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Florida Radon Research Program

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16. ABSTRACT The report supplements earlier published standard protocols for key measurements where data quality is vital to the Florida Radon Research Program. The report adds measurement of small canister radon flux and soil water potential to the section on soil measurements. It adds indoor radon progeny measurement, radon entry rate estimation, and duct system leakage measurement to the section on building measurements.

17. KEY WORDS AND DOCUMENT ANALYSIS

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Florida Radon Research Program

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ABSTRACT

This report is a supplement to Standard Measurement Protocols, Florida Radon Research Program, published by the U.S. Environmental Protection Agency, November 1991 (EPA-600/8-91-212). It includes five new protocols: Small Canister Radon Flux, Soil Water Potential, Indoor Radon Progeny, Radon Entry Rate, and Duct System Leakage.

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* Pages iv-vi, 1-1 through 1-87, and 2-1 through 2-26 are in the basic report, EPA-600/8-91-212 (NTIS PB92-115294), November 1991.

1.12.1 Small Canister Radon Flux Measurement

Abstract

A third method for radon flux measurements is presented in this section. It has been used by Florida Radon Research Program project members. This method is similar to the University of Florida version (see Section No. 1.12), except that it reduces the air space between the soil surface and the charcoal bed to minimize biases from disturbed radon profiles.

Applicability

Radon flux is a localized indicator of radon source strength, and has been used to define regulatory limits for radon emissions from uranium mill tailings piles, phosphogypsum stacks, etc. Radon flux measurements also may help identify the potential of building sites to cause elevated indoor radon levels.

Relationship to Other Methods

This method is a variant of the two similar methods for radon flux measurements given in Section 1.12. Radon flux measurements give an indication of radon source potential at a site. Source potential in turn is affected by soil radium and radon emanation, whose protocols are found in Section 1.6, and diffusivity, which is related to Section 1.11.

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Protocol for

Small-Canister Radon Flux Measurement

Revised from RAE QAP 5.6, May 1990

1. *Background and Purpose*

Radon (^{222}Rn) flux is the rate of radon gas emission from a unit area of soil in a unit time period, and is usually measured in units of picocuries of radon per square meter of soil per second (pCi/m^2s). It is a localized indicator of radon source strength, and has been used to define regulatory limits for radon emissions from uranium mill tailings piles, phosphogypsum stacks, etc.(1) Radon flux measurements also may help identify the potential of building sites to cause elevated indoor radon levels.

The following, small-canister (SC) protocol for measuring radon flux has been shown to give equivalent results(2) to U.S. Environmental Protection Agency (EPA) Method 115,(1) while improving on several potential problems with the EPA method. It should be noted that there is no calibration standard for radon flux. Instead, sampling devices are required to provide complete radon collection over the area and time sampled, and calibrations address only the measurement of radon on the charcoal sampling medium. The sample collection device and protocol are therefore important to assure accurate measurements, and should avoid air gaps, excessive sampling times, or other problems that have been shown to bias the radon flux sample.(3-4)

The SC radon flux samplers cover a smaller area than the Method 115 samplers (approximately 0.005 m^2 vs. 0.1 m^2),(5) but they offer lower cost, easier deployment and retrieval, and some important technical advantages. These include (a) more than twice the charcoal mass per unit area used by Method 115; (b) reduced air space between the soil surface and the charcoal bed to minimize biases from disturbed radon profiles; (c) permanently-packaged charcoal to avoid losses during open-air transfer of granulated charcoal to counting containers; and (d) immediate sealing of the canister upon retrieval to avoid losses to ambient air during transport to a field charcoal transfer station. In side-by-side comparisons, the SC method differed from Method 115 (BL)(2) by less than 9%, and was well within its 1-σ uncertainty range. The SC method has served as a basis for uranium mill tailings cover designs,(6) and has been used in other U.S. Nuclear Regulatory Commission studies.(3) Protocols for sampling radon flux are identical to the Method 115 protocols except as specifically indicated.

2. *Equipment and Facilities*

2.1 Sampling Equipment

The equipment and configuration for radon flux sampling is illustrated in Figure 1. The charcoal canister is placed on the soil surface, separated only by a permeable paper filter to avoid canister contamination. It is covered by a metal can of similar diameter and height to define the sampling area and to prevent radon losses to the atmosphere. The following equipment is used for sample collection:

- Charcoal canister (chemical gas-mask cartridge for organic vapors, Type GMA, Mine Safety Appliances Co., Pittsburgh, PA or equivalent).
- Metal can (8.3 cm diameter x 4.1 cm, 8-oz. Ness Can, Embarcadero Home Cannery, Oakland, CA, or equivalent).
- Paper or Cloth Filter (8-9 cm diameter, Handi Wipes, Colgate, New York, NY, 10022-7499, or equivalent).
- Plastic Bag, re-sealable, to contain canister (7x8-inch, 4-mil heavy-gauge freezer bag, Ziploc Brand, DowBrands Inc., Indianapolis, IN, or equivalent).
- Clock, notebook and markers to record deployment & retrieval times and to label the canister bag.

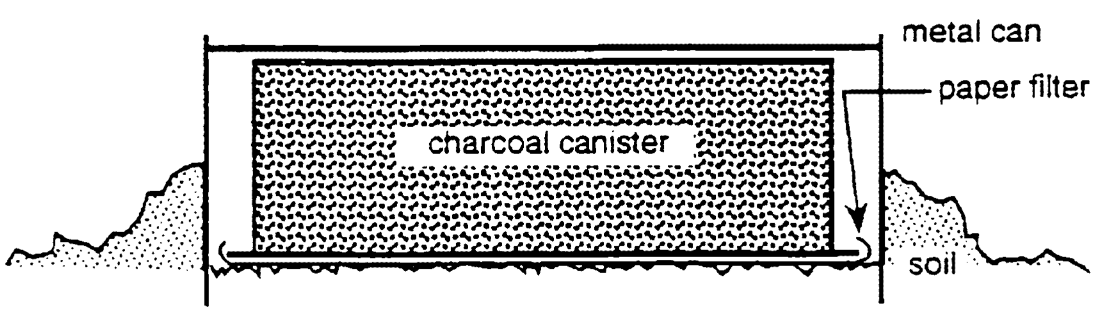

Figure 1. Charcoal Canister Configuration During Radon Flux Sampling.

2.2 Measurement Equipment and Facilities

The radon activity in the charcoal canister is measured by gamma-ray spectrometry. Any suitably-calibrated gamma spectrometer system may be utilized, including high-resolution Ge(Li) spectrometers, high-efficiency NaI(Tl) spectrometers, or gamma scintillation survey detectors (with integrating digital output). The gamma spectrometers should include suitable shielding to reduce background activity, and supporting electronics to operate the detectors and to integrate gamma-ray intensities over suitable energy ranges. Since charcoal can be assumed to collect only radon gas, the gamma-ray spectrometers need not distinguish nuclides specifically (i.e., as ^{214}Pb, ^{214}Bi, etc.), but may be set to measure total gamma-ray activity.

The following equipment and facilities should be available for sample analysis:

- Gamma-ray Spectrometer (shielded, with high-voltage bias power and digital scaler or multi-channel analyzer).
- Calibration standard or check source relatable to a calibration standard.
- Blank sample
- Clock and notebook to record count times and results.

3. *Sampling Procedure*

3.1 A new or dried-and-aged charcoal canister is transported to the field sampling location sealed in a plastic bag. Previously-used canisters shall be prepared for re-use by drying for at least 8 h at 130 ± 10° C, and sealing in plastic bags for storage until use.

3.2 The sampling location is cleared of dense turf-grass, or is (preferably) placed between plants on exposed soil to facilitate pressing the metal can into the soil surface. The filter material is placed on the soil surface, and the charcoal canister is placed on the filter with the large (black) side facing down. The metal can then is inverted over the canister and pressed 1-2 cm into the soil to minimize void space in the can, or 1-2 cm of surrounding soil is pressed against the base of the can to seal it to the soil surface (Figure 1). The sampler deployment time is recorded to the nearest 5 minutes.

3.3 After a collection period of approximately 24 h (at least 2 h, and less than 30 h), the charcoal canister shall be retrieved. For retrieval, the can is removed, and the canister is immediately (within <1 min.) sealed in a plastic bag or metal can for transport to the laboratory. The retrieval time shall be recorded to the nearest 5 minutes. Sampling shall not be conducted within 24 hours of significant rainfall, and samples shall not be considered valid if rain during the sampling period caused ponding or compromised the sampler seal to the soil surface.

4. *Analysis Procedure*

4.1 Analysis of the charcoal canister shall occur at least 2 hours after sample retrieval, and generally within 3-4 days of sample retrieval. The canister shall be maintained sealed in its plastic bag from the time of retrieval until after analysis.

4.2 The charcoal canister shall be counted with the calibrated laboratory counting system for an appropriate, fixed time interval (generally on the order of 10 minutes), and the time at the beginning of the count shall be recorded to the nearest 5 minutes.

4.3 The gamma-ray counts in the selected energy region shall be integrated and recorded.

4.4 A sealed, blank charcoal canister (a field blank if available) shall be counted using the same system and its gamma-ray counts in the same selected energy region shall be integrated and recorded.

4.5 A check source or reference standard shall be counted within 8 h of the sample count using the same system, and its gamma-ray counts in the same selected energy region shall be integrated and recorded. Its standard count rate for the given detector system, at the time of calibration, shall be used as "α" in the flux calculation in Figure 2. If a different-sized sampling can is used, the α factor should be multiplied by 0.00535 m^2/A, where A is the sampling-can area.

4.6 The radon flux shall be calculated by the equation given in Figure 2.

4.7 Following analysis, charcoal canisters shall be dried as in step 3.1, and immediately upon cooling, shall be sealed in plastic bags for storage. They shall not be re-used within the first 15 days of drying unless background activity levels are confirmed by gamma-ray analyses.

RECORDED DATA	*CALCULATED DATA*
Sample ID / Location ________	
Sampler Deployed __/__/__ at __:__ Sampler Retrieved __/__/__ at __:__	T_1 = sampling duration ____ min.
Sample Counted __/__/__ at __:__ Counting Duration T_2 = ____ min. Canister Activity ________ counts	T_3 = decay time ____ min. (sample retrieval to start of count)
Blank Canister Activity ________ counts	$C_{net} = (\text{Canis.-Blnk}) \pm \sqrt{(\text{Canis.+Blnk})}$
Standard Activity ________ counts	$S_{net} = (\text{Standard - Blank})$

CONSTANTS

Radon Decay 1 = 1.26×10^{-4} min^{-1}

$\alpha_{det.1} = 2.11 \times 10^{-4}$ pCi $m^{-2}s^{-1}min^{-1}$ (GMA std.)

$\alpha_{det.2} = 1.51 \times 10^{-4}$ pCi $m^{-2}s^{-1}min^{-1}$ (GMA std.)

$\alpha_{det.2} = 1.05 \times 10^{-2}$ pCi $m^{-2}s^{-1}min^{-1}$ (IPL2 std.)

(using sampler area = 0.00535 m^2)

$$\text{Flux}^a = \frac{C_{net}\ \alpha\ T_2}{S_{net}[1-\exp(-\lambda T_1)]\ [\exp(-\lambda T_3) - \exp(-\lambda T_2 - \lambda T_3)]}$$

[a]Assumes equal counting times (T2) for the sample, blank, and standard.

Figure 2. Data Requirements and Calculation of Radon Flux.

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6. Rogers, V.C. and Nielson, K.K., "Radon Attenuation Handbook for Uranium Mill Tailings Cover Design," U.S. Nuclear Regulatory Commission report *NUREG/CR-3533*, 1984.

1.13 Soil Water Potential

Abstract

This method is used for field measurements of soil moisture potential. The moisture potential is defined to be the pressure of the tensiometer water necessary to equilibrate mechanically and hydraulically with the soil solution phase.

Applicability

This method is specified as a field procedure and measurement to be conducted in the research house projects of the Florida Radon Research Program. As presented here, it is a "stand-alone" procedure used for long-term monitoring.

This method may not give a truly representative result if dissolved gases come out of the solution or if the water in the tensiometer system is reduced to the level of the vapor pressure of water at the ambient temperature of the system, or if the difference between the gas pressure and the pressure in the tensiometer cup water forces a gas phase through the wetted porous cup. Any of these phenomena that introduce a gas phase into the tensiometer system will seriously interfere with its operation. These conditions are most likely to occur when the soil is very dry.

Relationship to Other Methods

This method is related to the determination of soil moisture as given in Section 1.5, in that the soil moisture and soil water potential for any given soil are monotonically related one to another.

Field Procedures for Soil Water (Moisture) Potential Measurements Using Tensiometry

1. Scope

1.1 This procedure covers the field determination of the water (moisture) potential of soil by tensiometry.

1.2 For studies involving water transport and storage in soils, the energy status of the soil solution phase (soil water) is required rather than the actual soil water content. The soil water potential is defined to be the pressure of the tensiometer water necessary to equilibrate mechanically or hydraulically with the soil solution phase. The common term for this potential is usually the soil moisture suction or tension in units of pressure (centibars, kilopascals, inches of water column).

1.3 This procedure does not give true representative results for: soils with large macropores, such as root and worm holes; soil and air temperatures below freezing; wide fluctuations of air and soil temperature (especially at shallow depths); or sands at low water content and finer textured soils with high specific surface. For situations such as these, a modified method of testing or data calculation may be established to give results consistent with the purpose of the measurement.

2. Summary of Procedure

2.1 The porous ceramic tip or cup of the tensiometer is sealed to a barrel or connecting tube. A removable air-tight cap, through which water is introduced, is used to seal the barrel. A device to measure the pressure in the water in the tensiometer cup (a Bourdon-vacuum gauge) is attached near the upper end of the barrel. The connecting tube and all pores in the porous cup are filled with deaerated water. As the water content of the soil surrounding the water-filled porous tensiometer cup decreases, the energy level of the soil water decreases relative to that of the water in the tensiometer cup, and water moves out of the tensiometer through the pores in the tensiometer cup and into the soil. The pressure in the water in the tensiometer cup is reduced. If the soil surrounding the porous cup receives additional water, the soil water pressure is increased, and soil water flows through the walls of the porous cup into the tensiometer, thereby increasing the pressure of the water in the tensiometer cup. The energy status of the soil water (soil water matric potential) is estimated from that of the tensiometer water, assuming that the latter is relatively close to being in equilibrium with the soil water.

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3. Significance and Use

3.1 For many soil types, the soil water matric potential is one of the most significant index properties used in establishing a correlation between soil behavior and an index property.

3.2 A tensiometer measures the potential of the solution phase, including the effects of gas phase pressure (sometimes not atmospheric), adsorptive forces (important in sands at low water content and in finer textured materials with high specific surface), and overburden load (important in swelling soils). The potential so obtained is the proper one to be used in analyses of direction and rate of flow based on the Darcy equation.

3.3 The response time of a tensiometer is a measure of its responsiveness to changes in soil water pressure head at the external surface of the cup. Increasing the cup conductance and the gauge sensitivity will decrease the response time of the tensiometer. If the hydraulic conductivity of the soil surrounding the cup is sufficiently low, the response of the instrument may become limited by the conductivity of the soil.

3.4 If the pressure of the water in the tensiometer system decreases (the soil is very dry), dissolved gases may come out of the solution. If the pressure in the water in the tensiometer system is reduced to the level of the vapor pressure of water at the ambient temperature of the system, the liquid water will spontaneously convert to water vapor. If the difference between the gas phase pressure and the pressure in the tensiometer cup water equals or exceeds that required to force a gas phase through a wetted porous cup, air will be drawn into the cup. Any of these phenomena that introduce a gas phase into the tensiometer system will seriously interfere with its operation.

4. Apparatus

4.1 A tensiometer constructed with a ceramic sensing tip (cup) of conductance on the order of $1\text{-}3 * 10^{-5}$ cm^2/s is sufficient for most field studies. For manual data collection, the pressure (suction) is usually measured by a mercury-water manometer or a Bourdon vacuum gauge. For automated data collection systems, electrical pressure transducers provide an electrical output that may be used. It is useful to provide a space in the tensiometer barrel above the point of connection of the vacuum sensing element to serve as a gas trap. This upper portion of the barrel should be transparent. Tensiometer barrels are typically approximately 20 mm in diameter and are available in lengths appropriate for installation of the porous cup at depths of 15, 30, 45, 61, 76, 91, 106, 122, or 152 cm below the soil surface.

4.2 Kits for complete servicing of tensiometers are generally available and recommended for use. Sometimes these include a colored additive to be mixed with the tensiometer water to inhibit algae growth and to provide greater visual contrast between the water and accumulated air. If one is not supplied with the service kit, a plastic filler bottle (0.5 L or 16 oz) and a filling tube will be needed. The service kit usually supplies a vacuum hand pump used to deaerate the tensiometer water or fluid. A deep sink or bucket and a board may be useful in the filling and deaerating processes.

4.3 If firm soils are going to be sampled, a properly sized coring or insertion tool will also be needed. This tool will usually need to be driven by a mallet or hammer. For shallow depths, a spade may be used to dig a hole rather than a coring tool.

5. Procedure

5.1 Prepare a solution of the tensiometer fluid (or use water without the additive). Fill the tensiometer body full of fluid. Allow the tensiometer to remain in a vertical position until fluid completely saturates the sensing tip and begins to drip from the end of the tip. If a group of tensiometers is being filled, they can be placed in a deep sink or empty bucket for support during the tip wetting process. Let the fluid drip from the tip for about 5 minutes to wet thoroughly.

5.1.1 When the sensing tip is thoroughly wetted, fill the unit completely to the top and pull a vacuum within the tensiometer using the vacuum hand pump. Let the sensing tip of the tensiometer sit on a board for support while the rubber end of the vacuum hand pump is held in tight contact with the "O" ring cap seal of the tensiometer. Pull up on the pump handle to cause air to bubble out from the stem of the dial gauge. After each pumping, refill the tensiometer completely to the top with fluid. This pumping operation should be repeated four or five times until no further air is seen to bubble from the stem of the dial gauge. Seal the unit by screwing the service cap in place.

5.2 Core a hole in the soil to accept the tensiometer. The hole should be the right size to insure a snug fit between the ceramic sensing tip and the soil. Drive the coring or insertion tool into the soil by a mallet or hammer to the depth required. Remove the coring or insertion tool.

5.3 Push the tensiometer down into the soil until the bottom of the dial gauge is 5 to 8 cm (2 to 3 in.) above the soil surface. Tamp the soil around the body tube at the surface to seal around the body tube and prevent surface water from running down around the body tube.

5.3.1 If a rock or other impediment is encountered, move to an adjacent location to avoid possible damage to the tensiometer when putting it in place.

6. Operation, Maintenance, and Servicing

6.1 After installation, wait several hours before reading the tensiometer. This delay is because of the disturbance to the soil caused by the installation procedure. The correct reading will be reached more quickly in moist soils than in dry soils.

6.2 If the soil in which the tensiometer has been installed is moist and the soil suction readings are low, very little air will accumulate in the body tube of the tensiometer. If the tensiometer has been installed in relatively dry soil and soil suction values are in the range of 40 to 60 kPa (or cbar), air will accumulate rather quickly for the first few days after installation. After initial installation, check the tensiometer every day or two and service the unit for accumulated air. Refill the tensiometer with fluid when the accumulated air level is 1 to 3 cm (0.5 to 1 in.) or more below the service cap. After the first few air removal servicing operations, the rate of air accumulation will drop off markedly, and air removal servicing will then be required only on a weekly or longer basis.

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6.3 If a gauge has been left unattached for a long period of time at a high soil suction value and the fluid level is very low or not observable, the unit should be refilled and then pumped with the vacuum hand pump to make sure that all air is removed.

7. Report

7.1 The report (data sheet) shall include the following:

7.1.1 Identification of the sample being measured by location, station number, test number, etc.

7.1.2 Soil water (moisture) potential reading from the gauge to the nearest centibar (kPa).

7.1.3 Dates and times of insertion or last maintenance and of current measurement.

7.1.4 Approximate time and amount of rainfall since the last measurement, if known.

7.1.5 Depth of tensiometer sensing tip.

7.1.6 Indication of accumulated air in the body tube of the tensiometer and any air removal servicing that was accomplished.

8. Precision and Accuracy

8.1 The dissolution of dissolved gases and the spontaneous vaporization of the water cause the tensiometer not to be accurate at suctions of greater than about 85 kPa (cbar) when the ambient atmospheric pressure is approximately 76 cm of mercury. The operating range of tensiometers used at higher elevations with lower ambient pressures is correspondingly reduced.

8.2 The sensitivity of measurement of the pressure in the tensiometer with a Bourdon vacuum gauge is about 1 to 2 kPa (cbar) (10 to 20 cm of water).

8.3 Other requirements for the precision and accuracy of this procedure have not yet been developed.

REFERENCE

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2.6 Indoor Radon Progeny

Indoor Radon and Radon Decay Product Measurement Device Protocols. EPA-402/R-92-004 (NTIS PB92-206176), U.S. Environmental Protection Agency, Washington, D.C.

Abstract

The referenced document contains indoor radon decay product measurement protocols by three commonly used techniques. The method most suitable for use in FRRP projects is Protocol 3.1 (Continuous Working Level Monitors). Other radon and decay product methods are also included which either are already covered in the initial manual (Protocol 2.5 - Indoor Radon) or are less likely to be applicable to the program. The protocol describes the method deployment strategies, operation, documentation, analysis, and quality assurance considerations.

Applicability

This method is generally applicable to the FRRP research house projects, but may be applicable to any other FRRP project that requires information concerning radon progeny. Generally continuous working level monitors will be used in these projects. They will be deployed at least once a quarter when continuous baseline indoor radon measurements are being made. Such continuous simultaneous radon and radon progeny measurements will be made for at least two consecutive days each quarter. If occupant risks, progeny levels, or equilibrium ratios are of interest in any other of the specialty studies (de-pressurized conditions, various HVAC conditions, etc.) of any of the research house groups, then similar continuous simultaneous measurements may be taken. For certain of these special-purpose measurements, standard deployment procedures (closed house conditions, etc.) may deliberately be ignored. Because progeny measurements may be made under a variety of conditions, care must be taken to document the actual house conditions at the time of the measurement. For instance, the occupancy status, the HVAC operational mode, the open/closed conditions of interior as well as exterior doors and windows, and any pressurized or depressurized conditions should be noted.

Section 3: INDOOR RADON DECAY PRODUCT MEASUREMENT DEVICE PROTOCOLS

3.1 PROTOCOL FOR USING CONTINUOUS WORKING LEVEL MONITORS (CW) TO MEASURE INDOOR RADON DECAY PRODUCT CONCENTRATIONS

3.1.1 Purpose

This protocol provides guidance for using continuous working level monitors (CW) to obtain accurate and reproducible measurements of indoor radon decay product concentrations. Adherence to this protocol will help ensure uniformity among measurement programs and allow valid intercomparison of results. Measurements made in accordance with this protocol will produce results representative of closed-building conditions. Measurements made under closed-building conditions have a smaller variability and are more reproducible than measurements made when the building conditions are not controlled. The investigator should also follow guidance provided by the EPA in "Protocols for Radon and Radon Decay Product Measurements in Homes" (U.S. EPA, Washington, DC, June, 1993, EPA 402-R-92-003, NTIS PB-93-204014) or other appropriate EPA measurement guidance documents.

3.1.2 Scope

This protocol covers, in general terms, the sample collection and analysis method, the equipment needed, and the quality control objectives of measurements made with CW. It is not meant to replace an instrument manual but, rather, provides guidelines to be incorporated into standard operating procedures by anyone providing measurement services. Questions about these guidelines should be directed to the U.S. Environmental Protection Agency, Office of Radiation Programs, Radon Division (6604J), Problem Assessment Branch, 401 M Street, S.W., Washington, D.C., 20460.

3.1.3 Method

The CW method samples the ambient air by filtering airborne particles as the air is drawn through a filter cartridge at a low flow rate of about 0.1 to one liter per minute. An alpha detector such as a diffused-junction or surface-barrier detector counts the alpha particles produced by the radon decay products as they decay on the filter. The detector is set normally to detect alpha particles with energies between two and eight MeV. The alpha particles emitted from the radon decay products radium A (PO-218) and radium C' (Po-214) are the significant contributors to the events that are measured by the detector. All CW detectors are capable of measuring individual radon and thoron decay products, while some can be adapted to measure the percentage of thoron decay products. The event count is directly proportional to the number of alpha particles emitted by the radon decay products on the filter. The unit contains typically a microprocessor that stores the number of counts and elapsed time. The CW detector can be set to record the total counts registered over specified time periods. The unit must be calibrated in a calibration facility to convert count rate to Working Level (WL) values. This may be done initially by the manufacturer, and should be done periodically thereafter by the operator.

3.1.4 Equipment

In addition to the CW detector, equipment needed includes replacement filters, a readout or programming device (if not part of the detector), an alpha-emitting check source, and an air flow rate meter.

3.1.5 Predeployment Considerations

The plans of the occupant during the proposed measurement period should be considered before deployment. The CW measurement should not be made if the occupant will be moving during the measurement period. Deployment should be delayed until the new occupant is settled in the house.

The CW detector should not be deployed if the user's schedule prohibits terminating the measurement at the appropriate time.

3.1.5.1 Pre-Sampling Testing. The CW detector should be tested carefully before and after each measurement in order to:

- Verify that a new filter has been installed and the input parameters and clock are set properly;
- Measure the detector's efficiency with a check source such as Am-241 or Th-230 and ascertain that it compares well with the technical specifications for the unit; and
- Verify the operation of the pump.

When feasible, the unit should be checked after every fourth 48-hour measurement or week of operation to measure the background count rate using the procedures that are in the operating manual for the instrument.

In addition, participation in a laboratory intercomparison program should be conducted initially and at least once every 12 months thereafter, and after equipment repair, to verify that the conversion factor used by the microprocessor Is accurate. This is done by comparing the unit's response to a known radon decay product concentration. At this time, the correct operation of the pump also should be verified by measuring the flow rate.

3.1.6 Measurement Criteria

The reader should refer to Section 1.2.2 for the list of general conditions that must be met to ensure standardization of measurement conditions.

3.1.7 Deployment and Operation

3.1.7.1 Location Selection. The reader should refer to Section 1.2.3 for standard criteria that must be considered when choosing a measurement device location.

3.1.7.2 Operation. The CW detector should be programmed to run continuously, recording the -periodic integrated WL and, when possible, the total integrated average WL. The sampling period should be 48 hours, with a grace period of two hours (i.e., a sampling period of 46 hours is acceptable if conditions prohibit terminating sampling after exactly 48 hours). The longer the operating time, the smaller the uncertainty associated with using the measurement result to estimate a longer-term average concentration. The integrated average WL over the measurement period should be reported as the measurement result. If results are also reported in pCi/L, it should be stated that this approximate conversion is based on a 50 percent equilibrium ratio, which is typical of the home environment, and any individual environment may have a different relationship between radon and decay products.

3.1.8 Retrieval of Detectors

When the measurement is terminated, the operator should note the stop-date and -time and whether the standardized conditions are still in effect.

3.1.9 Documentation

The reader should refer to Section 1.2.4 for the list of standard information that must be documented so that data interpretation and comparison can be made.

In addition, the serial number of the CW detector and calibraton factor used should be recorded.

3.1.10 Analysis Requirements

3.1.10.1 Sensitivity. All known commercially available CW detectors are capable of a lower limit of detection (LLD [calculated using methods described by Altshuler and Pasternack 1963])[1] of 0.01 WL or less.

3.1.10.2 Precision. Precision should be monitored and recorded using the results of side-by-side measurements described in Section 3.1.11.3 of this protocol. This method can produce duplicate measurements with a coefficient of variation of 10 percent or less at 0.02 WL or greater. An alternate measure of precision is a relative percent difference, defined as the difference between two duplicate measurements divided by their mean; note that these two measures of precision are not identical quantities. It is important that precision be monitored frequently over a range of radon concentrations and that a systematic and documented method for evaluating changes in precision be part of the operating procedures.

3.1.11 Quality Assurance

The quality assurance program for a CW system includes four parts: (1) calibration and known exposures, (2) background measurements, (3) duplicate measurements, and (4) routine instrument checks. The purpose of a quality assurance program is to identify the accuracy and precision of the measurements and to ensure that the measurements are not influenced by exposure from sources outside the environment to be measured. The quality assurance program should include the maintenance of control charts (Goldin 1984)[2]; general information is also available (Taylor 1987[3], U.S. EPA 1984)[4].

3.1.11.1 Calibration and Known Exposures. Every CW detector should be calibrated in a radon calibration chamber before being put into service, and after any repairs or modifications. Subsequent recalibrations should be done once every 12 months, with cross-checks to a recently calibrated instrument at least semiannually.

3.1.11.2 Background Measurements. Background count rate checks must be conducted after at least every 168 hours (fourth 48-hour measurement) of operation and whenever the unit is calibrated. The CW should be purged with clean, aged air or nitrogen in accordance with the procedures given in the instrument's operating manual. In addition, the background count rate may be monitored more frequently by operating the CW in a low radon environment.

3.1.11.3 Duplicate Measurements. When two or more CW detectors are available, the precision of the measurements can be estimated by operating the detectors side-by-side. The analysis of duplicate results should follow the methodology described by Goldin (section 5.3 in Goldin 1984)[ibid], by Taylor (Taylor 1987)[ibid], or by the EPA (U.S. EPA 1984)[ibid]. Whatever procedures are used must be documented prior to beginning measurements. Consistent failure in duplicate agreement may indicate a problem in the measurement process and should be investigated.

3.1.11.4 Routine Instrument Checks. Checks using an Am-241 or similar-energy alpha check source must be performed before and after each measurement. In addition, it is important to check regularly all components of the equipment that affect the result.

Pump and flow meters should be checked routinely to ensure accuracy of volume measurements. This may be performed using a dry-gas meter or other flow measurement device of traceable accuracy.

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[1] Altshuler, B. and Pasternack, B., 1963, "Statistical Measures of the Lower Limit of Detection of a Radioactivity Counter," Health Physics, Vol. 9, pp. 293-298.3.1.10.2.
[2] Goldin, A.F., 1984, "Evaluating Internal Quality Control Measurements and Radioassays," Health Physics, Vol.47, No.3, pp. 361-364.
[3] Taylor, J.K., 1987, Quality Assurance of Chemical Measurements, Lewis Publishing, Chelsea, MI.
[4] US EPA, Dec. 1984, "Quality Assurance Handbook for Air Pollution Measurement Systems, Vol. 1," EPA-600/9-76-005 (NTIS PB254658), Research Triangle Park, NC.

2.7 Radon Entry Rate

Abstract

This section contains a test procedure for estimating the radon entry rates through portions of the building envelope in communication with the soil or soil gas under controlled depressurization.

This method is for measuring radon concentrations inside a building after fixed times of controlled depressurization, during which careful measurements of the indoor-outdoor pressure differential and the exhaust flows are made to ensure as close to constant levels as possible. The method is most accurate when small temperature differentials and low wind-pressure conditions are maintained. This method requires fairly simple measurements and produces results that characterize the radon entry rates at various levels of depressurization. This can be extrapolated down to normal ranges of building pressure differentials.

Applicability

This method will be used as a building diagnostic tool on several Florida Radon Research Program projects, including the Research House projects and the New House Evaluation Program projects. The test should not be run when strong wind and large indoor-outdoor temperature differentials are likely. Because of differences between the various conditions under which a building may be found and the test conditions on any given day, such measurements cannot be interpreted as direct measurements of radon entry rates that would occur on any given day. If the building has a very high leakage rate, or if the radon source potential is very low, then the radon concentrations under depressurized, high exhaust flow conditions may be near or below detection limits of the instruments. However, buildings with these features tend not to have severe indoor radon concentration problems.

Relationship to Other Methods

This method uses much of the same equipment as the Standard Test Method for Determining Air Leakage Rate by Fan Pressurization (Section 2.4.1; ASTM E779-87) and Alpha Scintillation Cell Grab Samples (Section 2.1) and Indoor Radon by grab sampling (Section 2.5).

Test Procedure for
Estimating Radon Entry Rate by Fan De-pressurization

1. Scope

1.1 This test procedure describes an experimental technique for estimating the radon entry rates through the portions of the building envelope in communication with the soil or soil gas under controlled de-pressurization.

1.2 This test procedure is applicable to small temperature differentials and low wind-pressure conditions. For tests conducted in the field, it must be recognized that field conditions may be less than ideal. Nevertheless, strong winds and, to a lesser degree, large indoor-outdoor temperature differentials should be avoided.

1.3 The proper use of this test procedure requires a knowledge of the principles of air flow and pressure measurements and of indoor radon concentration measurements.

1.4 This test procedure is intended to produce a measure of radon entry into a structure. Because of differences between natural load and test conditions, however, such measurements cannot be interpreted as direct measurements of radon entry rates that would occur under natural conditions. However, they may provide a measurement which can be performed in less than a day, is less variable than other short term tests that may be tried, and has reduced possibility of tampering than most other tests.

2. Other Referenced Protocols

2.1 Florida Radon Research Program Protocols,
EPA-600/8-91-212 (NTIS PB92-115294)
Section 2.1 Alpha Scintillation Cell Grab Samples
Section 2.4.1 Building Leakage by Blower Door Measurements

2.2 ASTM Standard:
E 779 Test Method for Determining Air Leakage Rate by Fan Pressurization

3. Definitions

3.1 *building envelope* - the boundary or barrier separating the interior volume of a building from the outside environment.

3.2 *exhaust flow rate* - the volume of air movement per unit time out of the structure.

3.3 *expected mean radon potential* - the estimated radon concentration derived from dividing the expected radon entry rate by the typical infiltration rate (with appropriate unit conversions).

3.4 *expected radon entry rate* - the estimated radon entry rate at the typical level of depressurization the structure is expected to have, extrapolated from the radon entry graph.

3.5 *fan de-pressurization response curve* - the graph that shows the relationship of measured air flow rates to the corresponding measured pressure differences (usually plotted on a log-log scale).

3.6 *radon entry graph* - the graph that shows the relationship of calculated radon entry rates to the corresponding measured pressure differences.

3.7 *radon entry rate* - radioactivity of radon gas that enters a structure per unit of time, calculated by multiplying the equilibrium radon concentration in radioactivity per unit volume by the measured exhaust flow rate in volume of air per unit time (normally expressed as picocuries per second, pCi/s).

3.8 *test pressure difference* - the actual pressure difference across the building envelope, expressed in pascals or inches of water.

3.9 *typical infiltration rate* - the infiltration rate at the typical level of de-pressurization the structure is expected to have, extrapolated from the air-leakage graph.

4. Summary of Test Procedure

4.1 This test procedure consists of mechanically de-pressurizing a structure to levels greater than the mean environmental de-pressurization, measuring the resulting air flow rates at given indoor-outdoor static pressure differences, measuring the indoor radon concentrations after a delay to reach a steady state, and then repeating the sequence at two higher levels of de-pressurization. From the air flow rates and radon concentrations, the radon entry rate for each pressure difference can be determined. From the relationship between the radon entry rates and pressure differences, the radon entry rates and expected mean radon potential of the structure can be evaluated.

5. Significance and Use

5.1 A performance evaluation of radon resistance of houses based on standard short-term measurement protocols may not be completely satisfactory. The wide variability of radon concentrations in a single house may require measurement periods too long, or threshold levels too low, for public acceptance of a standard enforced by such measurement. There is also the potential problem of tampering with measurements that take more than one day when the structure cannot be monitored continuously.

5.2 Radon entry into houses is believed to be primarily due to pressure-driven flow of soil gas, although a diffusive component may also be present.

5.3 For typical Florida sandy soil and low permeability sub-slab fill, soil gas entry rates should be relatively low. Soil radon entry rates should vary linearly with applied pressure, and no significant local depletion of radon should occur with increased soil gas entry.

5.4 Applying external driving forces in excess of the natural thermally induced pressure differentials should reduce the relative fluctuations in radon entry, so more reproducible measurements should be possible.

5.5 The house/soil system should reach a meaningful steady state within a few hours after a change in applied pressure.

5.6 The effects of central HVAC systems should not dominate the effects induced by the de-pressurizations imposed.

5.7 The fan-de-pressurization procedure should provide an unambiguous alternative test which may be completed in less than a day with reduced possibility of tampering and less variability of radon concentrations.

6. Apparatus

6.1 The following description of apparatus is general in nature. Any arrangement of equipment using the same principles and capable of performing the test procedure within the allowable tolerances may be used.

6.2 *Major Components:*

6.2.1 *Air-Moving Equipment* - A fan, blower, or blower door assembly that is capable of moving air out of the conditioned space at required flow rates under a range of test pressure differences. The system shall provide constant air flow at each incremental pressure difference at fixed pressure for the period required to obtain samples of indoor radon concentrations after a meaningful steady state has been reached.

6.2.2 *Pressure-Measuring Device* - A manometer or pressure indicator to measure pressure difference with an accuracy of ± 2.5 Pa (± 0.01 in H_2O).

6.2.3 *Air Flow or Velocity-Measuring System* - A device to measure air flow within $\pm 6\%$ of the average value. The calibration of this air flow-measuring system shall follow the manufacturer's instructions, and be recorded as such. The instrument may also be calibrated in a calibrating wind tunnel.

6.2.4 *Wind Speed-Measuring Device,* to give an accuracy with ± 0.25 m/s (5 mph).

Perform wind speed measurements at a distance three to five building heights away from the structure. List the height above ground at which wind speed is measured.

6.2.5 *Temperature-Measuring Device*, to give an accuracy of ±0.5°C (1°F).

6.2.6 *Air Flow-Regulating System* - A device such as a damper, variable motor speed control, or valve(s), that will regulate and maintain air flow and pressure difference to specific limits.

6.2.7 *Alpha-Scintillation Radon Monitors or Counting Station*, for Lucas-type radon grab sample cells.

6.2.8 *Calibrated Alpha Scintillation Cells*, for radon grab sampling. Two stem (flow-through) cells are preferable.

6.2.9 *Pump Assembly*, for filling scintillation cells, capable of flow rate range from 0.5 - 2.0 1/min (or vacuum of -28 in. Hg or less if single stem cells are used).

6.2.10 *Clock/Timer*, to give an accuracy of ±1 sec.

6.2.11 The size of the air duct and the capacity of the fan or blower shall be matched so that the linear flow velocity within the air duct falls within the range of measurement of the air flow meter.

7. Hazards

7.1 Glass should not break at the pressure differences normally applied to the test structure. However, for added safety, adequate precautions such as the use of eye protection should be taken to protect the personnel.

7.2 The test is most likely conducted in the field. Therefore, safety equipment required for general field work also applies, such as safety shoes, hard hats, etc.

7.3 Because air-moving equipment is involved in this test, provide a proper guard or cage to house the fan or blower and to prevent accidental access to any moving parts of the equipment.

7.4 When the blower or fan is operating, a volume of air is being forced out of the structure. Provide adequate shields or guards at the outlet of the air duct.

7.5 Noise may be generated by moving air or the equipment used. Therefore, make available hearing protection for personnel who must be close to the noise.

7.6 Care should be exercised not to suck debris or exhaust gases from fireplaces and flues into the interior of the structure.

8. Procedure

8.1 All interconnecting doors (except for closets, which should be closed) in the space being tested should be opened such that a uniform pressure will be maintained within a range of less than 10% of the measured inside/outside pressure difference. This condition should be verified by selected differential pressure measurement throughout the structure at the highest pressure contemplated.

8.2 HVAC balancing dampers and registers should not be adjusted. Fireplace and other operable dampers should be closed.

8.3 Establish baseline conditions for the structure for at least one hour before proceeding.

8.4 Measure and record the wind speed and direction, indoor and outdoor temperatures, and the time of day at the beginning and the end of the test. Fill duplicate Lucas alpha-scintillation cells with house air to get baseline radon concentration before de-pressurizing. Note time and set aside for at least four hours.

8.5 Perform fan de-pressurization test per ASTM E779-87 with the following modification. At the 10 Pa de-pressurization, calculate the exhaust flow rate and determine the volume of the living area. Maintain the 10 Pa de-pressurization for at least one hour or the time sufficient to exhaust three air changes. Fill duplicate Lucas alpha-scintillation cells with house air in line with the intake of the de-pressurization flow. Note time and flow rate. Set aside for at least four hours. Raise structure de-pressurization to 20 Pa and maintain for 1 hour or 3 air changes, whichever is longer. Note time and flow rate. Fill two more Lucas cells and set aside. Raise the de-pressurization to about 30 Pa and record the exhaust flow rate and de-pressurization. Raise structure de-pressurization to 40 Pa and maintain for 1 hour or 3 air changes, whichever is longer. Note time and flow rate. Fill two more Lucas cells and set aside. Raise the structure de-pressurization to 50 Pa and 60 Pa if possible, and record the exhaust flow rates and de-pressurization, completing the fan de-pressurization test.

8.6 Disassemble test apparatus. The remainder of the test sequence need not be performed at the structure.

8.7 Using the calibrated scintillation cell counting station or radon monitor, count each cell for 1 minute or 100 counts, whichever is longer. Allow at least 4 hours after collection before starting to count. Convert cell counts to radon concentrations in pCi/1 using predetermined calibration factors. To be valid, counts in duplicate cells should not differ by more than the greater of 20% or 50 counts. Average each pair of calculated radon concentrations to obtain a single concentration at each de-pressurization.

9. Data Analysis and Calculations

9.1 Using the measured exhaust flow rate Q and the calculated radon concentration C for each de-pressurization dP, calculate the approximate radon entry rate R for each dP as follows:

$$R\ (pCi/sec) = 0.47(1\text{-}min/ft^3\ \text{-}sec) C(pCi/1) Q(cfm)$$

or

$$R(pCi/sec) = 1000(1/m^3)\ C(pCi/1) Q(m^3/sec)$$

9.2 Plot R versus dP and extrapolate to dP = 0. If the data do not appear to be linear, especially at higher ΔP, then the experiment may have to be repeated at three levels of de-pressurization where linearity is expected. Estimate the value for R where dP is about 2.4 Pa, the estimated mean structure de-pressurization. Call this value R_{typ}, the expected radon entry rate.

9.3 Using the fan de-pressurization response curve, extrapolate to obtain the estimated air exhaust rate at 2.4 Pa. This will be assumed to represent a typical infiltration rate for the house Q_{typ}.

9.4 Define C_{typ}, the expected mean radon potential of the structure, by

$$C_{typ}(pCi/l) = \frac{R_{typ}(pCi/sec)}{1000\ (l/m^3) Q_{typ}(m^3/sec)} = \frac{R_{typ}(pCi/sec)}{0.47(l\text{-}min/ft^3\text{-}sec) Q_{typ}(cfm)}$$

10.1 Report at least the following information:

10.1.1 *Building Description:*
10.1.1.1 Location and construction
10.1.1.2 Floor area of conditioned space
10.1.1.3 Volume of conditioned space

10.1.2 *De-pressurization Measurements:*
10.1.2.1 Equipment used
10.1.2.2 Measurement results

10.1.3 *Radon Concentration Measurements*

10.1.4 *Weather:*
10.1.4.1 Wind speed/direction
10.1.4.2 Temperature (indoor and outdoor, both before and after the experiment)
10.1.4.3 *Humidity* (indoor and outdoor), if obtainable

10.1.5 *Fan De-pressurization Response Curve*

10.1.6 *Radon Entry Graph*

10.1.7 The expected radon entry rate, R_{typ}, and the estimated mean structure de-pressurization used to approximate it.

10.1.8 The typical infiltration rate for the structure used in the calculations, Q_{typ}.

10.1.9 The expected mean radon potential of the structure, C_{typ}.

10.1.10 An estimate of the standard error of the mean radon potential of the structure.

11. Precision and Bias

11.1 The precision and bias of this test procedure is largely dependent on the instrumentation and apparatus used and on the ambient conditions under which the data are taken.

11.2 It is more precise to take pressure and flow data at a higher pressure difference than at lower differences. Therefore, special care should be exercised when measurements are taken at low pressure differences. However, the typical infiltration rate for the structure used in the calculations is approximated from a low pressure difference, usually between 1 and 4 Pa. There is inherently poor precision in measurements made in this range, so the extrapolated values will have low precision as well.

2.8 Duct System Leakage

Abstract

This section contains a simple heating and air conditioning duct leakage testing protocol for determining first if the air handler operation has a strong influence on the house pressure differential and then a quantification of gross duct leakage. If either or both of these simplified protocols produce measurable results, then a more involved protocol is introduced for determining the external air leakage characteristics of the air distribution systems by fan pressurization. The actual procedures for this more involved protocol are still being tested by an ASTM sub-committee; so they cannot be reproduced here for general distribution. A source to contact concerning the procedures is given.

Applicability

These methods will be used as building diagnostic tools on several Florida Radon Research Program projects, including some Research House projects and the New House Evaluation projects. The tests should not be run on days with strong winds or large indoor-outdoor temperature differentials. Because of the difficulty in isolating the air handling system or its component parts from various zones of the building structures, it is not possible to determine precisely the duct leakage by these protocols. The problems vary as widely as the differences in individual houses and their unique air handling systems.

Relationship to Other Methods

This method is an extension of the Standard Test Method for Determining Air Leakage Rate by Fan Pressurization (Section 2.4.1; ASTM E 779-87). Indeed it incorporates and supersedes the last four pages of Sectio 2.4.1, Test Method for Determining the HAC Duct System Leakage. It is also related to Trace Dilution Methods (Section 2.4.2; ASTM E 741-83).

Simplified Heating/Air Conditioning (HAC) Duct Leakage Testing Protocols

Kenneth J. Gadsby
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I. Measurement of HAC Operation Influence on House Pressure Differential

A. This method describes a simplified technique to quantify the pressure differential across the building envelope with the HAC system operating.

B. Apparatus

1. Pressure-Measuring Device - A manometer or pressure indicator to measure pressure difference with an accuracy of ±0.5 PA (±0.002 in WG).
2. Plastic tubing.
3. Sealant (rope-caulk, duct tape, etc.)

C. Procedure

1. Open all interior doors, except closet doors.
2. Close all exterior doors and windows.
3. Close all fireplace and other operable dampers that control flow between the interior and exterior of the house.
4. Do not adjust HAC balancing dampers.
5. Route plastic tubing from central location in the interior of house to the outside through partially opened window or other convenient pathway and locate outside end so as not to be directly affected by wind (could be connected to manifolding that would have input tubes from each side of the house).
   a. Interior location should not be near HAC registers to avoid localized pressure anomalies.
   b. The tubing may be connected to a 1 liter reservoir or to a fitting with hypodermic tubing as an orifice to damp pressure oscillations.
6. Seal opening through which tubing was passed with rope caulk or other non-staining, easily removed material.
7. Connect outside tubing to reference (or low side) port of micromanometer or other sensitive pressure measuring device, after zeroing instrument. This makes the outside ambient the reference pressure.
8. Record pressure reading with HAC and all other fans that connect to the outside of the house in the OFF position. Pay particular attention to sign of pressure readings.
9. Turn on the HAC distribution fan and record the pressure difference reading after 2 minutes of operation.
   a. A positive reading means that the house is pressurized by the HAC system, conversely, a negative reading means HAC depressurization of the house.
10. Turn off HAC fan.

11. Record pressure difference.
12. Repeat 9.
13. Turn off HAC fan.
14. Record pressure difference.
15. Average pressure differences, 9-11 and 12-14. This averaged pressure difference is the pressure influence of the HAC on the structure.
16. Preferred test conditions are wind speed of 0 to 4.5 m/s (0 to 10 mph) and an outside temperature from 5 to 35 C (41 to 95 F).
17. This technique may be used to test the effects of other fan system operation on house pressure differentials by turning on and off those fans other than the HAC fan.

II. Quantification of Gross Duct Leakage

A. This method describes a technique to measure the gross duct leakage under controlled depressurization and/or pressurization.

B. Reference Document
   1. ASTM Standard
      a. E779-87 Determining Air Leakage Rate by Fan Pressurization

B. Apparatus
   1. Same as E779-87

C. Procedure
   1. Same setup as E779-87
   2. With HAC system and all other ventilating fans in the off position, depressurize the house in 6 increments of 10 Pa, from 10 to 60 Pa and record flow/pressure data.
   3. Turn on the HAC fan.
   4. Repeat 2 and record flow/pressure data.
   5. Data analysis and calculations are the same as E779-87:
      a. Convert flows to m^3/sec (ft^3/min) at reference conditions.
      b. Plot the measured leakages against the corresponding pressure differences on a log-log plot for both HAC off and HAC on.
      c. Calculate effective leakage area as per E779-87 for HAC off and HAC on.
   6. The difference between the flows, HAC off and HAC on, at any pressure difference, is the net leakage of the duct system at that pressure difference.
      a. If the flow through the blower door is higher with the HAC fan on, the return system leaks dominate - the HAC fan is pressurizing the house.
      b. If the flow through the blower door is lower with the HAC fan on, the supply leaks dominate - the HAC fan is depressurizing the house.
   7. If pressurization is used, all pressure operated dampers to the outside must be sealed. These include bathroom and range vents, and whole house fan louvers.
   8. Preferred test conditions are wind speeds of 0 to 4.5 m/sec (0 to 10 mph) and an outside temperature from 5 to 35 C (41 to 95 F).

Summary of Draft Standard Test Method for Determining the External Air Leakage Characteristics of Air Distribution Systems for Fan Pressurization

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1. Scope

This test method is intended to produce a measure of the air tightness between an air distribution system and its surroundings exterior to the conditioned spaces of a building. Two standardized techniques are described and are applicable to small temperature differentials and wind pressures, the uncertainties in the measured results increasing with increasing wind speeds and temperature variations.

2. Referenced Documents

ASTM Standard: E 779 - Standard Test Method for Determining Air Leakage Rate by Fan Pressurization.

3. Test Methods

The test method consists of mechanical pressurization and depressurization of an air distribution system and the conditioned space of the building through which it passes, and measurements of air flow rates at different pressure differentials between the distribution system and its surroundings outside the conditioned portion of the building. From the relationship between the measured air flow rates and pressure differences, the air leakage characteristics of the external leaks on the supply and return sides of the air distribution systems can be separately evaluated. Two alternative measurement techniques are specified, one of which is recommended for leakier ducts, the other for tighter ducts.

4. Significance and Use

Air leakage between an air distribution system and unconditioned spaces affects the energy losses from the distribution system, the ventilation rate of the building, and potentially the entry rate of various pollutants.

Air infiltration with and without an air distribution system operation may be measured directly using a tracer dilution method. The fan pressurization method provides an indirect way to relate the infiltration rate to the leakage of the structure and the leakage of the air distribution system. The fan pressurization method thus has several advantages over the tracer dilution method.

5. Apparatus

Major components are as follows: (1) air moving equipment, (2) a pressure-measuring device, (3) a direct pressure measuring probe with a small velocities-pressure coefficient, (4) a device to measure air flow within ± 3% of the true value, (5) a duct air flow measuring system to measure air flow into or out of an air distribution register within ± 6% of the true value, (6) a wind speed measuring device to give an accuracy within ± 0.25 m/s (0.5 mph) at 2.5 m/s (5 mph) , (7) a temperature measuring device to give an accuracy of ± 0.5°C (1 °F), (8) a simultaneous pressure and flow measurement system -- three alternative systems are: (a) a computerized data acquisition system, (b) a multi-channel sampler and hold system, or (c) an interleaved multi-pylon sampling technique, (9) and air flow regulating system that will regulate and maintain air flow and pressure difference within specific limits, and (10) a blower door - a door mounted fan or blower that is adjustable to fit common door openings. The fan or blower should possess a variable-speed motor to accommodate the wide range of required flow rates up to 1.4 m^3/s (3000 cfm).

6. Procedure

Because this procedure is undergoing ASTM review, it can not be reproduced here. Therefore, for details of the procedure and analysis of data, the reader is requested to contact Mark P. Modera at the Lawrence Berkeley Laboratory.