (excluding windows) associated with each type of defect shall be determined and listed in the table.

Submittals: For each survey, the testing agent shall provide the date and time of the survey, the environmental conditions (inside and outside air temperature, wind speed, and outdoor relative humidity), and a description of all site factors that may influence the thermal image. A description of the thermal imaging system, including equipment type and serial number, shall also be provided. All thermograms and photographs obtained during the survey must also be submitted. A list of the thermal defects identified must be submitted, including a description of each defect type, the location of each occurence of each defect, and the percent of wall area associated with each defect type.

References:

ASHRAE Standard 101, "Application of Infrared Sensing Devices to the Assessment of Building Heat Loss Characteristics," American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 1981.

ASTM Standard C 1060, "Standard Practice for Thermographic Inspection of Insulation Installations in Envelope Cavities of Wood Frame Buildings," American Society for Testing and Materials, 1986.

Grot, R.A., Persily, A.K., Chang, Y.M., Fang, J.B., Weber, S., Galowin, L.S., "Evaluation of the Thermal Integrity of the Building Envelopes of Eight Federal Office Buildings," NBSIR 85-3147, National Bureau of Standards, 1985.

ISO Standard 6781, "Thermal Insulation - Qualitative Detection of Thermal Irregularities in Building Envelopes - Infrared Method," International Organization for Standardization, 1983.

2. R-Value Measurement: To measure the thermal resistance of the building envelope at several locations for comparison to the resistance expected from calculations based on design. The tests shall employ both heat flow transducers and portable calorimeters, as described below. The heat flow transducer tests shall be conducted in accordance with ASTM C 518-76, Standard Test Method for Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter.

Test Conditions: At the time of these measurements, the exterior envelope of the building must be completed and the building must be heated to a constant, interior temperature (±2 $^{o}$F). The outside temperature must be low enough to maintain a sufficiently large temperature difference across the building envelope, as described in detail below.

Equipment:

The equipment required to conduct the heat flow transducer measurements is described in detail in ASTM C 518-76. The R-value measurements shall also employ portable calorimeter boxes, as described in the references and shown in figures 4 and 5. The portable calorimeter is a five-sided, insulated box containing an electric heater. The open end of the box is sealed against the outside wall that is being tested. Once installed, the heater is controlled to maintain a zero degree temperature difference between the box and the room, thus all the heat supplied to the box passes through the wall to the outside. This temperature difference is measured with a thermopile across the back of the box. The dimensions of the box depend on the size of the wall sections being tested, but two sizes shall be sufficient. For large wall sections the box should be roughly 4 ft by 6 ft, and for small wall sections the box should be about 3 ft by 3 ft. The five sides of the calorimeter must be insulated to at least R-20.

The R-value measurement system must include the following intsrumentation: a watt-hour meter to measure the power input to the electric heater; a controller to vary the power input based on the output of the thermopile across the box wall; the thermopile across the box wall; a safety thermostat within the calorimeter to prevent overheating; thermistors to measure the air temperatures outdoors, within the box, and within the room; heat flux transducers; and a data acquistion system to automatically record the air tempertures, power consumption, and the output of the heat flux transducers. The watt-hour meter must be accurate to within 1% and output a voltage pulse between 1 and 10 VDC for each 1 to 2 watt-hours of electricity use. The control system must maintain a temperature difference between the inside of the calorimeter and the room of no more than 2 $^{o}$F. An eighteen-junction thermopile, with the thermocouple junctions placed on the inner and outer surfaces of the box wall, must be installed across the back wall of the box. The safety thermostat must turn off the calorimeter heater if the temperature within the calorimeter reaches 120 $^{o}$F. The thermistors must measure the air temperatures with an accuracy of 0.5 $^{o}$F. The heat flux transducers must output a voltage of about 0.1 mVDC at a heat flux of 1 Btu/hr-ft$^{2}$-$^{o}$F. The transducers must be calibrated within 1%, at the temperatures and heat flux rates that are expected during the R-value measurements, using a hot plate apparatus as described in ASTM C 177-76. The data acquisition system must be compatible with the output of the watt-hour meter, the thermistors and the heat flux transducers, and must be able to calculate hourly averages of the temperatures, power consumption and heat flux based on readings every 60 seconds. The system must also be able to automaticaly record at least 2 weeks of such hourly averages.

Measurement Locations:

The calorimeter tests must be conducted at no less than three locations on each type of wall construction where the wall is judged to be properly insulated according to the infrared thermographic inspection. If thermal defects are detected, then there shall be three R-value measurements for each type of defect. All these locations will be located on shaded sides of the building to prevent the influence of solar radiation on the measurements. Additional measurement locations, such as overhangs, will be specified by the procuring agent. At each location there shall be one calorimeter and four heat flux transducers, unless the wall area is too small for a calorimeter, in which case only the heat flux transducers will be used. When both calorimeters and heat flux transducers are used, the transducers must be located within the wall area being tested with the calorimeter. Two of the heat flux transducers shall be located over wall framing members, if they exist, while the other two shall be located between framing members.

Procedure:

The measurement procedure involves installing the equipment at each measurement location and monitoring the air temperatures, heat flux, and power input to the calorimeter box at each location. The calorimeter must be secured to the test wall such that there is no air leakage between the calorimeter interior and the room. The four heat flux transducers must be secured to the wall with an appropriate cement or other material such that there is intimate contact between the transducer and the wall over the full area of the transducer. Thermistors must be placed within the room, outside the test wall, and within the calorimeter. Care must be taken to shield the thermistors from radiation, particularly the sensors located within the calorimeter and outside.

During the test, the building interior must be maintained at a temperature that is constant within 3 $^{\circ}$F. Also, the outside air temperature must be low enough such that the average inside-outside temperature difference over the entire test period is at least 20 $^{\circ}$F, and the minimum hourly average temperature difference is 10 $^{\circ}$F. Each measurement must last a minimum of four days in order to avoid inaccuracies aassociated with thermal mass effects. During the test, the following variables must be recorded as hourly averages, and their standard deviations, based on readings every 60 seconds: inside and outside air temperatures, air temperature within the box, power input to the calorimeter box, and heat flux transducer reading.

Analysis:

The analysis is based on hourly averages and standard deviations of the inside-outside temperature difference $\Delta T$, power input to the calorimeter Q, and heat flux through the transducers $Q_t$. From this hourly data, calculate the average of these three quantities over the entire test period, as well as the standard deviations of these averages. The averaging period shall be an integer multiple of twenty-four hours. Based on the test period averages, one calculates the test wall R-value by dividing the average temperature difference $\overline{\Delta T}$ ($^oF$) by the average heat flux per unit area $\overline{Q'}$ (Btu/hr-ft$^2$). For the calorimeter Q' is equal to the power input to the calorimeter Q (Btu/hr) divided by the calorimeter area. The heat flux transducer output $Q_t$ is equal to Q'. The uncertainty in the R-value shall be determined according to the following equation:

$$dR = ( \overline{Q'}/\overline{\Delta T}) [ (d\Delta T/\overline{\Delta T})^2 + (dQ'/\overline{Q'})^2 ]^{0.5}$$

where $d\Delta T$ is the standard deviation of $\overline{\Delta T}$ and dQ' is the standard deviation of $\overline{Q'}$. The calculation of R and dR must be made separately for the calorimeter and the heat flux transducers at each location.

Submittals: For each test the following materials must be submitted:

A list of the measurement locations including clear sketches noting the locations of the room within the building and the specific locations of the test walls within the room.

Descriptions and specifications of all test equipment used as obtained from the equipment manufacturers or as determined by the testing agent, including calibration data for heat flux transducers.

For each measurement location, hourly averages and standard deviations of all measured data including inside and outside air temperatures, air temperature within the calorimeter, power input to the calorimeter, and the output from all four heat flux transducers.

Calculated test period averages and standard deviations of inside-outside temperature difference, power input to the calorimeter, and heat flux through the transducers. Calculated R-values and uncertainties in R-value for each wall based on the calorimeter and the four heat flux transducers.

For each measurement location, the calulated R-value of the wall based on building design and standard ASHRAE handbook procedures.

References:

ASTM Standard C 177, "Standard Test Method for Steady-State Thermal Transmission Properties by Means of the Guarded Hot Plate," American Society for Testing and Materials, 1976.

ASTM Standard C 518, "Standard Test Method for Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter" American Society for Testing and Materials, 1976.

Brown, W.C., Schuyler, G.N., "A Calorimeter for Measuring Heat Flow Through Walls," Proceedings of the ASHRAE/DOE Conference on Thermal Performance of the Exterior Envelopes of Buildings, ASHRAE SP 28, 1981.

Brown, W.C., Schuyler, G.N., "In-Situ Measurements of Frame Wall Thermal Resistance," <u>ASHRAE Transactions</u>, Vol.88, Part 1, 1982.

Fang, J.B., Grot, R.A., "In Situ Measurements of the Thermal Resistance of Building Envelopes of Office Buildings," ASHRAE Transactions, Vol.91, Part 1, 1985.

Flanders, S.N., "Confidence in Heat Flux Transducer Measurements of Buildings," ASHRAE Transactions, Vol.91, Part 1, 1985.

Grot, R.A., Persily, A.K., Chang, Y.M., Fang, J.B., Weber, S., Galowin, L.S., "Evaluation of the Thermal Integrity of the Building Envelopes of Eight Federal Office Buildings," NBSIR 85-3147, National Bureau of Standards, 1985.

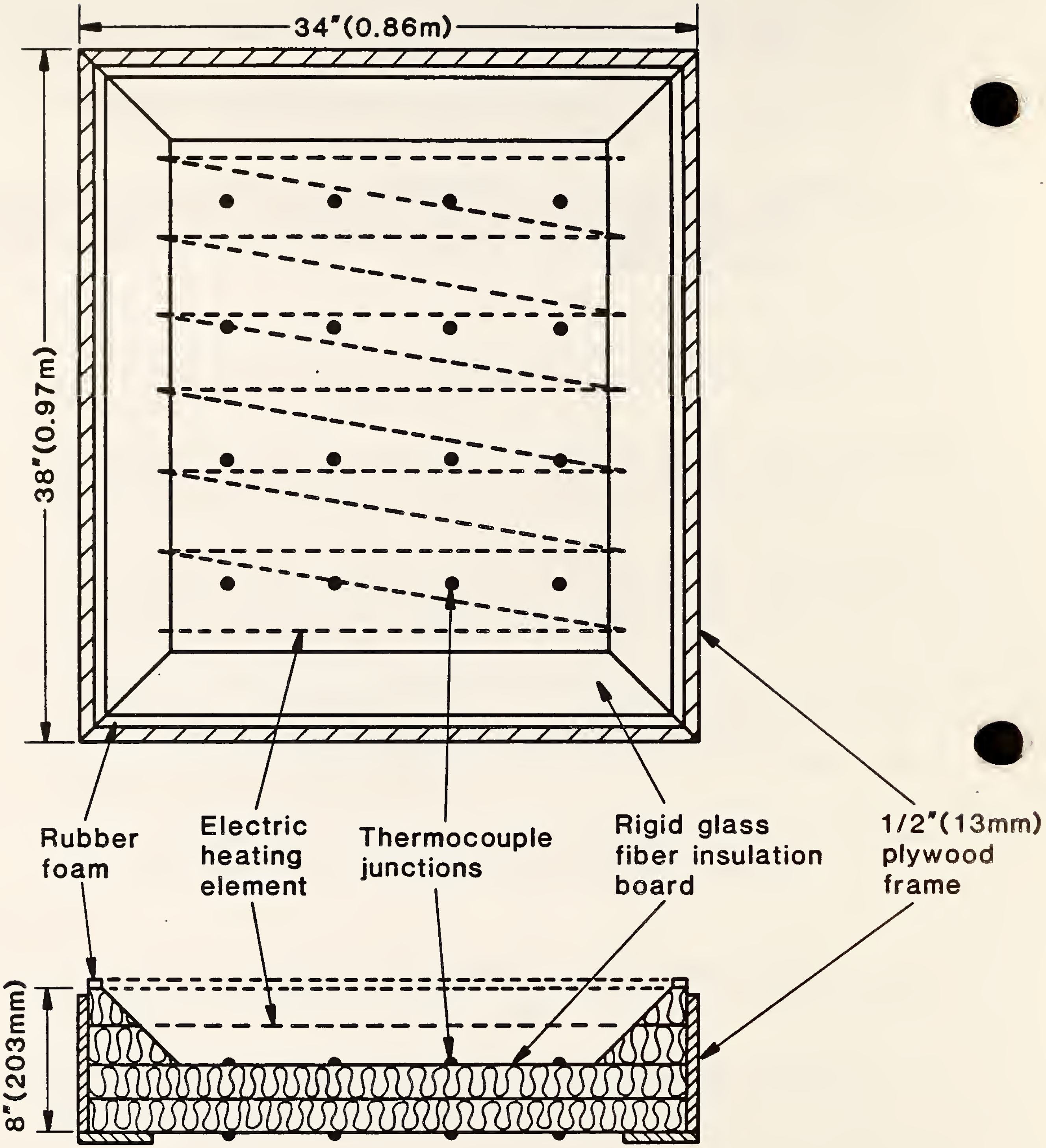



Figure 4 Schematic of Portable Calorimeter

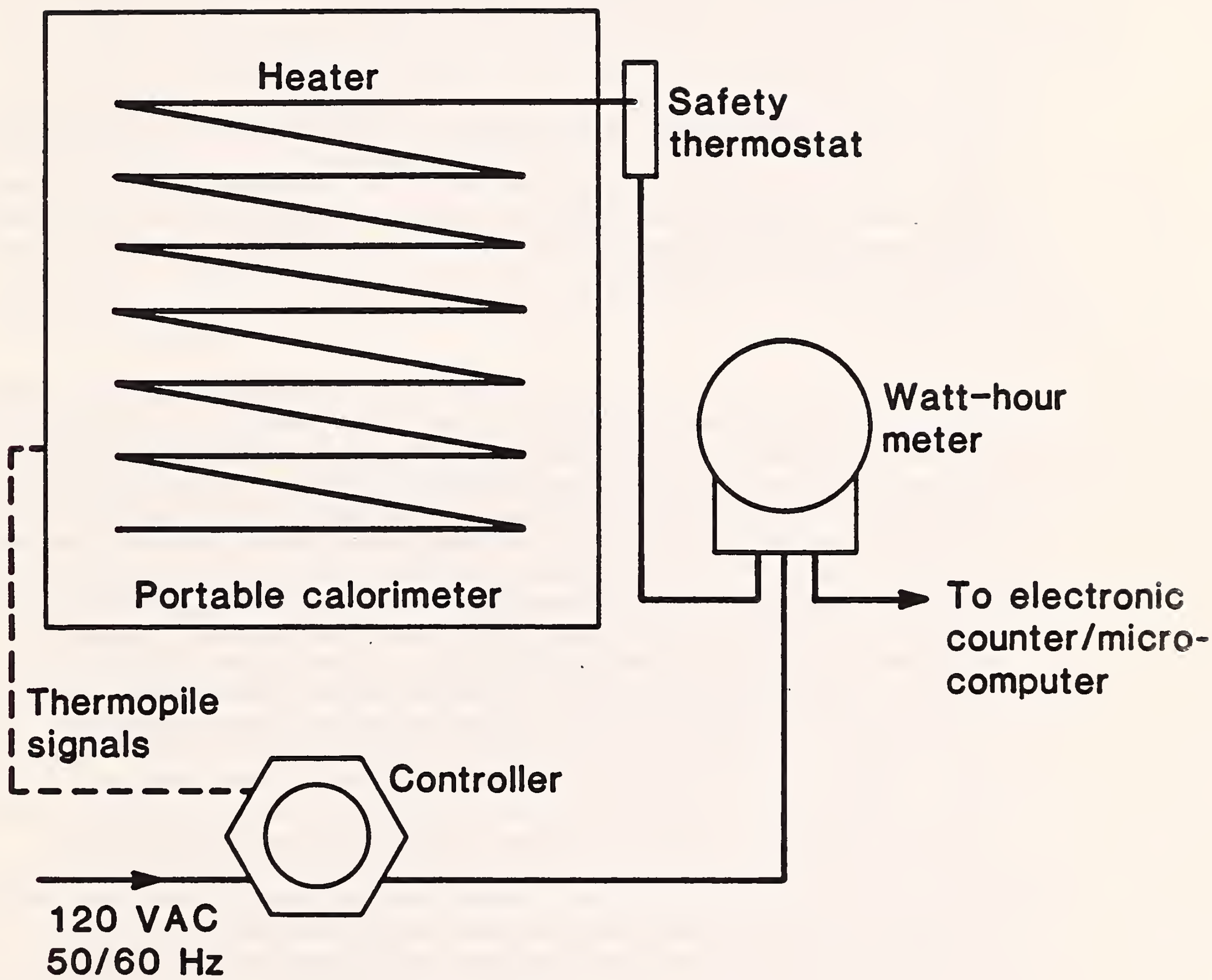



Figure 5 Schematic of Measurement and Control System of Portable Calorimeter

3. <u>Whole Building Pressurization</u>: To measure the airtightness of the building envelope by measuring the airflow rate required to induce specific inside-outside pressure differences. The tests shall be conducted in accordance with ASTM E 779-81, Standard Practice for Measuring Air Leakage by the Fan-Pressurization Method, making sure to account for the stack pressures in tall buildings. The airflow will be induced using the building's air handling equipment if possible. Otherwise, auxiliary fans must be brought to the building by the testing agent.

Test Conditions:

At the time of this test, all windows and outside doors must be installed and closed, all interior doors must be open, and all air handlers and dampers must be operable. The building must be unoccupied. The average wind speed during the test must be less than 5 mph, the average outside temperature greater than 60 $^{o}$F and the average inside-outside temperature difference less than 10 $^{o}$F.

Equipment:

The test requires the measurement of the airflow rate through the main supply and return fans, or any auxiliary fans brought to the building by the testing agent, and the pressure difference across the building envelope. If there are airflow monitoring stations installed in the main supply and return ducts, then these may be used to measure the airflow rate providing the devices have been calibrated as installed and found to be accurate within 6% of the measured airflow rate for the range of airflow rates of interest. If no such airflow monitoring stations exist then one must use a constant tracer gas (sulfur hexafluoride, $SF_6$) injection procedure for measuring the airflow rate. The tracer gas technique requires a tracer gas concentration measurement system that is accurate within 2% of the reading, a tracer gas injection rate measurement system that is also accurate within 2% of the measurement, differential pressure gauges capable of measuring pressure differences up to 0.25 in. $H_2O$ within 0.01 in. $H_2O$, and air sample pumps to bring air at a rate of at least 20 scfh from the sampling locations to the tracer gas concentration measurement device. All of this equipment will already be installed in the building, and details will be provided to the testing agent regarding equipment specifications and pressure difference gauge locations. Tubing for tracer gas injection into and air sampling from the air handlers will already be installed in the building, and run from these locations to the DC. The injection tubing will be 1/8 in. OD nylon and the sampling tubing will be 3/8 in. OD nylon, and will terminate in the DC. Information regarding injection and sampling locations, and the correspondence between these locations and labels on the DC end of the tubes will be provided. If the testing agent brings auxiliary fans to the building, the testing agent must also provide airflow rate measuring equipment as specified in ASTM E 779-81, accurate to within $\pm$6% of the average airflow rate used in the test. Thermistors for measuring inside and outside temperatures, and an anemometer for measuring wind speed, will already be installed in the building. The thermistors will require a supply voltage of 3 VDC or less, and will produce a DC output voltage that is linearly related to temperature. An appropriately sized precision resistor for each thermistor will be available for use in reading the thermistor output. The anemometer will produce a DC voltage output that is linearly related to the wind speed, with a sensitivity of about 4 VDC at 100 mph. Specifications on the thermistors and anemometer, and the correspondence between these sensors and labels on the DC end of the sensor wires will be provided to the testing agent.

Pressure Difference Measurement:

In order to verify that a uniform pressure difference is being induced over the entire building envelope, the inside-outside pressure difference must be measured at several locations. At least six locations are required including two on the ground floor, two on the top floor and two on an intermediate floor, with each pair located on opposite sides of the building.

Before the fans are operated, the zero of each gauge must be checked in order to verify the absence of any weather induced pressure differences. If weather induced pressure differences greater than 0.01 in. $H_2O$ exist, then the test must be delayed until milder wind and temperature difference conditions exist.

Measurement Technique:

The test involves the depressurization of the building interior relative to the outside, followed by the pressurization of the building interior. The depressurization mode must be conducted before the pressurization mode. Each test mode is described below.

> Depressurization - In the depressurization mode, air is forced out of the building by the return fan(s) such that all the incoming air enters through leaks in the building envelope. If the building does not have return fans, then the testing agent must provide fans capable of depressurizing the building to 0.10 in. $H_2O$ relative to the outside. The airflow rates required to induce and sustain a series of inside-outside pressure differences are then measured.
>
> Air Handler Set-up: During the test, the air handling system is arranged as shown in figure 6. All supply fans are off, all exhaust fans are off, all exhaust vents are closed, and all supply dampers are closed. These conditions must be verified by visual inspection. If any of these dampers or vents are leaky, they must be sealed with plastic film. During the test the return fans will be operated with the spill dampers open in order to induce the required pressure differences between inside and outside. (An HVAC control mode referred to as "depressurization" will be available and will automatically provide the air handler conditions described above. Visual inspection to verify the existence of these conditions is still required.)
>
> Airflow Modulation: In order to obtain the required inside-outside pressure differences, one must modulate the airflow rate through the air handlers. This can be done in several ways. If there are multiple fans serving the building, then individual fans can be turned on or off to provide a range of airflow rates. The airflow rate through a single fan can be modulated by adjusting the position of the spill dampers, adjusting the intake vanes on centrifugal fans, or

changing the fan speed of variable speed fans.

Procedure: Turn on and modulate the return fan(s) at a low airflow rate in order to induce a pressure difference of 0.05 in. $H_2O$ across the building envelope. Record the pressure difference at each measurement location. Measure the total airflow rate out of the building using airflow monitoring stations if available. Otherwise, measure the tracer gas concentration downstream of each return fan to insure that there is no source of tracer gas within the building. If tracer is detected, ventilate the building until the concentration decreases to zero. When it has been established that there is no tracer gas within the building, inject tracer gas upstream of each operating return fan and measure the tracer gas concentration downstream of each return fan once every minute. Adjust the tracer gas injection rate in order to get measurable tracer gas concentrations. Record the tracer gas injection rate. After ten successive concentration readings with a standard deviation less than 3% of the mean, record these equilibrium concentrations and go on to the next pressure difference.

Induce inside-outside pressure differences of 0.10, 0.15, 0.20, 0.25, and 0.30 in. $H_2O$. At each pressure difference measure the airflow rate as described above. If the airflow rate or tracer gas concentration oscillates significantly, or if all the specified pressure differences cannot be induced, check to make sure all outside doors, windows and appropriate dampers are closed and all fans and dampers are operating appropriately. If a pressure difference of 0.30 in. $H_2O$ still cannot be induced, make measurements at six pressure differences approximately evenly spaced from 0.0 in. $H_2O$ to the maximum pressure difference that can be achieved. If a pressure difference of 0.10 in. $H_2O$ cannot be induced with all fans operating at their maximum airflow rates, it will be necessary to bring an appropriately sized fan(s) to the building.

<u>Pressurization</u> - In the pressurization mode, air is forced into the building by the supply fan(s) such that all the outgoing air leaves through leaks in the building envelope. The airflow rates required to induce and sustain a series of inside-outside pressure differences are then measured.

Air Handler Set-up: During the test, the air handling system is arranged as shown in figure 7. All return fans are off, all exhaust fans are off, all exhaust vents are closed, and all spill dampers are closed. These conditions must be verified by visual inspection. If any of the dampers or vents are leaky, they must be sealed with plastic film. During the test the supply fans will be operated with all intake and supply dampers open in order to induce the required pressure differences between inside and outside. (An HVAC control mode referred to as "pressurization" will be available and will automatically provide the air handler conditions described above. Visual inspection to verify the existence of these conditions is still required.)

Airflow Modulation: In order to obtain the required inside-outside pressure differences, one must modulate the airflow rate through the air handlers. This can be done in several ways. If there are multiple fans serving the building, then individual fans can be turned on or off to provide a range of airflow rates. The airflow rate through a single fan can be modulated by adjusting the position of the intake dampers, adjusting the intake vanes on centrifugal fans, or changing the fan speed of variable speed fans.

Procedure: Turn on and modulate the supply fan(s) at a low airflow rate in order to induce a pressure difference of 0.05 in. $H_2O$ across the building envelope. Record the pressure difference at each measurement location. Measure the total airflow rate into the building using airflow monitoring stations if available. Otherwise, measure the tracer gas concentration downstream of each supply fan to insure that there is no source of tracer gas within the system. If tracer is detected, operate the system until the concentration decreases to zero. When it has been established that there is no tracer gas within the system, inject tracer gas upstream of each operating supply fan and measure the tracer gas concentration downstream of each supply fan once every minute. Adjust the tracer gas injection rate in order to get measurable tracer gas concentrations. Record the tracer gas injection rate. After ten successive concentration readings with a standard deviation less than 3% of the mean, record these equilibrium concentrations and go on to the next pressure difference.

Induce inside-outside pressure differences of 0.10, 0.15, 0.20, 0.25, and 0.30 in. $H_2O$. At each pressure difference measure the airflow rate as described above. If the airflow or tracer gas concentration oscillates significantly, or if all the specified pressure differences cannot be induced, check to make sure all outside doors, windows and appropriate dampers are closed and all fans and dampers are operating appropriately. If a pressure difference of 0.30 in. $H_2O$ still cannot be induced, make measurements at six pressure differences approximately evenly spaced from 0.0 in. $H_2O$ to the maximum pressure difference that can be achieved. If a pressure difference of 0.10 in. $H_2O$ cannot be induced with all fans operating at their maximum airflow rates, it will be necessary to bring an appropriately sized fan(s) to the building.

Analysis: The following procedure must be applied to the depressurization and pressurization data separately.

If airflow monitoring stations were not used, calculate the airflow rate $\dot{V}$ (cfm) at each induced pressure difference $\Delta p$ for each fan operating to induce that pressure. One must first calculate the average equilibrium tracer gas concentration $\overline{c}$ for each pressure difference. The airflow rate $\dot{V}$ for each fan is determined by dividing the tracer gas injection rate i by the average equilibrium tracer gas concentration $\overline{c}$ for the corresponding fan. Calculate the total airflow rate $\dot{V}_T$ at each pressure difference by adding the airflow rates through all the fans used to induce that pressure difference. Calculate the average pressure difference $\overline{\Delta p}$, and its standard deviation, based on the measured pressure differences at all pressure difference measurement locations.

The total airflow rate $\dot{V}_T$ and average pressure difference $\overline{\Delta p}$ data must be fit to a curve of the form

$$\dot{V}_T = C\ (\overline{\Delta p})^n$$

where C is the flow coefficient in units of cfm/(in $H_2O)^n$ and n is the flow exponent. The values of C and n are obtained by applying least squares linear regression to the following transformed equation

$$\ln(\dot{V}_T) = \ln C + n\ \ln(\overline{\Delta p})$$

The value of the coefficient of determination $r^2$ associated with the regression of the transformed equation must also be calculated. Based on the curve fit to the data, calculate the predicted airflow rate at a pressure difference of 0.1 in. $H_2O$ V(0.1), and the standard error associated with this estimate. Divide the predicted airflow rate V(0.1) by the building volume in $ft^3$, converting this quantity to units of air changes per hour. Divide V(0.1) by the building's exterior surface area to determine the leakage rate in units of cfm/$ft^2$ at 0.1 in. $H_2O$.

Submittals:

A description of any equipment supplied by the testing agent, including calibrations, must be submitted. In addition, the pressure difference measurement locations must be reported. Environmental conditions (outside temperature, inside temperature, and wind speed and direction) during the test must also be reported as test period averages and standard deviations.

The data collected for both the depressurization and pressurization modes must be reported. For each induced pressure difference these include the measured pressure differences at each measurement location. They also include the airflow measurement from the airflow monitoring station if such a device is used. Otherwise, one must report the tracer gas injection rate and all measured concentrations for each fan used in the test.

For both the depressurization and pressurization modes the calculated values of $\overline{c}$, $\dot{V}$, $\dot{V}_T$, $\overline{\Delta p}$ and the standard deviation of $\overline{\Delta p}$ must be reported, as well as the values of C,n and $r^2$ from the curve fits. The predicted airflow rate at 0.1 in. $H_2O$ must be reported in units of cfm, air changes per hour, and cfm/$ft^2$ of envelope area. The standard error of the estimate of the predicted airflow at 0.1 in. $H_2O$ must also be reported.

References:

ASTM E 779, "Standard Practice for Measuring Air Leakage by the Fan-Pressurization Method," American Society for Testing and Materials, 1981.

Persily, A.K., Grot, R.A., "Pressurization Testing of Federal Buildings," Proceedings of ASTM E-6 Conference of Measured Air Leakage Performance of Buildings, Philadelphia, 1984.

Shaw, C.Y., Sanders, D.M., Tamura, G.T., "Air Leakage Measurements of the Exterior Walls of Tall Buildings," ASHRAE Transactions, Vol.79, Part 2, 1973.

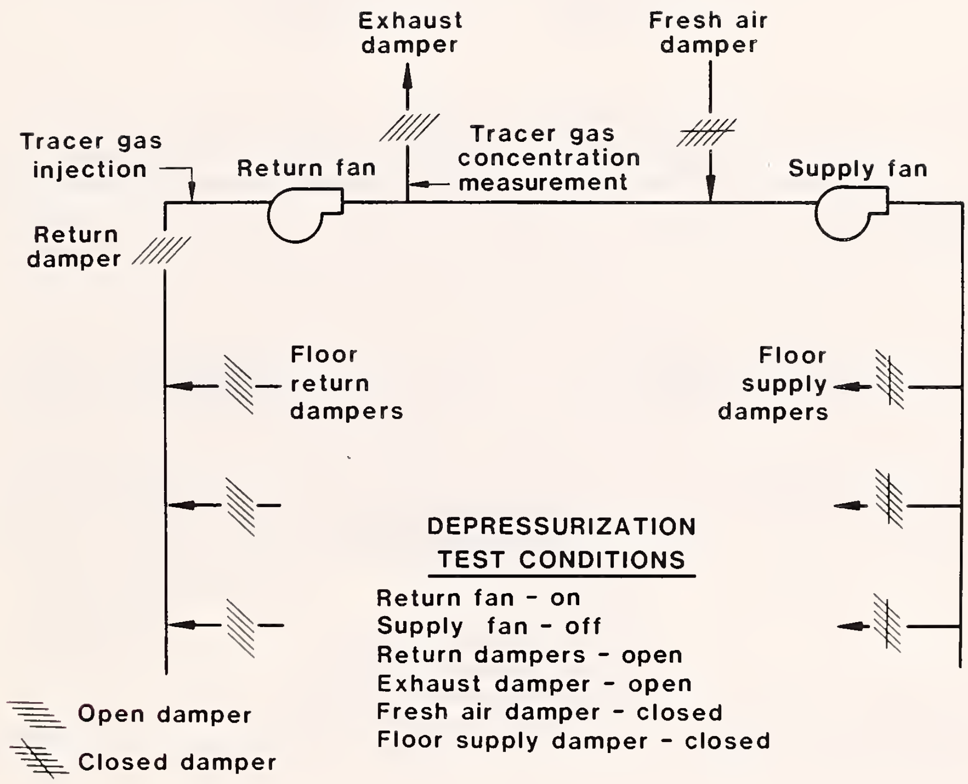



Figure 6 Whole Building Depressurization Test Set-Up

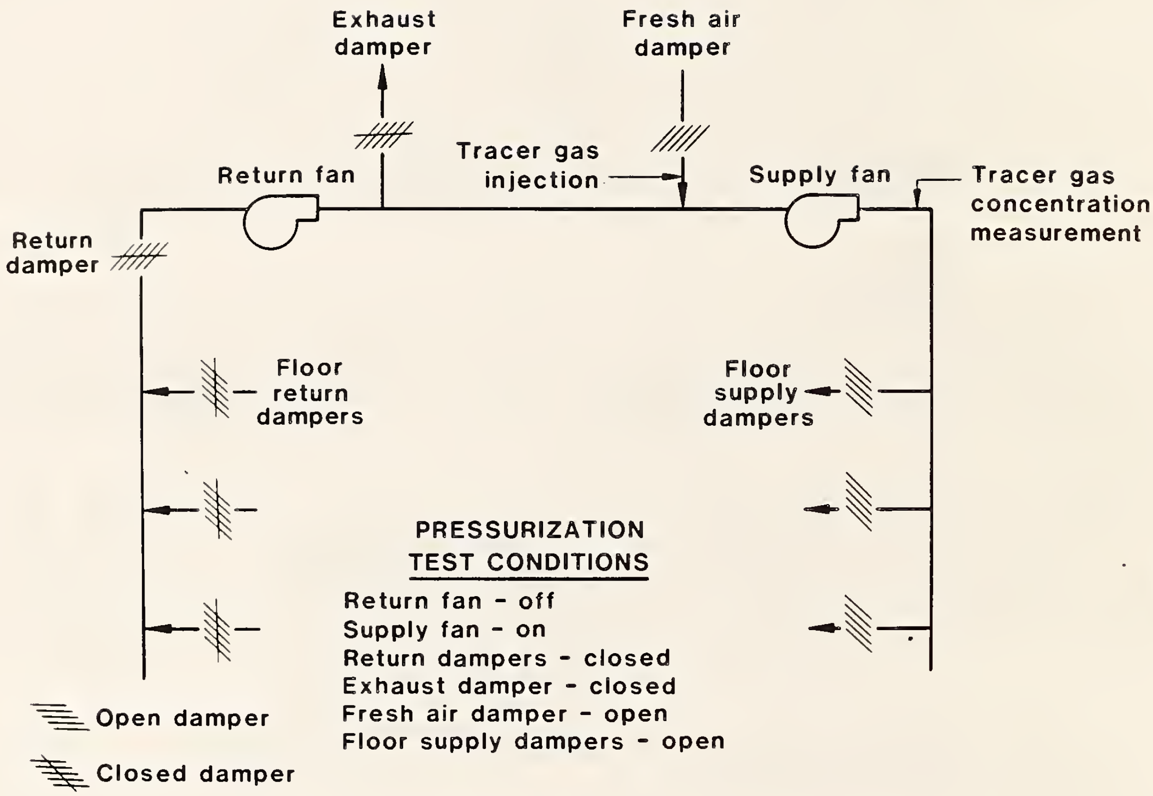



Figure 7 Whole Building Pressurization Test Set-Up

4. <u>Component Pressurization</u> - To measure the airtightness of individual components (windows and doors) by measuring the airflow rate required to induce specific pressure differences across the components. The tests shall be conducted in accordance with ASTM E 783-81, Standard Method for Field Measurement of Air Leakage Through Installed Exterior Windows and Doors.

Test Conditions:

At the time of this test, all windows and outside doors must be installed and the building must be heated or cooled to a level appropriate for occupancy. The average wind speed during the test must be less than 5 mph, the average outside temperature greater than 60 $^{o}$F, and the average inside-outside temperature difference less than 10 $^{o}$F.

Equipment:

The equipment required for the test is described in detail in ASTM E 783-81 and only brief descriptions are presented below. The procedure requires a test chamber, an air system, a pressure-measuring apparatus, and an airflow-metering system. The test chamber shall be designed to enclose the test specimen with openings for air supply to, or exhaust from, the chamber, and with pressure taps to measure the chamber static air pressure versus the outdoor air pressure. The air system consists of a controllable fan to provide the airflow necessary to induce the specified pressure difference across the test specimen. The pressure measuring apparatus shall be capable of measuring the test pressure difference across the test specimen within 2% of full-scale, or 0.01 in. $H_2O$, whichever is greater. The airflow-metering system shall be capable of measuring the airflow rate through the test specimen at an accuracy of 10%. Thermistors for measuring inside and outside temperatures, and an anemometer for measuring wind speed, are also required.

Test Specimens:

The components to be tested shall include at least 2% of each window type, including both operable and inoperable windows. All outside doors are to be tested.

Procedure:

The test involves the depressurization of the test chamber relative to the outside, followed by the pressurization of the chamber. The airflow rates required to induce and sustain a series of specified pressure differences are then measured. There are three parts to the test method, preparation of the test specimen, preparation of the test apparatus, and measurement procedure. The procedure is described in detail in ASTM E 783-81. This procedure will be used twice on each specimen, once to measure only the sash leakage and again to measure the sash and frame leakage together.

Inspection of the Test Specimen: For each test specimen inspect and record the general conditions of the specimen, including existence and condition of weatherstripping and squareness of the installation. Measure and record the dimensions of the specimen (height and width). Describe the specimen in detail, including the number and dimensions of panes in a window or glass panels in a door.

Preparation of the Test Apparatus: The test chamber must be installed over the test specimen in two different ways to measure the sash leakage and the sash-plus-frame leakage as shown in figure 8. In each mode, install the test chamber over the test specimen, making sure to seal all joints between the specimen perimeter and the test chamber. Again in each mode, measure the extraneous leakage $q_1$ through and around the test chamber, test apparatus, and test specimen as specified in ASTM E 783-81. This extraneous leakage shall be measured at pressure differences $\Delta p$ across the specimen of 0.05, 0.10, 0.15, 0.20, 0.25 and 0.30 in. $H_2O$.

Measurement Procedure: This procedure shall be carried out twice, once in the sash leakage mode and again in the sash-plus-frame leakage mode. Adjust the airflow rate through the test chamber, induced by the air system, required to induce the required pressure differences. When the static air pressure difference has stabilized, measure and record the airflow rate $q_m$ as determined by the airflow-metering system and the actual static air pressure difference. If a stable pressure difference does not exist, it may be necessary to delay the measurement until the inside-outside temperature difference and wind speed have decreased. Measure and record the average inside and outside air temperatures and wind speed during the test. Record the barometric pressure and relative humidity as measured at a nearby weather station.

Analysis: The following analysis procedure must be applied to the depressurization and pressurization data of each specimen separately.

The air leakage through the test specimen $q_c$ at each pressure difference is calculated as follows

$$q_c = q_m - q_1$$

The calculated airflow rate is converted to the airflow rate at reference standard conditions $q_s$ based on the barometric pressure and relative humidity of the air at the test site.

The airflow rate $q_s$ and pressure difference data must be fit to a curve of the form

$$q_c = C\ (\Delta p)^n$$

where C is the flow coefficient in units of cfm/(in $H_2O)^n$ and n is the flow exponent. The values of C and n are obtained by applying least squares linear regression to the following transformed equation

$$\ln(q_c) = \ln C + n \ln(\Delta p)$$

The value of the coefficient of determination $r^2$ associated with the regression of the transformed equation must also be calculated. Based on the curve fit to the data, calculate the predicted airflow rate at a pressure difference of 0.3 in. $H_2O$ q(0.3) and the standard error associated with this estimate. Divide q(0.3) by the total crack length to get the air leakage rate in cfm per ft of crack. This normalized airflow rate at 0.3 in. $H_2O$ shall also be calculated for the measured airflow rates at 0.3 in. $H_2O$.

Submittals:

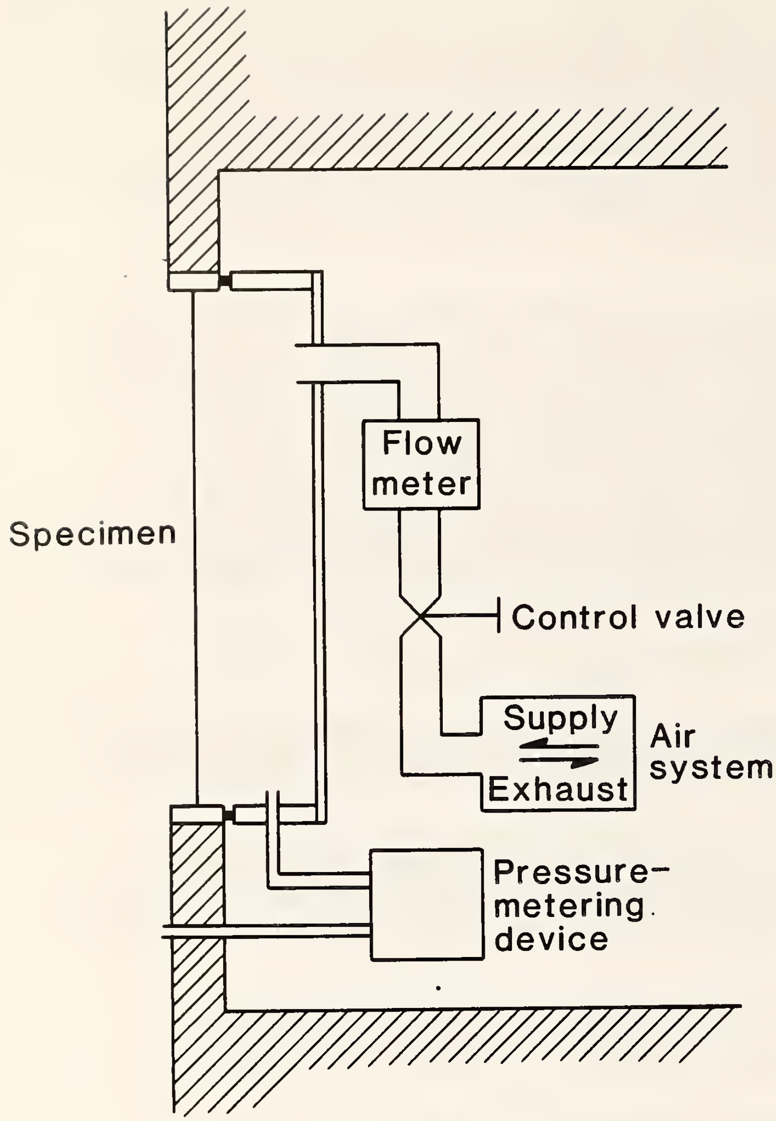
For each test report the date and time of the test, a description of all equipment used including specifications and calibrations, and the average weather conditions during the test including inside and outside air temperature, wind speed, barometric pressure, and relative humidity. Provide a precise description of each test specimen including its location within the building and its general condition, as well as its dimensions, including the total crack length.

For each test specimen the following information must be provided for both the depressurization and pressurization modes: test apparatus leakage rate $q_l$ at each test pressure difference, the measured airflow rate through the specimen $q_m$, the calculated airflow rate through the test specimen $q_c$, and the airflow rate corrected to reference standard conditions $q_s$. The results of the curve fits to the data must be reported, i.e. C, n, and $r^2$. The measured and predicted airflow rates at 0.3 in. $H_2O$, as well as the standard error of the predicted flow rate at 0.3 in. $H_2O$, must be reported. The measured and predicted airflow rates normalized for crack length must also be reported.

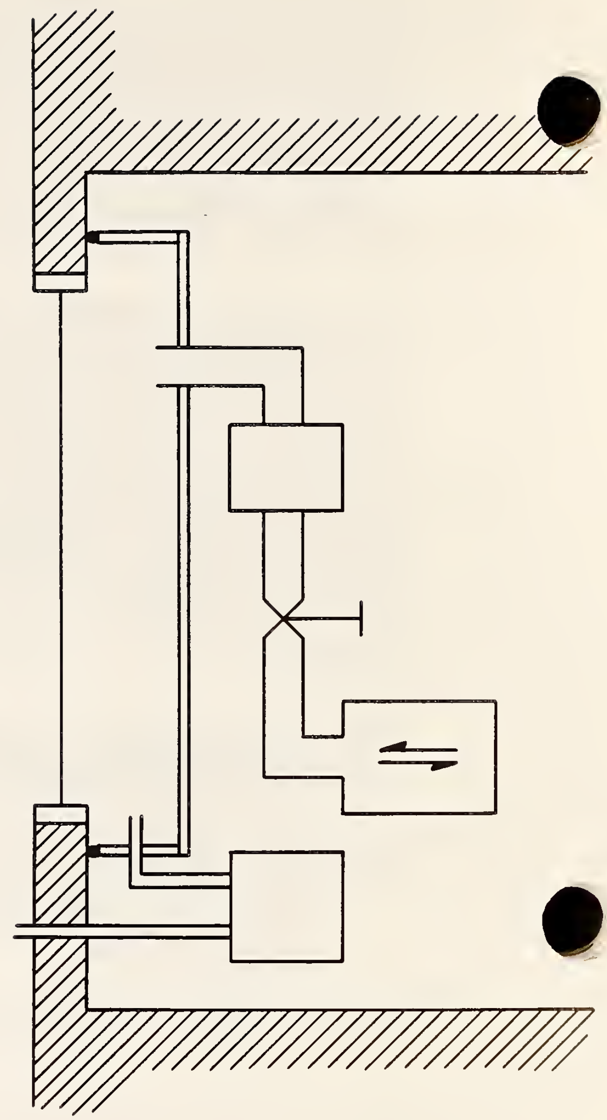
References:

ASTM Standard E 783, "Standard Method for Field Measurements of Air Leakage Through Installed Exterior Windows and Doors," American Society for Testing and Materials, 1981.

Grot, R.A., Persily, A.K., Chang, Y.M., Fang, J.B., Weber, S., Galowin, L.S., "Evaluation of the Thermal Integrity of the Building Envelopes of Eight Federal Office Buildings," NBSIR 85-3147, National Bureau of Standards, 1985.




Sash Leakage Only



Sash and Frame Leakage

Figure 8 Component Pressurization Test Set-Ups

5. Tracer Gas Measurement of Air Infiltration - To measure building air infiltration rates caused by weather induced pressure differences using an automated system. The test shall be conducted in accordance with ASTM E 741-83, Standard Test Method for Determining Air Leakage Rate by Tracer Dilution.

Test Conditions:

At the time of these tests, the exterior envelope must be complete, though the interior finishing need not be. All windows and exterior doors must be installed and closed, and all air handlers must be operable and controllable.

Equipment

In order to conduct these tests one will require a combination of equipment already located in the building and equipment to be brought to the site. Details on the equipment located on site will be provided to the testing agent. The requirements for equipment to be brought to the building will depend in part on the number of air sampling locations to be used in the building, the number of tracer gas injection locations, and the supply fans corresponding to these injection locations. This information will all be provided to the testing agent.

The following equipment will be provided for use by the testing agent:

Tracer gas concentration measuring device: A gas chromatograph equipped with an electron capture detector, for measuring the concentration of sulfur hexafluoride ($SF_6$), will be located in the DC.

Compressed gas: Cylinders of carrier gas appropriate to the tracer gas concentration measuring device, as well as cylinders of $SF_6$, will be located in the DC.

Tracer gas injection tubes (1/8 in. OD) running from the DC to the main supply fans: Each of these tubes will be attached to a rotameter flowmeter for the control and measurement of the tracer gas injection rate. The input to the flowmeters will pass through a solenoid valve for controlling the tracer gas injection. A 10 ft length of two-conductor wire, rated for 115 VAC and 1 amp, will run from each solenoid valve to enable automated tracer gas injection.

Air sampling tubes (3/8 in. OD) running from a series of duct, interior and exterior air sampling locations to the DC: Air sample pumps for pulling air through these tubes, from the sampling locations, will also be located in the DC.

Thermistor and anemometer wires: Thermistors will be used to measure inside and outside air temperatures. The thermistor circuit requires a supply voltage of 3 VDC or less, and the 2-conductor thermistor wires in the Diagnostic Center will produce a DC voltage output that is linearly related to temperature. An appropriately sized precision resistor for each thermistor will be available for use in the data acquisition system reading the ouput of the thermistors. The five-conductor anemometer wire will include the output voltage of a DC generator that is linearly related to wind speed, with a sensitivity of about 4 VDC at 100 mph. The remaining leads are used to measure wind direction with a transmitter vane employing a 1000 Ohm potentiometer, requiring a supply voltage no greater than 12 VDC. The three wires include the supply voltage, ground, and an output voltage yielding a linear relation between 0-360° direction and 0-1000 Ohm potentiometer resistance.

Fan switch wires: Two-conductor wires attached to relays at each fan will provide a switch closure when the corresponding air handler is operating.

The following equipment must be brought to the building:

Data acquisition and control system (DACS): This device must be capable of controlling air sampling and tracer gas injection. It must be able to sample from each air sampling location at least once every ten minutes, and direct the air sample to the tracer gas detector. It must be able to turn on the tracer gas injection solenoid valves for varying lengths of time as required. The valve to a given injection location must be activated if and only if the corresponding fan switches indicate that the fans are operating. The system must be able to read and record the output of the tracer gas detector, as well as the thermistors and anemometer.

Tracer gas manifold system: A manifold and associated plumbing will be required for the tracer gas injection lines. This equipment must connect the cylinder(s) of tracer gas to the tracer gas injection solenoids. The DACS must control the manifold system such that tracer gas is injected at the desired locations for the desired lengths of time.

Air sampling manifold system: A manifold and associated plumbing will be required for the air sampling lines. The air sampling manifold must connect to the outlets of the air sample pumps, and the manifold must be designed such that the DACS can select among the air sample locations for connection to the tracer gas detector.

Fittings and tubing. Fittings and tubing will be required to connect the air sample pumps to the air sampling manifold, the tracer gas cylinders to the tracer gas manifold, and the tracer gas manifold to the solenoid valve inlets. The outlets of the pumps will be fitted with 20 ft lengths of 3/8 in. OD nylon tubing. The inlets to the solenoid valves will be fitted with 10 ft lengths of 1/8 in. OD nylon tubing.

Sampling Locations:

In order to verify the existence of good mixing of the tracer gas with the interior air, the tracer gas must be injected at several locations and the concentration must be measured at several locations throughout the building. These air sampling locations will be specified by the procuring agent, and the tracer gas concentration in the air from each location must be measured at least once every ten minutes.

Procedure: The tests involve tracer gas decay measurements of air infiltration rates as described in ASTM E 741-83. In these tests a small quantity of a tracer gas ($SF_6$) is released in the building and allowed to mix with the interior air. The decay rate of the tracer gas concentration is then monitored and related to the building air change rate.

Building conditions: The tests must be conducted when the building is unoccupied and must not interfere with normal HVAC operation such as preoccupancy cool-down or warm-up. During the test the following conditions are required: all air handlers on continuously, all outside air intake and spill dampers closed, and all exhaust fans off. The goal is to use the air handlers to mix the interior air, and not to induce any air exchange with the ventilation system. (An HVAC control command referred to as "infiltration" will be available and will automatically provide these required test conditions.)

Tracer gas injection: Tracer gas must be injected at each injection site once every three hours. The amount of gas injected must be such that the intitial tracer gas concentration in the building is approximately 90% of full-scale of the tracer gas detector. This initial concentration is achieved by modulating the tracer gas flow rate with the flowmeters and the time of injection for each injection site. The injection must last no longer than ten minutes. The DACS must automatically control the injection times to achieve the same initial concentration throughout the building, employing an iterative algorithm that determines injection times based on concentration increases during past injections.

Air sampling and concentration measurement: The air sampling and tracer gas concentration measurement must begin twenty minutes after the injection ends. The concentration at each sampling location is determined in succession, with each location being monitored at least once every ten minutes. All measured concentrations must be recorded. At the end of each hour the data acquisition system must calculate the infiltration rate for each sampling location using least squares linear regression on the natural logarithms of the tracer gas concentrations. The slope of the log of concentration vs time is the negative of the infiltration rate. The coefficient of determination $r^2$ and standard error of the estimate of the slope must also be calculated. The slope, $r^2$, and error of the slope must be recorded for each air sampling location.

Environmental data: All temperatures, inside and outside, must be monitored every minute. Hourly averages and standard deviations must be calculated and recorded for all locations. The wind speed and direction must be monitored every 30 seconds, and the means and standard deviations of these two quantities must be calculated every hour and recorded.

Lengths of tests: Infiltration measurements must be conducted for at least two weeks during each season of the year in order to obtain data under a wide range of weather conditions. During each seasonal testing period, one must obtain at least one-hundred fifty hours of infiltration data.

Analysis: The data analysis involves inspecting the data for bad readings, determining building average infiltration rates, tabulating the results, and sorting the infiltration rates according to weather conditions.

Data inspection: The hourly infiltration rates must be inspected for excessive variation. For the decay during the first hour after the injection, examine the values of $r^2$ associated with the infiltration rates calculated at each sampling location. If more than one-third of these $r^2$ are less than 0.90, then neglect that hour's data. If this first test is passed, neglect those locations for which $r^2$ is less than 0.90. During the next two hours, again examine the values of $r^2$. If more than one-third of these $r^2$ are less than 0.90, then combine the two hours and recalculate the infiltration rates, $r^2$, and the errors of the slopes for the two hour period. For the two hour infiltration rates, neglect the data obtained during the first hour after injection and neglect those locations associated with a value of $r^2$ less than 0.90.

Determine building averages: After the data inspection described above, one must calculate hourly (or two hour) average infiltration rates for the whole building $I_B$. $I_B$ is calculated from the average infiltration rates for each zone of the building $I_{Bi}$. The zonal average infiltration rates are determined from

$$I_{Bi} = (\Sigma V_i I_i) / (\Sigma V_i)$$

where $I_i$ is the infiltration rate associated with the ith air sample location and $V_i$ is the volume associated with that same location. The whole building average infiltration rate $I_B$ is based on a similar volume weighted average of the average infiltration rates for the building zones. Information regarding the zones of the building, their volumes, and the corresponding air sample locations will be provided.

Tablulate data: All the whole building average infiltration rates and the corresponding environmental conditions must be tabulated according to the following format. The environmental conditions include the inside-outside temperature difference, wind speed and wind direction averaged over the hour (or two hour) period for which the corresponding infiltration rate is determined. The data must be tabulated as follows:

| Day | Hour | $I_B$ | Temperature Difference ($^oF$) | Wind Speed (mph) | Wind Direction (degrees) |
|---|---|---|---|---|---|
| 1/20/85 | 08 | 0.50 | 25.1 | 4.5 | 180 |
| " | 09 | 0.55 | 24.5 | 4.0 | 180 |

Table 1 Summary of Infiltration and Weather Data

Sort infiltration data: The infiltration rate data in the above table must then be sorted according to the environmental conditions during the measurements. The infiltration rates must be sorted into intervals of wind speed and inside-outside temperature difference. The wind speed ranges are (0,2), (2,4), (4,6), ... mph, and the temperature difference ranges are ...(-10,-5), (-5,0), (0,5), (5,10), ... °F. One must create a grid of the following form:

| u / ΔT | (0,2) | (2,4) | (4,6) | (6,8) ... |
|---|---|---|---|---|
| (-10,-5) | | | | |
| (-5,0) | | | | |
| (0,5) | | | | |
| (5,10) | | | | |
| (10,15) | | | | |

Table 2 Summary of Infiltration Data Sorted by Weather Conditions

For all the infiltration rates in each grid location, calculate the average infiltration rate, the standard deviation and the number of infiltration measurements for the location in the grid. These three values must be entered in the grid itself.

Submittals: The following information and data regarding the tests must be submitted.

General: A detailed description of the equipment used in the tests, including calibrations of the tracer gas detector must be provided. In addition, the air sample locations monitored and the tracer gas injection rates must be provided.

Data: All recorded data must be submitted, including all measured tracer gas concentrations and all hourly data, i.e. inside temperatures, outside temperature, wind speed and direction, calculated infiltration rates, standard error of these infiltration rates, and the value of $r^2$ corresponding to these infiltration rates. These infiltration data must include those values that do not pass through the data inspection procedure.

Tables: The summary table of the all the infiltration data (table 1) must also be submitted, as well as the grid table in which the infiltration rates are averaged in weather intervals (table 2).

References:

ASTM E 741-83, "Standard Test Method for Determining Air Leakage Rate by Tracer Dilution," American Society for Testing and Materials, 1983.

Grot, R.A., Persily, A.K., Chang, Y.M., Fang, J.B., Weber, S., Galowin, L.S., "Evaluation of the Thermal Integrity of the Building Envelopes of Eight Federal Office Buildings," NBSIR 85-3147, National Bureau of Standards, 1985.

6. Tracer Gas Measurement of Ventilation - To measure building ventilation rates during occupied conditions induced by the building air handling equipment, as controlled by the building's control system and affected by weather conditions. These tests shall be conducted in accordance with ASTM E 741-83, Standard Test Method for Determining Air Leakage Rate by Tracer Dilution.

Test conditions: Same as section 5

Equipment: Same as section 5

Sampling locations: Same as section 5

Procedure: The test procedure is the same as those described in section 5, with the following exceptions. During these ventilation measurements the building air handlers are to be operated under normal occupied conditions. The HVAC control system shall be in its normal mode of operation as is in effect when the building is occupied, controlling the outside air intake and spill damper positions and fan airflow rates. All exhaust fans and vents shall be operated normally. These tests may be conducted when the building is occupied.

Analysis: Same as section 5, however when ventilation rates are very large, the tracer gas concentration may be undetectably low after the first hour. In this case, this hour must not be neglected in the data inspection procedure.

Submittals: Same as section 5

References: Same as section 5

7. <u>Indoor Air Quality Measurement</u> - To measure indoor concentrations of several contaminants. These measurements will begin before the building is occupied and continue well into the building's occupancy. Due to differences in the various pollutants to be measured and in the available measurement techniques appropriate to each, there are differences in the evaluation procedures for each pollutant. These differences are primarily in the specific measurement locations and in the sampling frequency. Unless otherwise specified to the testing agent, during all indoor pollutant measurements the building must be ventilated as if it were occupied 24 hours a day, and the building air change rate and environmental conditions must be measured according to the techniques described in sections 5 and 6. The evaluation procedures for each pollutant are outlined separately below.

The air quality evaluation will require the simultaneous measurement of the concentrations of several different pollutants, as directed by the procuring agent. The testing agent must provide equipment to direct the outflow from the air sample pumps to the various concentration measuring devices at an air pressure consistent with their calibrations.

The contaminant concentration measuring techniques and the protocols for contaminant sampling in buildings are based on the latest available information. In general there are no standard test methods or protocols for indoor contaminant sampling. As such protocols are developed, and as other measurement techniques are put into practice, it may be advisable to use this new material in modifying the following work statements.

A. <u>Carbon</u> <u>Monoxide</u> (CO): The evaluation of the interior CO concentration involves the measurement of one hour and eight hour average concentrations at several locations within the building. A list of the sampling locations, including the measurement period appropriate to each, will be provided to the testing agent.

Test Scheduling and Sampling Locations: Each CO evaluation must last for one week and several such evaluations are to be made. During each one week period, one-hour average concentrations must be determined at the designated locations every day, twenty four hours a day. The eight hour average concentrations must be determined at the designated locations once a day from approximately 9 a.m. to 5 p.m. The first series of evaluations shall be conducted before the building has been occupied and subsequent evaluations shall be made under a range of weather conditions and ventilation system operation modes in order to enable the examination of the effects of weather, ventilation rates, and outdoor concentration on interior CO concentrations. The important interior sources of CO are combustion processes, particularly smoking and the entrainment of engine exhaust in the intake air. Therefore sampling locations will be located throughout the building. Particular attention will be given to the loading dock, garage and nearby spaces, and to connections between these spaces and the rest of the building. Since CO is relatively nonreactive at room temperature, it may be drawn to the DC through long lengths of sample tubing for the real-time monitoring.

Equipment: The measurements of the one-hour average CO concentration will employ a real-time CO monitor already existing in the building. Details on the device, along with a current calibration, will be provided to the testing agent. Cylinders of calibration gases for the monitor will also be available in the DC and include ultra zero air, 5 ppm CO in dry air, and 20 ppm CO in dry air. Air sample tubing (3/8 in. OD nylon) will already be installed in the building, running from the air sample locations to the DC. Air sample pumps will be available to draw air from the interior and exterior locations, through the air sample tubing, to the DC. Equipment to monitor air change rates and environmental conditions will also be available and is described in section 5. Equipment must be supplied by the testing agent to control the air change rate measurement equipment and to record the data. In addition this data acquisition and control system (DACS) must be able to automatically select among the air sample locations and direct the outflow from the appropriate pump to the CO monitor. The DACS must also be able to direct the calibration gases to the monitor as appropriate. The tubing, valves and other equipment necessary to automate this switching of inputs to the monitor must be supplied by the testing agent. The determination of eight hour averages of the CO concentration will require the use of air sample containers (10 liter capacity air sample bags) and personal exposure pumps (battery operated with an adjustable airflow rate from about 0.03 to 0.30 scfh) that will be available in the building. Details regarding this equipment will be provided to the testing agent.

Procedure: The CO evaluation involves measuring the CO concentration at several locations within the building with the real-time monitor while simultaneously monitoring hourly average values of the building air change rate and environmental conditions as described in sections 5 and 6. The CO evaluation also involves measuring average concentrations over 8 hours by filling air sample containers with personal exposure pumps over the sample period, and measuring the concentration in the containers with the real-time monitor.

During the real-time measurements the DACS, and other equipment supplied by the testing agent, will be used to direct air samples from various interior and exterior locations, as well as calibration gases, to the CO monitor for analysis. All of the air sample pumps must be operated continuously to insure that a current air sample is available to the monitor when each location is sampled. Based on a one minute response time for the CO monitor, each sample must be directed to the device continuously for two minutes. The CO monitor output for each location must be read every 10 seconds and recorded. The average reading for the last minute of the two minute sample, and the standard deviation of this average, must also be calculated and recorded. Every three hours, during the tracer gas injection, the calibration of the CO monitor must be checked by directing the ultra zero air, the 5 ppm CO in dry air and the 20 ppm CO in dry air to the monitor continuously for five minutes each. The output of the CO monitor during the last four minutes of each five minute calibration check must be read every 10 seconds and recorded.

For the 8 hour averages of CO concentration, air sample bags must be filled at the specified locations with personal exposure pumps at an airflow rate of approximately 0.035 scfh. The bags must be filled from roughly 9 a.m. to 5 p.m. After the bags are filled, the concentration within the bags will be determined with the real-time CO monitor. Each bag should be monitored continuously for three minutes, and the output of the detector should be read every 10 seconds and recorded. The mean and standard deviation of these 10 second readings must be calcuated and recorded for the last 2 minutes of each 3 minute sample. Both before and after all the bags are analyzed, the monitor's calibration must be checked with the three calibration gases continuously for five minutes with each gas. For each of the three calibration gases the output of the CO monitor should be read every 10 seconds and recorded for the last four minutes of each five minute calibration check.

During all tests, investigate and record the use of building loading docks and interior or attached garages, and the current state of building occupancy. All data required for the air change rate and environmental conditions measurements, as specified in sections 5 and 6, must also be recorded.

Analysis: The air change rate and environmental conditions are to be analyzed as described in sections 5 and 6 to produce a table of hourly (or two hourly) building average air change rates and average environmental conditions (see table 1). The one minute averages of the measured CO concentrations from the real-time monitoring must be adjusted for any drift in calibration observed during the calibration checks. The procedure for adjusting the CO calibration will be provided to the testing agent. For the real-time monitoring, hourly average CO concentrations, both as recorded and adjusted, for each air sampling location must be calculated based on the one minute averages. These hourly averages, and their standard deviations, should be calculated even for those hours during which the air change rate data are not available. Make a table of these hourly average concentrations and standard deviations, including the date and time of the measurement, such as that shown in the following example:

| | Recorded Concentrations (ppm) | | Adjusted Concentrations | |
|---|---|---|---|---|
| | Mean | Standard Deviation | Mean | Standard Deviation |
| Date: 01/10/86<br>Time: 09:00 | | | | |
| Location | | | | |
| 1-E/A | 5.6 | 1.0 | 5.1 | 1.0 |
| 1-E/B | 6.9 | 1.2 | 6.4 | 1.2 |
| Outside-1 | 2.1 | 0.4 | 1.6 | 0.4 |

Table 3 Summary of Real-Time Carbon Monoxide Measurement Results

For the eight hour average samples, the recorded 2 minute averages and their standard deviations must also be adjusted to account for calibration drift. Make a table of these average concentrations and standard deviations, including the date and time of the samples, such as that shown in the following example:

| | Recorded Concentrations (ppm) | | Adjusted Concentrations (ppm) | |
|---|---|---|---|---|
| | Mean | Standard Deviation | Mean | Standard Deviation |
| Location: 1-E/A | | | | |
| <u>Averaging Times</u> | | | | |
| Start: 01/10/86 09:00 | | | | |
| Finish: 01/10/86 17:00 | 6.0 | 0.5 | 5.7 | 0.5 |
| Location: 1-E/B | | | | |
| <u>Averaging Times</u> | | | | |
| Start: 01/10/86 09:05 | | | | |
| Finish: 01/10/86 17:05 | 4.6 | 0.4 | 4.1 | 0.6 |

Table 4 Summary of Long-Term Average Carbon Monoxide Measurement Results

Submittals: For each CO evaluation, a detailed description of the test and test conditions must be submitted including when the test was conducted, the state of the building occupancy and construction activity, and the use of the loading dock and any attached or interior garages during the test. Provide a description of the DACS and the equipment used to switch among the air sampling locations and the calibration gas cylinders, along with a list of the air sample locations that were monitored using each technique. All recorded data must be submitted, including tracer gas concentrations, measured CO concentrations, measured calibration gas concentrations, and all hourly data, i.e. inside and outside temperatures, wind speed and direction, calculated infiltration and ventilation rates, and values of the standard errors and $r^2$ for these air change rates. The two tables referred to in the analysis section, the hourly average CO concentrations from the real-time monitoring (table 3) and the results of the 8 hour average measurements (table 4), must also be submitted. A summary table of the hourly infiltration/ventilation and environmental conditions data for all times during which CO concentration measurements took place must also be submitted (see section 5 for a description of table 1).

B. <u>Carbon Dioxide</u> ($CO_2$): The procedure, analysis and submittals for the $CO_2$ evaluation are the same as for the CO evaluation in section 7.A. The primary indoor source of $CO_2$ is occupant respiration, and to a lesser degree combustion. Therefore, the $CO_2$ sampling locations will be located throughout the building with selected sampling associated with the loading dock and the garage. A real-time $CO_2$ monitor will be available in the building, and details on the device, including a current calibration and a procedure for adjusting this calibration to account for drift, will be provided to the testing agent. Similar equipment for switching among the air sample locations and calibration gases, controlling the air change rate measurements, and recording the data, as discussed in section 7.A, must be supplied by the testing agent. The cylinders of calibration gas located in the DC will include $CO_2$ free air, 250 ppm $CO_2$ in dry air and 750 ppm $CO_2$ in dry air.

C. <u>Formaldehyde</u> (HCHO): The evaluation of the interior HCHO concentration involves instantaneous readings at several locations within the building using a real-time monitor and the determination of long term averages using passive monitors. A list of the sampling locations within the building for each approach will be provided to the testing agent.

Test Scheduling and Sampling Locations: Each HCHO evaluation must last for one week and several such evaluations are to be made. During each one week period the real-time locations must be monitored every day, twenty four hours a day. The eight hour average concentrations must be determined at the designated locations once a day from approximately 9 a.m. to 5 p.m. The one week average concentrations must be determined at the designated locations during the entire test period. The first evaluations should be made before the building is occupied and subsequent evaluations should be made under a range of weather conditions and ventilation system operation modes in order to enable the examination of the effects of weather, ventilation rates, and outdoor concentration on interior HCHO concentrations. The important indoor sources of HCHO are interior furnishings and combustion processes. Therefore sampling locations will be located throughout the building. Particular attention will be given to the loading dock, garage and nearby spaces, and to connections between these spaces and the rest of the building. Since HCHO is so reactive, the air samples for real-time monitoring can be drawn to the DC only through short lengths of tubing (100' or less).

Equipment: A real-time HCHO monitor and calibration gas generator will be available in the DC, and specifications regarding this equipment will be provided to the testing agent. Equipment to monitor air change rates and environmental conditions during these tests will also be available, and is described in section 5. Equipment must be supplied by the testing agent to control the air change rate measurement equipment and to record the data. In addition this data acquisition and control system (DACS) must be able to automatically select among the air sample locations and direct the outflow from the appropriate pump to the HCHO monitor. The DACS must also be able to direct the calibration gases to the monitor as appropriate. The tubing, valves and other equipment necessary to automate this switching of inputs to the monitor must be supplied by the testing agent.

Passive samplers for long-term average measurements of HCHO concentration must be supplied by the testing agent and obtained from a commercial manufacturer of established reputation, with experience in the production and analysis of such monitors. These passive samplers must be able to detect concentrations as low as 0.05 ppm for a one week sampling period and 0.1 ppm for an eight hour period. The devices must be able to determine these concentrations with an accuracy of 25%. The analysis of the monitors must be conducted by the manufacturer. When purchasing the passive samplers, consideration must be given to the shelf-life in relation to the test schedule.

Procedure: The HCHO evaluation involves real-time monitoring of the HCHO concentration at several locations within the building while

These adjusted concentrations must be calculated and recorded for each air sample location. The uncertainty in the adjusted concentration dC must be calculated based on the standard deviations of M, $M_o$ and $M_s$, i.e. dM, $dM_o$ and $dM_s$ respectively. To determine the uncertainty in the adjusted concentration, one calculates the following quantities

$$dMM_o = (dM^2 + dM_o^2)^{0.5}$$

$$dM_sM_o = (dM_s^2 + dM_o^2)^{0.5}$$

The uncertainty in C, denoted as dC, is determined from

$$dC = C_s \frac{(M-M_o)}{(M_s-M_o)} \left[ \left( \frac{dMM_o}{(M-M_o)} \right)^2 + \left( \frac{dM_sM_o}{(M_s-M_o)} \right)^2 \right]^{0.5}$$

The value of dC for each adjusted value of C must be recorded. A table must be produced that contains the results of each HCHO concentration determination, including the date, time and location of the sample, and the adjusted concentration and its uncertainty. The format of this table is as follows:

| | Adjusted Concentration | Uncertainty in Adjusted Concentration |
|---|---|---|
| Location: 1-E/A<br>Date: 01/10/86<br>Time: 09:05 to 09:15 | 0.090 ppm | 0.015 |
| Location: 1-E/B<br>Date: 01/10/86<br>Time: 09:20 to 09:30 | 0.074 ppm | 0.013 |

Table 5 Summary of Real-Time Formaldehyde Measurement Results

The passive pollutant monitors are to be analyzed by their manufacturers. The results of the manufacturer's analysis must be tabulated along with the air sample location corresponding to each measurement and the dates and times of the monitor deployment, in a table similar in format to table 4.

Submittals: For each HCHO evaluation, a detailed description of the test and test conditions must be submitted including when the test was conducted, the state of the building occupancy and construction activity, and the use of the loading dock and any attached or interior garages during the test. Provide a description of the DACS and the equipment used to switch among the air sample locations and the calibration gases, along with a list of the air sample locations that were monitored with each technique. Provide a description of the passive monitors that were used, including the manufacturer's simultaneously monitoring hourly average values of the building air change rate and environmental conditions as described in sections 5 and 6. The HCHO evaluation also involves measuring long term averages of concentration with passive samplers.

Due to the characteristics of real-time HCHO monitors in the concentration range of interest, 15 minutes is required to analyze the concentration at each air sample location. Therefore, only a small number of air sample locations will be monitored, typically in main return ducts for the larger zones of the building. During the real-time monitoring, the calibration of the HCHO monitor must be checked frequently with ultra zero air and a known concentration (roughly 0.1 ppm) from the calibration gas generator. Using the DACS and other equipment supplied by the testing agent, a 90 minute sampling cycle must be employed with 15 minutes each for four sampling locations, 15 minutes on ultra zero air, and 15 minutes on the calibration or span gas. The output of the HCHO detector must be read and recorded every 30 seconds and averaged over the last ten minutes of each of the six 15 minute portions of the 90 minute cycle. The mean and standard deviation of these averages must be recorded.

In building locations of particular interest, more detailed real-time evaluation may be required. In these cases, the HCHO monitor and the calibration equipment must be located in the area of interest to avoid the use of long lengths of sample tubing.

The passive HCHO monitors will be deployed according to the manufacturer's instructions within a limited number of the so-called environmental stations (ES) within the building interior. The ES are small, vented boxes, such as thermostat covers, that will already be installed within the building. The sampling locations for passive monitoring will be provided to the testing agent, along with the test duration for each (either 8 hours or one week).

During all tests, the state of building occupancy, construction activity and the installation of interior furnishings must be investigated and recorded. All data required for the air change rate and environmental conditions measurements, as specified in sections 5 and 6, must also be recorded.

Analysis: The air change rate and environmental conditions data are to be analyzed as described in sections 5 and 6 to produce a table of hourly (or two hour) building average air change rates and average environmental conditions (see table 1). The real-time HCHO monitoring data must be inspected for calibration drift, and if determined to be acceptable, the monitored readings must be adjusted for the zero and span readings. The limits of acceptable calibration drift depend on the HCHO monitor being used and this information will be provided to the testing agent. The data in an acceptable cycle include the 10 minute averages and standard deviations of the span readings $M_s$, the zero readings $M_o$, and the readings for each air sample M, along with the concentration of the span gas $C_s$. The adjusted HCHO concentration of each air sample is determined from

$$C = C_s [ (M-M_o)/(M_s-M_o) ]$$

specifications on accuracy, range of measurable concentration, and procedure for use. All recorded data must be submitted, including tracer gas concentrations, measured HCHO concentrations, measured calibration gas concentrations and all ten minute averages and standard deviations of the HCHO detector output for air samples and calibration checks, and all hourly data, i.e. inside and outside temperatures, wind speed and direction, calculated infiltration and ventilation rates, and values of the standard errors and $r^2$ for these air change rates. The two tables referred to in the analysis section, the real-time monitoring results (table 5) and the passive monitor results (similar in format to table 4), must also be submitted. A summary table of the hourly infiltration/ ventilation and environmental conditions data for all times during which HCHO concentration measurements took place must also be submitted (see section 5 for a description of table 1).

D. Particulates: The evaluation of the interior particulate levels involves both real-time measurements and the determination of eight hour averages at several locations within the building. A list of the sampling locations, including the measurement period appropriate to each, will be provided to the testing agent.

Test Scheduling and Sampling Locations: Each particulate evaluation must last for one week and several such evaluations are to be made. During each one week period, the designated real-time locations must be monitored for ten minutes each in succession, for a twelve hour period from roughly 7 a.m. to 7 p.m. The designated eight hour average sampling locations must be monitored only once a day from approximately 9 a.m. to 5 p.m. The first evaluations should be made before the building is occupied and subsequent evaluations should be made under a range of weather conditions and ventilation system operation modes in order to enable the examination of the effects of weather, ventilation rates, and outdoor particulate levels on interior particlulate levels. The indoor sources of particulates are quite variable and include smoking and other occupant activities. Particulate levels in the outside air also affect indoor particulate levels. Therefore sampling locations will be located throughout the building and outside. Due to the possibility of particle deposition on the interior of air sample tubes, the real-time monitoring must be conducted at the air sampling locations.

Equipment: A portable, real-time particle counter, based on optical scattering, will be available to the testing agent in the DC. Details on the device will be provided to the testing agent. The device will produce particle counts in specific size ranges for variable time periods, and will also be able to measure air temperature and relative humidity at each sampling location. The eight hour averages of particulate levels must be determined with equipment supplied by the testing agent. This equipment includes air sample pumps, impactors or cyclones, filters and equipment for gravimetric analysis of the filters. The measurement technique will involve low volume air sampling through an impactor or cyclone for respirable particulates, collection on a filter, and gravimetric analysis of the filter. The testing agent must be familiar with particulate sampling and analysis using filtration and gravimetric determination, as well as the filter preparation and analysis. The air sample pump must have an adjustable airflow rate from about 2 to 10 scfh and must be able to maintain a constant airflow rate (within 2%) during the entire sampling period. The pump must also have a low noise level, compatible with an office environment. The impactor must be designed to allow only particles with diameters less than 10 microns to reach the filter.

Equipment to monitor air change rates and environmental conditions during these tests will be available in the building, and is described in section 5. Equipment must be supplied by the testing agent to control the air change rate measurements and to record the data.

Procedure: The particulate evaluation involves measuring the particulate levels at several locations within the building with the real-time monitor while simultaneously monitoring hourly average values of the building air change rate and environmental conditions as described in sections 5 and 6. The particulate evaluation also involves measuring average concentrations over periods of 8 hours using filtration and gravimetric determination.

During the real-time measurements the portable, particle counter will be brought to each air sample location for ten minutes. It will be set to determine 2 minute particle counts in the following size ranges; 0.0 to 0.3, 0.3 to 0.5, 0.5 to 0.7, 0.7 to 1.0, 1.0 to 5.0, and 5.0 to 10.0 microns. Five such two minute averages will be determined and recorded at each location, along with the time of the measurement, the local air temperature and the local relative humidity. The indoor and outdoor air sampling locations will be monitored successively, and the cycle will be repeated continuously throughout the 12 hour sampling period.

The 8 hour average particulate level determinations will occur during occupied hours, roughly 9 a.m. to 5 p.m. The equipment will be deployed at the specified locations according to the equipment manufacturer's specifications. After the sampling is completed, the filter will be removed and analyzed according to the manufacturer's instructions. The measurement results will be in units of $\mu g/m^3$. This value must be recorded along with the measurement locations and the date and time of the test.

During all tests, investigate and record the use of building loading docks and interior or attached garages, and the current state of building occupancy. All data required for the air change rate and environmental conditions measurements, as specified in sections 5 and 6, must also be recorded.

Analysis: The air change rate and environmental conditions are to be analyzed as described in sections 5 and 6 to produce a table of hourly (or two hourly) building average air change rates and average environmental conditions (see table 1). The real-time particlate monitoring is analyzed by taking the 2 minute particle counts N in each particle size range, and the monitor's airflow rate $\dot{V}$, and calculating the particle concentration PC in each range. The value of PC is determined from

$$PC = N / (2 \text{ minutes})(\dot{V})$$

Based on the value of PC for each 2 minute sample, calculate and record the mean and standard deviation of the five 2 minute readings of particle concentration in each particle size range at each location. The values of PC must be calculated and recorded in units of number of particles per cubic foot and number per cubic meter. These means and standards deviations must be tabulated along with the corresponding sampling locations and environmental conditions (temperature and relative humidity) in a format similar to table 5.

The eight hour average particlulate levels, determined by filtration and gravimetric analysis, will be in units of $\mu g/m^3$s. These results must be tabulated with the corresponding air sample locations and the date and time of the sample collection in a format similar to table 4.

Submittals: For each particulate evaluation, a detailed description of the test and test conditions must be submitted including when the test was conducted, the state of the building occupancy and construction activity, and the use of the loading dock and any attached or interior garages during the test. Provide a description of the equipment and protocol used in the filtration and gravimetric determination of particulate levels. All data that are collected must be submitted, including tracer gas concentrations, all 2 minute particle counts for the real-time monitoring, and all hourly data, i.e. inside and outside temperatures, wind speed and direction, calculated infiltration and ventilation rates, and values of the standard errors and $r^2$ for these infiltration rates. For the 8 hour average particulate levels, submit the sample times, before and after filter weights, and particulate levels in $\mu g/m^3$ for each sample analyzed. The two tables referred to in the analysis section, average particle counts from the real-time monitoring and the results of the 8 hour average measurements, must also be submitted. A summary table of the hourly infiltration/ventilation and environmental conditions data for all times during which particulate level measurements took place must also be submitted (see section 5 for a description of table 1).

E. <u>Nitrogen Dioxide</u> ($NO_2$): The evaluation of the interior $NO_2$ concentration involves real-time monitoring of the concentrations of nitrogen dioxide $NO_2$, nitrogen oxide (NO), and $NO_x$, and 8 hour and 7 day averages of $NO_2$ concentration as determined with passive monitors. A list of sampling locations, including the measurement period appropriate to each, will be provided to the testing agent.

Test Scheduling and Sampling Locations: Each $NO_2$ evaluation must last for one week and several such evaluations are to be made. During each one week period the designated real-time locations must be monitored every day, twenty four hours a day. The designated eight hour average sampling locations must be monitored only once a day from approximately 9 a.m. to 5 p.m. The one week average sampling locations will be monitored during the entire test period. The first evaluations should be made before the building is occupied and subsequent evaluations should be made under a range of weather conditions and ventilation system operation modes in order to enable the examination of the effects of weather, ventilation rates, and outdoor concentration on interior concentrations. The important indoor sources of $NO_2$ include combustion processes, as well as the outdoor air. Therefore sampling locations will be located throughout the building. Particular attention will be given to the loading dock, garage and nearby spaces, and to connections between these spaces and the rest of the building. Since $NO_2$ is so reactive, the air samples for real-time monitoring can be drawn to the DC only through short lengths of tubing (100' or less).

Equipment: Both the real-time oxides of nitrogen analyzer and the passive monitors must be supplied by the testing agent, as well as equipment for controlling, calibrating and recording the output of the real-time monitor. Equipment to monitor air change rates and environmental conditions during the test will be available in the building and is described, along with the measurement and analysis procedures, in sections 5 and 6. Equipment must be supplied by the testing agent to control the air change rate measurement equipment and to record the results. In addition this data acquisition and control system (DACS) must be able to automatically select among the air sample locations and direct the outflow from the appropriate pump to the $NO_2$ monitor. The DACS must also be able to direct the calibration gases to the monitor as appropriate. The tubing, valves and other equipment necessary to automate this switching of inputs to the monitor must be supplied by the testing agent.

The real-time monitor must be based on the chemiluminescent reaction of NO with ozone, and must provide a continuous output of NO, $NO_2$ and $NO_x$ concentrations. The device must have several measurement scales including 0.05, 0.1, 0.2, 0.5 and 1.0 ppm full scale, a precision of at least 1% of full scale, a zero stability of 0.5% of full scale over 7 days, a span stability of 2% of full scale over 7 days, and a rise and fall time of no more than 3 minutes. The testing agent must also supply a calibration gas generator for on-site, real-time calibration checks of the monitor in the range of interest (approximately 0.005 to 0.10 ppm).

The passive $NO_2$ monitor must be based on the design of the "Palmes tube." The minimum detectable concentration for an eight hour exposure must be no more than 0.1 ppm and for a 7 day exposure it must be no more than 0.005 ppm. The measurement accuracy must be at least 25%. If the passive monitors are obtained from a commercial manufacturer, then the same manufacturer must analyze the monitors. The testing agent may use and analyze passive monitors of their own manufacture if they have demonstrated the ability to manufacture and analyze the monitors with repeatability and accuracy. When obtaining the passive samplers, consideration must be given to the shelf-life in relation to the test schedule.

Procedure: The $NO_2$ evaluation involves real-time monitoring of the $NO_2$, NO and $NO_x$ concentrations and measurement of long term averages of $NO_2$ with passive monitors, while simultaneously monitoring hourly average values of the building air change rate and environmental conditions as described in sections 5 and 6.

Due to the characteristics of the real-time monitors, 5 minutes are required to analyze the concentration at each air sample location. Therefore, only a limited number of air sample locations will be monitored, typically those in main return ducts for the larger zones of the building. During the real-time monitoring, the calibration of the monitor must be checked for drift with ultra zero air and the calibration gas generator. A measurement cycle will include 5 minute analyses of samples from each air sampling location, followed by analyses of the calibration gas and the ultra zero air. The switching among these input streams to the monitor must be controlled by the DACS using equipment supplied by the testing agent. During each 5 minute sampling period, the output of the monitor must be read every 10 seconds and recorded. For the last two minutes of each 5 minute sampling period, the mean and standard deviation of the 10 second readings of $NO_2$, $NO_x$ and NO concentrations must be calculated and recorded.

The passive $NO_2$ monitors must be deployed according to the manufacturer's instructions within the so-called environmental stations or ES within the building. The ES are small, vented boxes, such as thermostat covers, that will already be installed in the building. The long term averages will be determined for either 8 hour periods, roughly 9 a.m. to 5 p.m., or 7 day periods. The test duration for each sampling location will be provided to the testing agent.

During all tests, the state of building occupancy, construction activity and furniture installation must be investigated and recorded. All data required for the air change rate and environmental conditions measurements, as specified in sections 5 and 6, must also be recorded.

Analysis: The air change rate and environmental conditions data must be analyzed as described in sections 5 and 6 to produce a table of hourly (or two hour) building average air change rates and average environmental conditions (see table 1). The real-time monitoring data must be adjusted for calibration drift as specified by the manufacturer. For both the unadjusted and adjusted 2 minute averages and standard deviations of the $NO_2$, $NO_x$ and NO concentrations, hourly averages and standard deviations must be calculated for each air sampling location. These hourly data must be tabulated along with the corresponding air sampling location and the date and time of the concentration determinations in a format similar to table 3.

The passive pollutant monitors are to be analyzed by their manufacturers. The results of the manufacturer's analysis must be tabulated along with the air sample location corresponding to each measurement and the dates and times of the monitor deployment in a format similar to table 4.

Submittals: For each $NO_2$ evaluation, a detailed description of the test and test conditions must be submitted including when the test was conducted, the state of the building occupancy and construction activity, and the use of the loading dock and any attached or interior garages during the test. Provide a detailed description of the real-time monitor, the calibration gas generator, the DACS, and the equipment used to switch among the air sample locations and the calibration gases, along with a list of the air sample locations that were monitored with each technique. Provide a description of how the monitor readings were corrected for zero and span drifts. Provide a description of the passive monitors that were used, including the manufacturer's specifications on accuracy, range of measurable concentration, and procedure for use. All recorded data must be submitted, including tracer gas concentrations, all 10 second averages of the monitor's output, and all hourly data, i.e. inside and outside temperatures, wind speed and direction, calculated infiltration and ventilation rates, and values of the standard errors and $r^2$ for these infiltration rates. The two tables referred to in the analysis section, the hourly averages and standard deviations of the $NO_2$, $NO_x$ and NO concentrations and the results of the passive monitor tests, must also be submitted. A summary table of the hourly infiltration/ventilation and environmental conditions data for all times during which the $NO_2$ measurements took place must also be submitted (see section 5 for a description of table 1).

F. Sulfur Dioxide ($SO_2$): The evaluation of the interior $SO_2$ concentration involves real-time monitoring, and 8 hour and 7 day averages of $SO_2$ concentration as determined with passive monitors. A list of sampling locations, including the measurement period appropriate to each, will be provided to the testing agent.

Test Scheduling and Sampling Locations: Each $SO_2$ evaluation must last for one week and several such evaluations are to be made. During each one week period the real-time locations must be monitored every day, twenty four hours a day. The eight hour average sampling locations must be monitored once a day from approximately 9 a.m. to 5 p.m. The one week average sampling locations will be monitored during the entire test period. The first evaluations should be made before the building is occupied and subsequent evaluations should be made under a range of weather conditions and ventilation system operation modes in order to enable the examination of the effects of weather, ventilation rates, and outdoor concentration on interior concentrations. The important indoor sources of $SO_2$ include combustion processes, as well as the outdoor air. Therefore sampling locations will be located throughout the building. Particular attention will be given to the loading dock, garage and nearby spaces, and to connections between these spaces and the rest of the building. Since $SO_2$ is so reactive, the air samples for real-time monitoring can be drawn to the DC only through short lengths of tubing (100' or less).

Equipment: Both the real-time $SO_2$ monitor and the passive monitors must be supplied by the testing agent, as well as equipment for controlling, calibrating and recording the output of the real-time monitor. Equipment to monitor air change rates and environmental conditions during the test will be available in the building and is described, along with the measurement and analysis procedures, in sections 5 and 6. Equipment must be supplied by the testing agent to control the air change rate measurement equipment and to record the results. In addition this data acquisition and control system (DACS) must be able to automatically select among the air sample locations and direct the outflow from the appropriate pump to the $SO_2$ monitor. The tubing, valves and other equipment necessary to automate this switching of inputs to the monitor must be supplied by the testing agent.

The real-time monitor must employ UV fluorescence and provide a continuous output of $SO_2$ concentration. The device must have several measurement scales including 0.25, 0.5 and 1.0 ppm full scale, a precision of 1 ppb, a zero stability of 1 ppb per day, a span stability of 0.5% per day, and a rise and fall time of no more than 4 minutes. The monitor must be equipped with an internal span and zero check system based on a permeation source in a temperature controlled oven. The span must be checked in the concentration range of interest (approximately 0.001 to 0.1 ppm).

The passive $SO_2$ monitor must be based on the permeation of $SO_2$ through a plastic membrane to an absorbing reagent. The range of measureable concentration for an eight hour exposure must be 0.005 to 0.100 ppm. The measurement accuracy must be at least 25%. If the passive monitors are obtained from a commercial manufacturer, then the same manufacturer must analyze the monitors. When obtaining the passive samplers, consideration must be given to the shelf-life in relation to the test schedule.

Procedure: The $SO_2$ evaluation involves real-time monitoring of the $SO_2$ concentration and measurement of long term averages of $SO_2$ with passive monitors, while simultaneously monitoring hourly average values of the building air change rate and environmental conditions as described in sections 5 and 6.

Due to the characteristics of the real-time monitors, 6 minutes are required to analyze the concentration at each air sample location. Therefore, only a limited number of air sample locations will be monitored, typically those in main return ducts for the larger zones of the building. During the real-time monitoring, the calibration of the monitor must be checked for drift with ultra zero air and the calibration gas generator. A measurement cycle will include 6 minute analyses of samples from each air sampling location, followed by analyses of the zero and the internal span check. The switching among these input streams to the monitor must be controlled by the DACS using equipment supplied by the testing agent. During each 6 minute sampling period, the output of the monitor must be read every 10 seconds and recorded. For the last two minutes of each 6 minute sampling period, the mean and standard deviation of the 10 second readings of $SO_2$ concentration must be calculated and recorded.

The passive $SO_2$ monitors must be deployed according to the manufacturer's instructions within the so-called environmental stations or ES within the building. The ES are small, vented boxes, such as thermostat covers, that will already be installed in the building. The outside monitors must be shielded from sunlight according to the manufacturer's instructions. The long term averages will be determined for either 8 hour periods, roughly 9 a.m. to 5 p.m., or 7 day periods. The test duration for each sampling location will be provided to the testing agent.

During all tests, the state of building occupancy, construction activity and furniture installation must be investigated and recorded. All data required for the air change rate and environmental conditions measurements, as specified in sections 5 and 6, must also be recorded.

Analysis: The air change rate and environmental conditions data must be analyzed as described in sections 5 and 6 to produce a table of hourly (or two hour) building average air change rates and average environmental conditions (see table 1). The real-time monitoring data must be adjusted for calibration drift, using the monitor's internal span and zero checking system, as specified by the manufacturer. For both the unadjusted and adjusted 2 minute averages and standard deviations of the $SO_2$ concentration, hourly averages and standard deviations must be calculated for each air sampling location. These hourly data must be tabulated along with the corresponding air sampling location and the date and time of the concentration determinations in a format similar to table 3.

The passive pollutant monitors are to be analyzed by their manufacturer. The results of the manufacturer's analysis must be tabulated along with the air sample location corresponding to each measurement and the dates and times of the monitor deployment in a format similar to table 4.

Submittals: For each $SO_2$ evaluation, a detailed description of the test and test conditions must be submitted including when the test was conducted, the state of the building occupancy and construction activity, and the use of the loading dock and any attached or interior garages during the test. Provide a detailed description of the real-time monitor, the DACS, and the equipment used to switch among the air sample locations, along with a list of the air sample locations that were monitored with each technique. Provide a description of how the monitor readings were corrected for zero and span drifts. Provide a description of the passive monitors that were used, including the manufacturer's specifications on accuracy, range of measurable concentration, and procedure for use. All recorded data must be submitted, including tracer gas concentrations, all 10 second averages of the monitor's output, and all hourly data, i.e. inside and outside temperatures, wind speed and direction, calculated infiltration and ventilation rates, and values of the standard errors and $r^2$ for these infiltration rates. The two tables referred to in the analysis section, the hourly averages and standard deviations of the $SO_2$ concentration and the results of the passive monitor tests, must also be submitted. A summary table of the hourly infiltration/ventilation and environmental conditions data for all times during which the $SO_2$ measurements took place must also be submitted (see section 5 for a description of table 1).

G. Ozone ($O_3$): The evaluation of the interior $O_3$ concentration involves real-time monitoring. A list of sampling locations, including the measurement schedule appropriate to each, will be provided to the testing agent.

Test Scheduling and Sampling Locations: Each $O_3$ evaluation must last for one week and several such evaluations are to be made. During each one week period the locations must be monitored every day, twenty four hours a day, or as specified by the procuring agent. The first evaluations should be made before the building is occupied and subsequent evaluations should be made under a range of weather conditions and ventilation system operation modes in order to enable the examination of the effects of weather, ventilation rates, and outdoor concentration on interior concentrations. The important indoor sources of $O_3$ include electronic equipment and the outdoor air. Therefore sampling locations will be located throughout the building, with particular attention given to areas containing office equipment. Since $O_3$ is so reactive, the air samples for real-time monitoring can be drawn to the DC only through short lengths of tubing (100' or less).

Equipment: The real-time $O_3$ monitor must be supplied by the testing agent, as well as equipment for controlling, calibrating and recording the output of the real-time monitor. Equipment to monitor air change rates and environmental conditions during the test will be available in the building and is described, along with the measurement and analysis procedures, in sections 5 and 6. Equipment must be supplied by the testing agent to control the air change rate measurement equipment and to record the results. In addition this data acquisition and control system (DACS) must be able to automatically select among the air sample locations and direct the outflow from the appropriate pump to the $O_3$ monitor. The DACS must also be able to direct the calibration gases to the monitor as appropriate. The tubing, valves and other equipment necessary to automate this switching of inputs to the monitor must be supplied by the testing agent.

The real-time monitor must be based on UV photometry and must provide a continuous output of $O_3$ concentration. The device must have a measurement range of 0 to 1 ppm, a minimum detectable concentration of 0.002 ppm, a precision of at least 0.002 ppm, zero and span drifts of 0.001 ppm per day, and a response time of less than 1 minute. The monitor must be equipped with an internal span and zero check system based on a temperature controlled $O_3$ source. The span check must cover the concentration range of interest (approximately 0 to 0.050 ppm).

Procedure: The $O_3$ evaluation involves real-time monitoring of the $O_3$ concentration, while simultaneously monitoring hourly average values of the building air change rate and environmental conditions as described in sections 5 and 6.

Due to the characteristics of the real-time monitors, 2 minutes are required to analyze the concentration at each air sample location. During the real-time monitoring, the calibration of the monitor must be checked for drift using the internal span and zero check system within the monitor. A measurement cycle will include 5 minute analyses of samples from each air sampling location, followed by analyses of the calibration gas and the ultra zero air. The switching among these input streams to the monitor must be controlled by the DACS using equipment supplied by the testing agent. During each 5 minute sampling period, the output of the monitor must be read every 10 seconds and recorded. For the last minute of each 5 minute sampling period, the mean and standard deviation of the 10 second readings of $O_3$ concentration must be calculated and recorded.

During all tests, the state of building occupancy, construction activity and furniture installation must be investigated and recorded. All data required for the air change rate and environmental conditions measurements, as specified in sections 5 and 6, must also be recorded.

Analysis: The air change rate and environmental conditions data must be analyzed as described in sections 5 and 6 to produce a table of hourly (or two hour) building average air change rates and average environmental conditions. The real-time monitoring data must be adjusted for calibration drift as specified by the manufacturer. For both the unadjusted and adjusted 1 minute averages and standard deviations of the $O_3$ concentration, hourly averages and standard deviations must be calculated for each air sampling location. These hourly data must be tabulated along with the corresponding air sampling location and the date and time of the concentration determinations in a format similar to table 3.

Submittals: For each $O_3$ evaluation, a detailed description of the test and test conditions must be submitted including when the test was conducted, the state of the building occupancy and construction activity, and the use of the loading dock and any attached or interior garages during the test. Provide a detailed description of the real-time monitor, the DACS, and the equipment used to switch among the air sample locations, along with a list of the air sample locations that were monitored with each technique. Provide a description of how the monitor readings were corrected for zero and span drifts. All recorded data must be submitted, including tracer gas concentrations, all 10 second averages of the monitor's output, and all hourly data, i.e. inside and outside temperatures, wind speed and direction, calculated infiltration and ventilation rates, and values of the standard errors and $r^2$ for these infiltration rates. The table referred to in the analysis section, containing the hourly averages and standard deviations of the $O_3$ concentration, must also be submitted. A summary table of the hourly infiltration/ventilation and environmental conditions data for all times during which the $O_3$ measurements took place must also be submitted (see section 5 for a description of table 1).

H. Radon: The evaluation of the interior radon concentration involves real-time monitoring of the radon concentrations in working levels (WL), and one week averages of radon concentrations as determined with passive monitors. A list of sampling locations, including the measurement period appropriate to each, will be provided to the testing agent.

Test Scheduling and Sampling Locations: Each radon evaluation must last for one week and several such evaluations are to be made. During each one week period the real-time locations must be monitored every day, twenty four hours a day. The one week average sampling locations will be monitored during the entire test period. The first evaluations should be made before the building is occupied and subsequent evaluations should be made under a range of weather conditions and ventilation system operation modes in order to enable the examination of the effects of weather, ventilation rates, and outdoor concentration on interior concentrations. The important indoor sources of radon include soil gas, and in some cases building materials. Therefore sampling locations will be located throughout the building, with particular attention given to the lower levels of the building.

Equipment: Both the real-time working level monitor and the passive monitors must be supplied by the testing agent, as well as equipment for controlling and recording the output of the real-time monitor. Equipment to monitor air change rates and environmental conditions during the test will be available in the building and is described, along with the measurement and analysis procedures, in sections 5 and 6. Equipment must be supplied by the testing agent to control the air change rate measurement equipment and to record the results. In addition this data acquisition and control system (DACS) must be able to automatically select among the air sample locations and direct the outflow from the appropriate pump to the working level monitor, unless the working level monitor is located at the sampling location. The tubing, valves and other equipment necessary to automate this switching of inputs to the monitor must be supplied by the testing agent.

The real-time monitor must be based on filter collection of radon progeny and detection by alpha emission. The device must have a minimum detectable concentration of 0.001 WL and provide continuous readings of working levels for time periods ranging from 0.1 to 1.0 hours.

The passive radon monitor must have a minimum detectable concentration for a one week exposure of 1.0 pC/L. The measurement accuracy must be at least 25%. The passive monitors must be analyzed by their manufacturer.

Procedure: The radon evaluation involves real-time monitoring of the working level and measurement of one-week averages of the radon concentration with passive monitors, while simultaneously monitoring hourly average values of the building air change rate and environmental conditions as described in sections 5 and 6. Each air sample location must be monitored continuously, and therefore only a limited number of air sample locations will be monitored. The monitor should be set to provide the working levels at each location on an hourly basis, and these hourly levels must be recorded.

The passive radon monitors must be deployed according to the manufacturer's instructions within the so-called environmental stations or ES within the building. The ES are small, vented boxes, such as thermostat covers, that will already be installed in the building. The long term averages will be determined for one week periods.

During all tests, the state of building occupancy, construction activity and furniture installation must be investigated and recorded. All data required for the air change rate and environmental conditions measurements, as specified in sections 5 and 6, must also be recorded.

Analysis: The air change rate and environmental conditions data must be analyzed as described in sections 5 and 6 to produce a table of hourly (or two hour) building average air change rates and average environmental conditions. The hourly working level data must be tabulated along with the corresponding air sampling location and the date and time of the determinations in a format similar to table 3.

The passive monitors are to be analyzed by their manufacturers. The results of the manufacturer's analysis must be tabulated along with the air sample location corresponding to each measurement and the dates and times of the monitor deployment in a format similar to table 4.

Submittals: For each radon evaluation, a detailed description of the test and test conditions must be submitted including when the test was conducted, the state of the building occupancy and construction activity, and the use of the loading dock and any attached or interior garages during the test. Provide a detailed description of the real-time monitor, the DACS, and the equipment used to switch among the air sample locations, if such equipment is used, along with a list of the air sample locations that were monitored with each technique. Provide a description of the passive monitors that were used, including the manufacturer's specifications on accuracy, range of measurable concentration, and procedure for use. All recorded data must be submitted, including tracer gas concentrations, working level monitor output, and all hourly data, i.e. inside and outside temperatures, wind speed and direction, calculated infiltration and ventilation rates, and values of the standard errors and $r^2$ for these infiltration rates. The two tables referred to in the analysis section, the hourly readings of working levels and the results of the passive monitor tests, must also be submitted. A summary table of the hourly infiltration/ventilation and environmental conditions data for all times during which the radon evaluations took place must also be submitted (see section 5 for a description of table 1).

I. <u>Volatile Organic Compounds</u> (VOC): The evaluation of the interior levels of VOC involves the use of integrated sample collection on sorbent cartridges and subsequent analysis with a gas chromatograph equipped with a mass spectrometer (GC/MS). These samples must be collected over a period of 12 hours. A list of sampling locations will be provided to the testing agent. The preparation, handling and analysis of the sampling cartridges requires a large amount of care and experience. The testing agent must be familiar with the techniques, materials and equipment involved in the procedure.

Test Scheduling and Sampling Locations: Each VOC evaluation must last for one week and several such evaluations are to be made. During each one week period the locations must be monitored for twelve hours at a frequency to be specified by the procuring agent. The first evaluations should be made before the building is occupied and subsequent evaluations should be made under a range of weather conditions and ventilation system operation modes in order to enable the examination of the effects of weather, ventilation rates, and outdoor concentration on interior concentrations. The important indoor sources of VOC are quite variable and include combustion processes, interior furnishings, building materials, and various substances used within and outside the building. Therefore sampling locations will be located throughout the building. Particular attention will be given to the effects of furnishings and the activities of occupants and maintainance personnel.

Equipment: All equipment required for the VOC monitoring must be supplied by the testing agent. This equipment includes air sample pumps and solid sorbent cartridges for collecting the VOC in the air samples. The GC/MS used to analyze the samples will be located off-site, and the testing agent may use their own equipment or have the samples analyzed by a third party. The air sample pumps must have an adjustable airflow rate from about 2 to 10 scfh and must be able to maintain a constant airflow rate (within 2%) over the entire sampling period. The pump noise must be at a low level compatible with office use. The sampling cartridges must be filled with a porous polymer sorbent appropriate to VOC sampling. Equipment to monitor air change rates and environmental conditions during the test will be available in the building and is described, along with the measurement and analysis procedures, in sections 5 and 6. Equipment must be supplied by the testing agent to control the air change rate measurement equipment and to record the results.

Procedure: The VOC evaluation involves taking 12 hour samples of air on the sorbent material for subsequent analysis, while simultaneously monitoring hourly average values of the building air change rate and environmental conditions as described in sections 5 and 6. The pumps and sorbent cartridges must be placed in the designated locations. A blank sorbent cartridge, through which no air flows, must also be placed at each sample location. This blank must accompany the sample cartridge throughout the entire procedure from cartridge preparation to analysis. The sampling cartridge preparation, handling and storage procedures must be conducted employing current state-of-the-art to insure accurate results. The cartridges must be analyzed off-site with a GC/MS by the testing agent or a qualified third party. The results shall be given for total VOC in $\mu g/m^3$. Concentrations of individual VOC's should also be identified and the concentrations recorded, as directed by the procuring agent.

During all tests, the state of building occupancy, construction activity and furniture installation must be investigated and recorded. All data required for the air change rate and environmental conditions measurements, as specified in sections 5 and 6, must also be recorded.

Analysis: The air change rate and environmental conditions data must be analyzed as described in sections 5 and 6 to produce a table of hourly (or two hour) building average air change rates and average environmental conditions. The results of the VOC analysis must be tabulated in a format similar to table 4, along with the corresponding air sampling location, date and time of the sample collection, and the date and time of the analysis.

Submittals: For each VOC evaluation, a detailed description of the test and test conditions must be submitted including when the test was conducted, the state of the building occupancy and construction activity, and the use of the loading dock and any attached or interior garages during the test. Provide a detailed description of the air sample pumps, the sorbent cartridges, the GC/MS, the procedure used for preparing, handling, storing and analyzing the cartridges, and the DACS, along with a list of the air sample locations that were monitored. All recorded data must be submitted, including tracer gas concentrations, and all hourly data, i.e. inside and outside temperatures, wind speed and direction, calculated infiltration and ventilation rates, and values of the standard errors and $r^2$ for these infiltration rates. The table referred to in the analysis section, giving the results of the VOC analysis, must also be submitted. A summary table of the hourly infiltration/ventilation and environmental conditions data for all times during which the VOC evaluations took place must also be submitted (see section 5 for a description of table 1).

J. <u>Asbestos</u>: Although there are to be no asbestos containing materials used in the construction of the building, there must be an asbestos evaluation to insure that no asbestos containing materials were inadvertently used in the building and that no airborne asbestos fibers are migrating from adjoining, existing buildings or other sources. The evaluation must include a visual inspection of the building and interior air monitoring. Additional monitoring may be used based on the results of the preliminary investigation. The inspection and air monitoring must be done by a firm familiar with the measurement techniques, typical uses of asbestos containing material, and asbestos-related problems in buildings.

Test Scheduling and Inspection Locations: The asbestos evaluation must be made before the building is occupied, but after the interior is finished, and 6 months after the building is occupied. Visual inspection of certain building features can be conducted before the interior is finished and the suspended ceiling is installed, when these features are more accessible. During the evaluations particular attention must be given to those areas where asbestos containing materials have been used in past construction including return air plenums and shafts, mechanical equipment rooms and suspended ceiling panels, as well as connections between an existing building and the new building. Air sampling should be done in these same areas and in the occupied space. A list of locations for air monitoring shall be provided to the testing agent.

Procedure: The asbestos evaluation requires one or more visual, walk-through inspections of the building and limited air monitoring. The visual inspections should be preceded by a review of the building plans and specifications by the testing agent to identify potential places for the inadvertent substitution of asbestos containing materials. During the walk-through inspections of the building, the testing agent should compare as-built conditions with the plans and specifications to determine any additional sites where asbestos containing materials may have been substituted. All such suspected sites must be inspected for asbestos containing materials. Any materials suspected of containing asbestos shall be subjected to bulk sampling and off-site analysis with polarized light microscopy. A description of the suspect materials, along with their locations throughout the building and the results of the bulk sampling analysis must be tabulated. During each inspection, investigate and record the current state of building construction and occupancy.

Air monitoring using high volume pumps, collection on a membrane filter, and subsequent analysis with phase contrast microscopy must be done at several locations within the building. This monitoring must employ 8 hour sampling times, and the sampling pump airflow rate must pull a volume of 2 to 3 thousand liters through the filter. The fiber content of the air sample must be analyzed using phase contrast microscopy as specified in section 1910.1001(e) of Title 29, Code of Federal Regulations. The air monitoring shall be conducted after all interior finishing is completed and with the air handlers operating continuously. The air monitoring locations will be provided to the testing agent, and will include locations in the occupied space, return air plenums, mechanical rooms, and outside. Additional locations, based on the results of the visual inspection, will also be included. During the air monitoring, investigate and record the current state of building construction and occupancy.

During the air monitoring, the building air change rate and environmental conditions must be monitored as described in sections 5 and 6. The analysis of this data is described in the same sections.

Submittals: A detailed description of the asbestos evaluation must be submitted including when the test was conducted, and the state of building occupancy and construction activity at the time of the test. Provide a detailed description of the equipment used in the air change rate and environmental conditions monitoring, as well as all data collected as part of these tests, as described in section 5. A description of the walk-through inspection and air monitoring procedures, and all equipment and analysis techniques used in the bulk sample and air sample analysis, must also be submitted. Submit the tabulated results of the visual inspections and the air montioring. A summary table of the hourly infiltration/ventilation and environmental conditions data for all times during which the asbestos air monitoring took place must also be submitted (see section 5 for a description of table 1).

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**5. AUTHOR(S)**

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**10. SUPPLEMENTARY NOTES**

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

**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)*

Specifications for conducting a thermal and environmental evaluation program for advanced technology office buildings are presented. This program is to be used by the General Services Administration (GSA) in designing and assessing the performance of these new federal office buildings. The evaluations include quantification of the building envelope thermal integrity in terms of thermal resistance, insulation quality and airtightness, and the environmental performance in terms of outside air intake rates, air distribution system performance and indoor pollutant levels. These specifications cover the installation of sensors in the building and a "diagnostic center" that will contain measurement equipment and serve as a terminal point for wires and tubes from the sensor locations.

This document consists of three basic sections: (1) programing directives - a description of requirements regarding the diagnostic center and associated items, and quantitative architectural performance standards, to be used in the building design process; (2) construction specifications - detailed specifications regarding the procurement and installation of sensors and equipment for use in the evaluations, written in the Masterspec format developed by the Construction Specifications Institute; (3) work statements - detailed descriptions of each of the thermal and environmental evaluations for use in procuring the services of individuals or organizations to perform the tests. The three sections are intended for use by GSA in the design and procurement processes, and are therefore presented in formats appropriate to GSA's needs.

**12. KEY WORDS** *(Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)*

advanced-technology buildings; building design; building diagnostics; building thermal performance; design; whole building performance

**13. AVAILABILITY**

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