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## Standard Test Method for DETERMINING AIR LEAKAGE RATE BY TRACER DILUTION<sup>1</sup>

This standard is issued under the fixed designation E 741; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

<sup>ε1</sup> NOTE—Editorial changes were made throughout the standard, including the title, in July 1984.

<sup>ε2</sup> NOTE—Figure 3 was editorially corrected in July 1986.

<sup>ε3</sup> NOTE—Figure 3 was editorially changed in August 1987.

### 1. Scope

1.1 This test method describes a standardized technique for determining air change rate in buildings under natural meteorological conditions by trace gas dilution.

1.2 This test method shall not be used to determine the individual contribution of various building components to the air change rates of a building.

1.3 Use of this test method requires a knowledge of the principles of gas analysis and instrumentation.

1.4 The current state of the art does not possess analytical techniques to extrapolate precisely measured air change rates to meteorological conditions different from those prevailing during measurement.

1.5 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of whoever uses this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use. For specific precautionary statements, see Section 7.*

### 2. Applicable Document

#### 2.1 ASTM Standard:

E 779 Test Method for Determining Air Leakage Rate by Fan Pressurization<sup>2</sup>

### 3. Descriptions of Terms Specific to This Standard

3.1 *air change rate*—the ratio of hourly indoor air change and indoor space volume measured in identical volume units (normally ex-

pressed in air changes per hour, ACH or ACPH).

3.2 *air leakage rate*—the volume of air movement per unit time across the building envelope. This movement includes flow through joints, cracks, and porous surfaces, or combination thereof. The driving force for such air leakage in service can be either mechanical pressurization and evacuation, natural wind pressures, or air temperature differentials between the building interior and the outdoors, or combinations thereof.

3.3 *building envelope*—the exterior shell enclosing the indoor space.

3.4 *exfiltration*—air leakage from a building space.

3.5 *indoor space*—the volume of a building that exchanges air with outside ambient air. In most cases, this volume is the deliberately conditioned space within a building, generally not including the attic space, basement space, interstitial spaces (such as a double envelope), and attached structures, unless such spaces are connected to the heating and air conditioning system.

3.6 *infiltration*—air leakage into a building.

3.7 *tracer gas*—a gas that can be mixed with air and measured in very small concentrations, making it possible to detect air movements and measure air change rates.

<sup>1</sup> This test method is under the jurisdiction of ASTM Committee E-6 on Performance of Building Construction and is the direct responsibility of Subcommittee E06.41 on Infiltration Performances.

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<sup>2</sup> *Annual Book of ASTM Standards*, Vol 04.07.



#### 4. Summary of Method

4.1 This test method entails introducing a small amount of tracer gas into a structure, thoroughly mixing it, and measuring the rate of change (decay) in tracer concentration. The air change rate can be estimated from the decay rate of tracer concentration with respect to time. On-site meteorological conditions are measured concurrently. In the on-site monitor variant, tracer concentrations as a function of time are measured on site as air samples are obtained. In the container sample variant, after the tracer gas has thoroughly mixed, an initial air sample container is filled. The tracer gas is allowed to decay for a period of several hours during which a second and perhaps third sample container is filled. The air change rate can be determined from the decay in tracer concentrations.

#### 5. Significance and Use

5.1 Air leakage accounts for a significant portion of the thermal space conditioning load; it can introduce outdoor air contaminants in conditioned indoor air, and it can dilute indoor-generated contaminants, therefore detracting from or providing for occupant comfort.

5.2 Air leakage rates are difficult to predict analytically because they are functions of building tightness and configuration, inside-outside temperature differences, wind speed and direction, quality of workmanship in construction, and numerous other factors.

5.3 This test method describes measurements of air leakage rates. In applying the results of this test method to the design of buildings, consider that the air leakage characteristics of a structure are affected by building operation, maintenance, and the resistance of the building components to deterioration.

5.4 The tracer dilution method has been proven to be an effective way of measuring the air leakage rate of a structure under field conditions. The measurement of air infiltration using the tracer dilution method and on-site gas monitor equipment requires field deployment of equipment and the use of trained technicians. It is possible to take tracer gas samples on site and analyze them at a laboratory facility. The practice of taking container samples can be performed by persons not trained in the operation of the gas monitor equipment.

5.5 As an alternative to the tracer gas method,

the fan pressurization method (Test Method E 779) provides an indirect way to relate the air leakage rate or air tightness to the leakage area of a structure. This test method has several differences from the tracer dilution method. It can be used (1) to compare the relative air tightness of several buildings, (2) to identify the leakage source and rate of leakage from different components of the same building envelope, and (3) to determine the air leakage reduction for individual retrofit measures applied incrementally to an existing building.

5.6 When the absolute air leakage rate is needed, the tracer dilution method should be used over a wide range of wind velocities and indoor and outdoor temperature differences. It is best to use the fan pressurization method for diagnostic purposes and resolve the absolute air leakage rate with the tracer dilution method. However, the measuring equipment and techniques are relatively complicated for the tracer dilution method, and the data analysis and correlation are more involved.

5.7 In contrast with the tracer gas dilution method, two other tracer gas techniques are employed:

5.7.1 One is the constant concentration approach in which the tracer gas concentration is maintained essentially constant (order of  $\pm 10\%$ ) in a given volume. The air infiltration rate is determined from how much tracer gas must be injected to maintain the constant concentration. The constant concentration feature is particularly desirable in multi-chamber buildings, since leakage from chamber-to-chamber does not disturb the air infiltration measurement.

5.7.2 The second method is the constant injection method where, as the name implies, tracer gas injection is maintained constant over time.

5.7.3 The governing equations for both constant concentration and constant injection are different from the tracer gas dilution method.

#### 6. Apparatus

6.1 This description of apparatus is general in nature, and any equipment capable of performing the test measurements within the allowable tolerances is permitted. See Annex A1 for tracer gases and their measurement instrumentation that have been used in tracer dilution studies.

6.2 *Tracer Gas Monitor*—A device to measure tracer gas used in the study, capable of



measuring the tracer gas to within  $\pm 5\%$  at any concentration.

6.3 *Sampling Network*, consisting of tubing, tubing junctions, a pump, and possibly an aspirator. This network is used to draw samples from remote locations within a structure, blend them, and bring the blended sample to a convenient place for analysis. In general, it is best to avoid plasticized tubing, such as vinyl, and use copper, stainless steel, or possibly polypropylene or nylon. The technician should be aware that surface absorption within the sampling network can be a major source of confusion in any concentration decay measurement.

6.4 *Sample Containers*, non-absorbent, inert, low-permeability containers (such as, sample bags, syringes with needle caps, or plastic bottles) used to collect and store air samples from buildings under test.

6.5 *Pump*, non-contaminating air sample pump, either manual or powered, used to fill sample containers. Plastic bottles can be filled by hand squeezing.

6.6 *Syringes*—Disposable syringes may be used as sample containers if sealed or to inject gas samples when the gas monitor is a gas chromatograph. A plastic bottle containing tracer gas or tracer gas/air mix can also be used.

6.7 *Circulating Fans*, used to circulate air within a structure, capable of circulating air over  $360^\circ$ . Oscillating or hassock fans are preferred. Such fans are normally unnecessary in buildings with ducted forced air systems.

#### 6.8 *Meteorology Measurements:*

6.8.1 *Meteorology Stations*, portable, that records wind speed and direction, outside temperature, and (if available) relative humidity, is used to obtain on-site meteorological data.

6.8.2 *Barometer*—A device to measure local barometric pressure is useful. If one is not available, barometric pressure from the nearest weather station is obtained for the time during which measurements are performed. These data are corrected for any elevation difference between the weather station and the test structure.

6.9 *Tracer Gas*—A cylinder or container of gas chosen from those listed in Annex A1 is necessary as a source of the tracer used in the test.

6.10 *Timing Device*—A clock, watch, chronometer, or similar device suitable for measuring elapsed time and time intervals.

## 7. Safety Precautions

7.1 The maximum allowable concentration in air for each of the tracer gases that have been used for tracer dilution air leakage measurements is provided in Annex A1. Do not exceed this concentration under any circumstances. Good experimental practice is to ensure that the maximum allowable concentration of the particular tracer is less than this maximum by at least a factor of four. The initial tracer gas concentration must not exceed under any circumstances the OSHA<sup>3</sup> time-weighted average for substances included in the latest OSHA-controlled gases list.

## 8. Procedure, Sampling, and Calculations for On-Site Monitor Method

### 8.1 Procedure:

8.1.1 The assumption underlying the tracer gas measurement of air change rate is that for perfect mixing with steady air flow, the loss rate of tracer gas concentration conforms to the exponential dilution law; that is, the loss rate or dilution of an escaping gas is proportional to its concentration. Mathematically, this assumption leads to Eq 1. A detailed derivation and discussion of this equation are contained in publications cited in footnotes F and I of Table A1.1

$$C = C_0 \exp(-It) \quad (1)$$

where:

$C$  = tracer gas concentration at time  $t$ ,

$C_0$  = tracer gas concentration at time = 0,

$I$  = air change rate, and

$t$  = time.

8.1.2 *Injection and Mixing of Tracer Gas*—At one or more points in the test structure, release an amount of tracer gas sufficient to produce an easily discernible response in the gas-measuring instrument. The location of release is governed by the location of air handling system(s) or mixing fans in a structure with no air-handling system. This release can be done with a disposable syringe or a plastic bottle filled with tracer gas.

8.1.3 In a building with ducted forced air system(s), operate the main fan(s) continuously. Introduce tracer gas into the main supply or return duct(s), preferably in the vicinity of the main fan(s).

8.1.4 Leaks in the ductwork system may pro-

<sup>3</sup>Occupational Safety and Health Administration, 200 Constitution Ave. NW, Washington, DC 20210.



duce an incremental increase in the air leakage rate. Two methods to assess this leakage are:

8.1.4.1 After beginning a test, as in 8.1.3, operate the main fan(s) only for initial mixing and shortly before sampling.

8.1.4.2 Use portable fans for mixing after initiating a test as in 8.1.3. Perform the remainder of the test as in 8.1.5.

8.1.5 In a building without central heating and air conditioning system(s), release the tracer gas at one or more points within the structure. Use fans to circulate the air and mix the gas. Take care not to affect the pressure distribution within the structure. Open all doors connecting contiguous living spaces.

## 8.2 Sampling:

8.2.1 Before taking gas samples, allow at least 30 min for mixing.

8.2.2 To test for homogeneity in tracer gas concentration, take samples from a number of building spaces. When concentrations differ by less than 5 % of the average concentration measured within the structure, begin monitoring the decay of tracer concentration. In a residential structure, two or more samples from widely separated locations are required. In multi-story structures, two widely separated samples per floor are required.

8.2.3 Tracer samples may be measured at a single central location by taking individual samples (grab samples) at a number of distinct locations, or by drawing samples from a number of locations through a common network (multi-point sampling).

8.2.3.1 When multi-point sampling is used, place sensors at strategic points within the test structure and feed to a central measuring terminal. For methods that analyze air with a single measurement device, use a sampling network to bring blended air samples to the analyzer. A diagram of a sampling network and a sampling junction are shown in Figs. 1 and 2. Note that if the dilution rate in different rooms or floors is different, samples drawn by this method yield air leakage rates slightly less than the true average rate. For example, if one of the rooms or floors is leaking air at twice the rate of the other (1 ACPH and 0.5 ACPH), analysis of the blended samples of the two will lead to an air leakage rate estimate about 4 % lower than the true average rate.

## 8.3 Calculations:

8.3.1 Rearrange Eq 1 as follows:

$$I = (1/t)\ln(C_0/C) \quad (2)$$

where:

$C$  = measured time-dependent concentration,

$C_0$  = concentration at  $t = 0$ ,

$I$  = air change rate, and

$t$  = time.

Equation 2 is the starting point for several means of calculating air change rate from concentration and time measurements.

8.3.2 *Graphical Method*—Plot the natural logarithm of concentration on a linear scale against time in hours on a linear scale. The measurements should fall on a straight line with time, provided the air change rate remains constant. Scatter of points is expected and a straight line may have to be faired in the “best fit” sense. A minimum of three points over 1 h should be used to determine this straight line.

8.3.2.1 On the straight line determined in 8.3.2, choose two points with coordinates  $(C_1, t_1)$  and  $(C_2, t_2)$ , where  $C_1$  is the concentration at time  $i$ . Calculate  $I$ , the air change rate, as follows:

$$I = (\ln C_2 - \ln C_1)/(t_2 - t_1) \quad (3)$$

This technique is shown in Fig. 3.

8.3.2.2 This graphical method lends itself well to field study of the data, since it is easy to plot the log of concentration as a function of time. It is less sensitive to errors in concentration than other methods. It has the further advantage that a graph provides a visual display of any departures in the exponential decay law. So long as the data fall on a reasonably straight line, one has confidence that the data obtained are valid within the assumptions necessary for the validity of the tracer dilution method. One *caveat* that should be observed during any measurement interval is that the data points used in determining an air leakage rate should encompass the mean winds observed during the course of the measurement.

8.3.2.3 When many data points are obtained, a least-square computer program is used to calculate a “best fit” to the straight line.

8.3.3 *Finite Difference Method*—Calculate the air change rate after each sampling using the finite difference form of Eq 2 as follows:

$$I = \frac{L}{V} = \frac{1}{(t_{i+1} - t_i)} \ln \frac{C_i}{C_{i+1}} \quad (4)$$

where:

$L$  = leakage rate,



$V$  = room volume,

$t_i$  = time at  $i$ th interval, and

$C_i$  = tracer concentration at  $i$ th sample interval. For measurement over  $N$  sampling intervals, form a mean and standard deviation as follows:

$$\text{Mean } I = \bar{I} = (1/N)I$$

$$\text{Standard Deviation} = S_I = [I^2 - (I^2/N)/(N-1)] \quad (5)$$

The air change rate,  $I = L/V$ , is "best fit" to the sample values of this parameter. The best fit for  $I$  is the mean, and is determined from the test data in accordance with Eq 5. This finite difference method has the advantage of simplicity, but it is very sensitive to errors in concentration or to the effects of poor mixing, especially when short sampling intervals are used.

**8.3.4 Decay Time Method**—Concentration decay usually occurs quickly; this allows for a rapid means of estimating  $I$ . For example, with time measured in minutes, the time for one half the initial concentration to decay is noted as  $t_{1/2}$  and the  $I$  estimate is given by  $41.59/t_{1/2}$ . Similar ratios are given for other decay fractions and are shown in Table 1. These ratios are simply computed for  $C/C_0$  ratios of  $3/4$ ,  $2/3$ ,  $1/2$ , etc. The measurer has to record the time that a desired ratio is encountered.

## 9. Procedure, Sampling, and Calculations for Container Method

**9.1 Injection of Tracer Gas**—A predetermined quantity of the tracer gas is initially injected into the building so that the initial concentration of the tracer gas is below the safety limits listed in Annex A1 and within the optimum detection range of the gas monitor used. Graduated syringes can be used for this injection. These can be prepared before the test or filled from a bottle of compressed tracer gas at the site. The injection is accomplished by slowly walking around inside the structure, injecting gas into each room in a quantity approximately proportional to the volume of the room. The graduation on the syringe greatly aids in this process. A sample container with tracer gas/air can be used in a similar manner.

**9.2 Mixing of Tracer Gas in Dwelling**—A waiting period of approximately  $1/2$  to 1 h should then be allowed for proper mixing of the tracer gas. For a building with a forced air heating system, the fan on the furnace can be turned on to assist in the mixing. Experience in dwellings without an air handling system suggests that nat-

ural convection currents will mix the tracer gas well. This is also true for each floor of the building (if the doors between rooms are open). In multi-story structures there seems to be a tendency for the tracer concentration to be higher on the upper floors. This is probably due to natural convection currents caused by rising warm air. Circulating fans can be used to assist mixing of the tracer gas.

**9.3 Filling Initial Sample Containers**—After adequate mixing of the tracer gas, an initial air sample container is filled for each floor of living space. If it is suspected that certain volumes of the building are not in perfect communication with each other, then separate air sample containers should be filled for each volume. This is accomplished by walking around the floor, filling the sample container by means of a small pump, or hand squeezing a plastic sample bottle or syringe. This will provide an integrated sample. The important criterion is that the air sample container must be filled slowly, thus ensuring that an integrated sample is obtained.

**9.3.1** Label each air sample container as follows: identification of the building (address), time of injection, time of sample, section of building from which sample was taken (first floor, basement, etc.), meteorological conditions, and indoor temperature. A suitable alternative procedure is to record these data on a log sheet and identify the samples by numbers corresponding to log entries.

**9.4 Decay of Tracer Gas**—Wait 1 h for the tracer gas concentration to decay. Note the activities of occupants and the operating mode of mechanical equipment during this period.

**9.5 Fill Sample Containers**—Repeat the procedure in 9.4 at known intervals to obtain two or more additional samples of air for each floor of the building.

**9.6 Determination of Tracer Gas Concentration**—Tracer gas concentrations are determined in an off-site laboratory using gas monitor equipment. The air leakage rate  $I$  is then determined from Eq 2. For periods from 1 to 2 h, Eq 2 is an accurate relation for determining the air exchange.

**9.7** The procedures in 9.1 through 9.6 are graphically shown in Fig. 4.

## 10. Calibration

**10.1** State the method of calibration of the gas analyzer. If the analyzer is not provided with a

manufacturer's calibration, perform an actual calibration. Use standard mixtures of at least two different concentrations in the range anticipated in an actual test, unless manufacturer's specifications allow single point calibration.

**11. Report**

11.1 The report should include the following information. Include as much of this information as possible to facilitate comparison with other data at a later time.

11.1.1 *Measurement Characterization:*

11.1.1.1 *Air Mixing*—Method of initial mixing and method of maintaining mixing during the measurement if one is used.

11.1.1.2 *Air Sampling*—Location of sampling site, sample interval, initial sample time, and method of sampling.

11.1.1.3 *Tracer Gas*—Type, initial concentration, method of introduction.

11.1.1.4 *Detector*—Type and method of calibration.

11.1.1.5 *Type of Calculation*—Finite difference, decay time, graphical, least square.

11.1.2 *Meteorological Conditions:*

11.1.2.1 Location and height of meteorological measurement.

11.1.2.2 Wind speed and direction (both maximum and average).

11.1.2.3 Temperature and measurement technique.

11.1.2.4 Barometric pressure and measurement technique.

11.1.2.5 Relative humidity or wet bulb temperature.

11.1.3 *Test Space Characterization:*

11.1.3.1 *Structure Type*—Residential, commercial, industrial, other.

11.1.3.2 *Location of Structure Relative to:*

(a) Proximity to other structures (give type

and roadways.

(b) Description of surrounding terrain (give type, that is, gullies, mountain, mounds, cliffs, etc.)

(c) Structure orientation and elevation relative to 11.1.3.2(a) and 11.1.3.2(b).

11.1.3.3 *Windows*—Type, dimensions, number, and location in test space.

11.1.3.4 *Walls*—Interior and exterior.

11.1.3.5 *Leakage*—Noticeable areas.

11.1.3.6 Location of chimneys, vents, and other such specified opening.

11.1.3.7 Type and capacity of heating, ventilation, and air-conditioning systems.

11.1.4 *Test Space Operating Characteristics:*

11.1.4.1 *Doors*—Open or closed.

11.1.4.2 *Windows*—Open or closed.

11.1.4.3 *HVAC System*—On or off.

11.1.4.4 *Vent Fans*—On or off.

11.1.4.5 *Special Circumstances or Characteristics During Test*—Occupied, unoccupied, ingress, egress.

11.1.4.6 Indoor temperature and measurement technique.

11.1.4.7 Relative humidity and measurement technique.

**12. Precision and Bias**

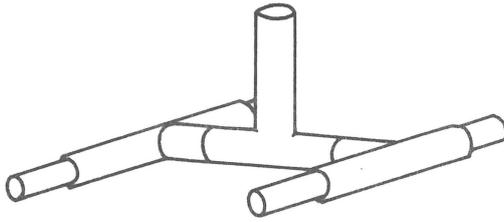
12.1 At present, insufficient data exist for purposes of precision and accuracy determination. A reasonable estimate of the uncertainty in a given air change rate determination is about 10 % or less.

12.2 Note that the air change rate is a strong function of indoor-outdoor temperature difference and wind speed and direction. When interpreting or comparing air change rate data, the fact that a pressure and temperature dependence does exist should be considered. It can have a strong effect on the results.

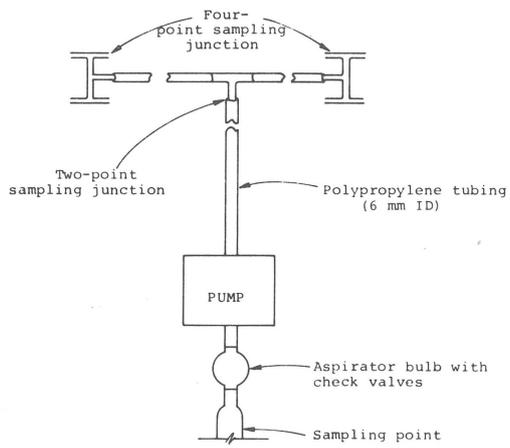
**TABLE 1 Decay Ratios to Compute ACPH**

Concentration Ratio	Decay Time, min	I, ACPH
3/4	$t_{3/4}$	17.26/ $t_{3/4}$
2/3	$t_{2/3}$	24.33/ $t_{2/3}$
1/2	$t_{1/2}$	41.59/ $t_{1/2}$
1/3	$t_{1/3}$	65.92/ $t_{1/3}$
1/4	$t_{1/4}$	83.18/ $t_{1/4}$
1/8	$t_{1/8}$	124.77/ $t_{1/8}$

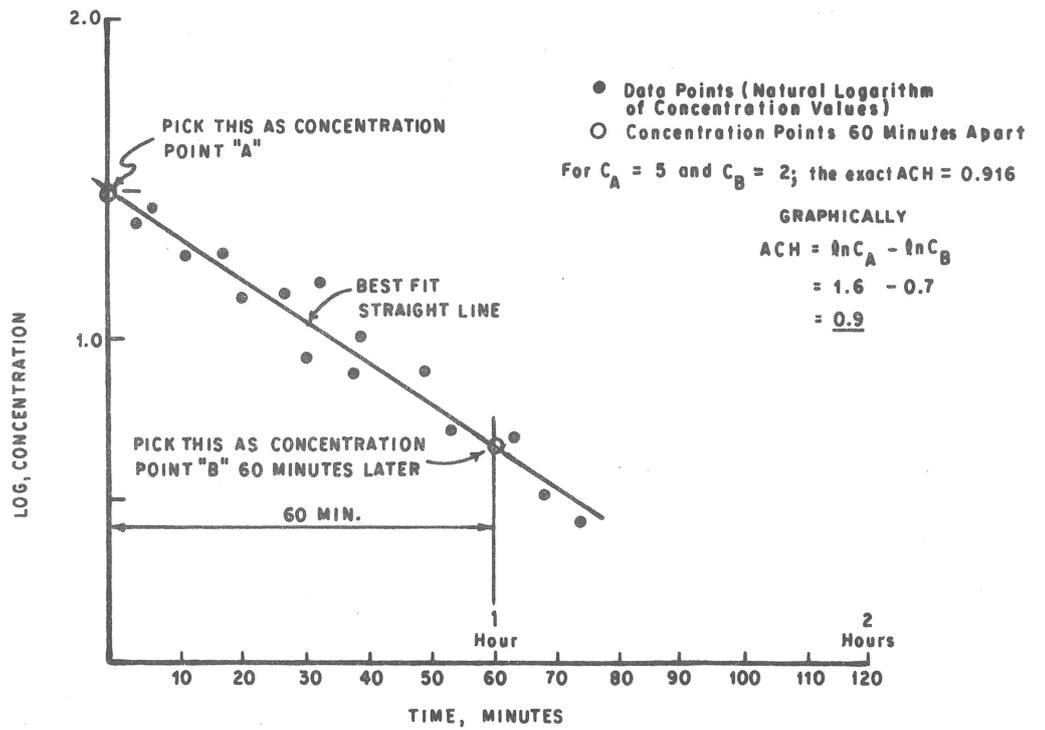
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**FIG. 1 Four-Point Sampling Junction**



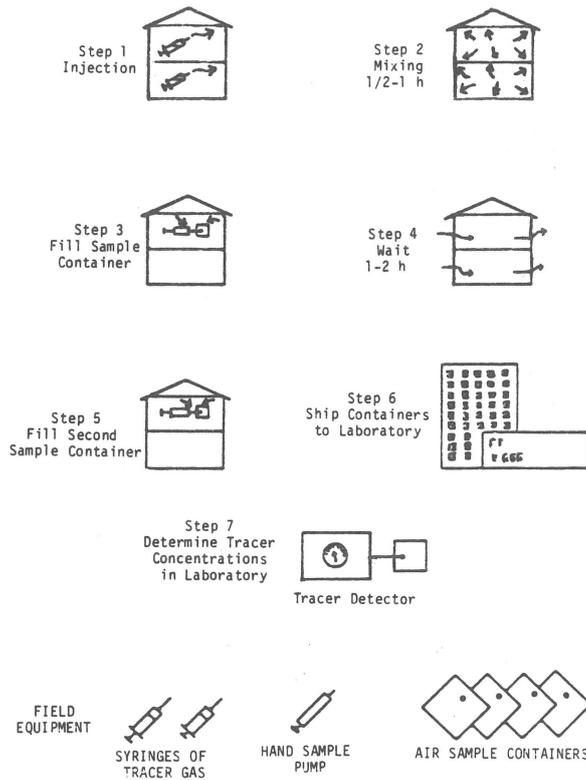
**FIG. 2 Symmetrical Eight-Point Sampling System**



NOTE—Shorter test times may be employed provided that correct time interval is used in calculating the air change rate.

FIG. 3 Graphical Determination of Air Change Rate

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**FIG. 4 Procedure for Measuring Air Leakage Rate Using Sample Containers**

**ANNEX**

**(Mandatory Information)**

**A1. SUMMARY OF TRACER GASES USED IN AIR LEAKAGE MEASUREMENTS**

A1.1 This annex presents a compilation of gases and associated instrumental techniques that have been used to perform air leakage measurements as well as a table of typical background levels of these gases. Note that some of these gases may not be suitable for use under current guidelines for health and safety. Nevertheless, these gases are presented for historical completeness.

A1.2 In general, the desirable characteristics of a tracer gas are:

- A1.2.1 Measurable at very low concentrations.
- A1.2.2 Inert, nonpolar, and not absorbed.

- A1.2.3 Nontoxic, nonallergenic.
  - A1.2.4 Nonflammable and nonexplosive.
  - A1.2.5 Easily and inexpensively measurable.
  - A1.2.6 Not a normal constituent of air.
  - A1.2.7 Measurable by a technique that is free of interference by substances normally in air.
  - A1.2.8 No single gas fulfills all these conditions.
- A1.3 It should be emphasized that the measurement of air change rate by the tracer dilution method is independent of which tracer is selected.

TABLE A1.1 Gases and Techniques for Tracer Dilution Method

Tracer	Measuring Apparatus	Maximum Allowable Concentration in Air (vol/vol)	Minimum Detectable Concentration, ppm	Toxicology <sup>d</sup>	Chemical Inertness	Comments <sup>d</sup>
Hydrogen	Katharometer <sup>B</sup>	4 % (lower explosive limit)	200	nontoxic	extremely reactive in presence of oxygen and heat or flame	flammable or explosive in presence of oxygen and heat or flame
Helium	Katharometer <sup>B,C</sup>	...	300	nontoxic	nonreactive	nonreactive
Carbon monoxide	infrared absorption; heat of absorption measurement; <sup>D</sup> gas chromatograph with gas flame ion detector <sup>E</sup>	50 ppm	5 ... 0.4	combines with hemoglobin to produce asphyxia	can be dangerous when exposed to open flame	can also react with oxygen in air in sufficient concentration; may explode when exposed to open flame
Carbon dioxide	infrared absorption; <sup>F</sup> gas chromatograph with thermal conductivity detector	5000 ppm	1 70	nontoxic	very soluble in water	
Sulfur hexafluoride	electron capture gas chromatograph <sup>G,H,I,J,K,L</sup>	1000 ppm	0.000002	nontoxic	chemically inert when pure	When heated to decomposition (550°C), toxic byproducts may be formed
Nitrous oxide	infrared absorption <sup>M,N</sup>	25 ppm <sup>O</sup>	1	nontoxic	very soluble in water	can form explosive mixtures in air
Ethane	flame ionization detector; <sup>P</sup> gas chromatograph with flame ionization	3 % (lower explosive limit)	5	nontoxic	will burn when exposed to flame	may explode in presence of oxygen and heat or flame
Methane	infrared absorption <sup>Q</sup>	5 % (lower explosive limit)	5	nontoxic	will burn when exposed to flame	may explode in presence of oxygen and heat or flame

<sup>A</sup> Sax, N. I., *Dangerous Properties of Industrial Materials*, Third Edition, Van Nostrand, New York, 1968.

<sup>B</sup> Dick, J. B., "Measurements of Ventilation Using Tracer Gas Technique," *Heating, Piping, and Air Conditioning Journal*, Vol 23, No. 5, May 1950, pp. 131-137.

<sup>C</sup> Coblenz, C. W., and Achenbach, P. R., "Design and Performance of a Portable Infiltration Meter," *ASHRAE Transactions*, Vol 69, 1963, pp. 358-365.

<sup>D</sup> Prado, R., Leonard, R. G., and Goldschmidt, V., "Measurement of Infiltration in a Mobile Home," Purdue University Report.

<sup>E</sup> Porter, K., and Volman, D. F., "Flame Ionization Detection of Carbon Monoxide for Gas Chromatographic Analysis," *Analytical Chemistry*, Vol 34, No. 7, June 1962, pp. 748-749.

<sup>F</sup> Hill, J. E., and Kusuda, T., "Dynamic Characteristics of Air Infiltration," *ASHRAE Transactions*, Vol 81, Part 1, 1975, pp. 168-185.

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<sup>H</sup> Harje, D. T., et al, "Automated Instrumentation for Air Infiltration in Buildings," Center for Environmental Studies, Engineering Quadrangle, Princeton University, Princeton, NJ, Report No. 13.

<sup>I</sup> Hunt, C. M., and Treado, S. J., "A Prototype Semi-Automated System for Measuring Air Infiltration in Buildings Using Sulfur Hexafluoride as a Tracer Gas," *National Bureau of Standards Technical Note 898*, March 1976.

TABLE A1.1 Continued

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**TABLE A1.2 Atmospheric Constituents**

Compound	Average Tropospheric Background Concentrations, ppm	Typical Indoor and Urban Ambient Concentrations, ppm	Anthropogenic Sources	References
H <sub>2</sub>	0.5	0.5	...	<sup>A</sup>
He	5.2	5.2	...	<sup>A</sup>
CO	0.1	5-50	combustion	<sup>A</sup>
CO <sub>2</sub>	320	30-5000	combustion	<sup>A</sup>
N <sub>2</sub> O	0.3	0.3-several ppm	combustion	<sup>B,C,D</sup>
Ethane	1.5 × 10 <sup>-3</sup>	0.1	incomplete combustion	<sup>E,F</sup>
Methane	1.5	2-5	incomplete combustion	<sup>E,F</sup>
SF <sub>6</sub>	10 <sup>-8</sup>	10 <sup>-5</sup>	telephone switching stations	<sup>G,H</sup>

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