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An American National Standard

# Standard Test Methods for Determining External Air Leakage of Air Distribution Systems by Fan Pressurization[1]

This standard is issued under the fixed designation E 1554; 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 (ε) indicates an editorial change since the last revision or reapproval.

## 1. Scope

1.1 These test methods cover two techniques for measuring the air leakage of the sections of air distribution systems that pass outside the conditioned space in low-rise residential and small low-rise commercial buildings. Both techniques use air flow and pressure measurements to determine the leakage characteristics, and include separate measurements of the supply-side and the return-side distribution system leakage.

1.2 These test methods also specify the auxiliary measurements needed to characterize the magnitude of the distribution system air leakage during normal operation (a measurement of pressure differentials across duct leaks during normal distribution-system operation), and to normalize the distribution system's air leakage by the total recirculating air flow induced by the distribution-system fan.

1.3 The air-leakage measurement portion of these test methods is applicable to small temperature differentials and low wind pressures; the uncertainty in the measured results increase with increasing wind speeds and temperature differentials.

1.4 The proper use of these test methods requires a knowledge of the principles of air flow and pressure measurements.

1.5 These test methods are intended to produce a measure of the air tightness between an air distribution system and its surroundings exterior to the conditioned space of a building.

1.6 The values stated in SI units are to be regarded as standard. The values given in parentheses are for information only.

1.7 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* For specific hazard statements, see Section 7.

## 2. Referenced Documents

2.1 *ASTM Standards:*

E 631 Terminology of Building Constructions[2]

E 741 Test Methods for Determining Air Change in a Single Zone by Means of a Tracer Gas Dilution[2]

E 779 Test Method for Determining Air Leakage Rate by Fan Pressurization[2]

E 1258 Test Method for Airflow Calibration of Fan Pressurization Devices[2]

2.2 *ASME Standard:*

MFC-3M Measurement of Fluid Flow in Pipes Using Orifice Nozzle and Venturi[3]

## 3. Terminology

3.1 *Definitions*—Refer to Terminology E 631 for definitions of other terms used in these test methods.

3.2 *air-handling unit*—the distribution-system fan and portion of the distribution system that is integral to the furnace, air-conditioner, or heat-pump.

3.3 *air-leakage rate*—the volume of air movement per unit time across the building envelope or the exterior envelope of the air distribution system.

3.3.1 *Discussion*—This movement includes flow through joints, cracks, and porous surfaces, or combinations thereof. The driving forces for such air leakage in service can be mechanical pressurization and depressurization, natural wind pressures, and air temperature differentials between the building interior and the outdoors.

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

3.5 *building pressure difference*—the pressure difference across the building envelope, expressed in pascals (inches of water, pounds-force per square foot, or inches of mercury).

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[1] These test methods are under the jurisdiction of ASTM Committee E-6 on Performance of Buildings and are the direct responsibility of Subcommittee E06.41 on Air Leakage and Ventilation.

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[2] *Annual Book of ASTM Standards*, Vol 04.11.

[3] Available from American Society of Mechanical Engineers, 345 E. 47th St., New York, NY 10017.

3.6 *distribution-system pressure difference*—the pressure difference across the exterior air-distribution envelope, expressed in pascals (inches of water, pounds-force per square foot, or inches of mercury).

3.7 *exterior air-distribution envelope*—the boundary or barrier separating the interior volume of the air distribution system from the outside environment or unconditioned spaces.

3.7.1 *Discussion*—For the purpose of these test methods, the interior volume is the deliberately conditioned space within a building, generally not including the attic space, basement space, and attached structures, unless such spaces are part of the heating and air conditioning system, such as a crawl space that acts as a plenum.

3.8 *unconditioned space*—any space that is not intentionally heated or cooled for human occupancy, including attics, crawlspaces, unfinished basements, attached structures (such as a garage), or any space completely outside the building envelope (for example, rooftop ductwork on small commercial buildings).

## 4. Summary of Test Methods

4.1 These test methods consist of mechanical pressurization and depressurization of an air distribution system and the conditioned space of the building through which it passes, during which measurements of air flow rates are made over a range of 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 external air leakage characteristics of the supply and return sides of the air distribution system are separately evaluated.

4.2 Two alternative measurement and analysis procedures are specified. The first of these techniques, Test Method A, is based upon comparisons of the air leakage rates from three fan pressurization tests: with the entire distribution system in good communication with the building, with the return side of the distribution system sealed from the building and the supply side, and with the entire distribution system sealed from the building. The second technique, Test Method B, is based upon two fan pressurization tests utilizing direct measurement of distribution-system leakage flows: with all but one supply register sealed, and with all but one return register sealed. Both tests in Test Method B are conducted with the supply side sealed from the return side at the distribution-system fan. Test Methods A and B are shown schematically in Figs. 1 and 2, respectively.

4.3 These test methods also include specifications for the auxiliary measurements to interpret the air leakage measurements. These include measurement of the pressures that drive air leakage during normal system operation and measurement of the recirculating flow through the distribution system. The former involves measurement of the characteristic pressures across the distribution-system surface, and the latter involves measurement of the airflow into the return grill(es) with only the distribution-system fan in operation.

## 5. Significance and Use

5.1 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 air pollutants.

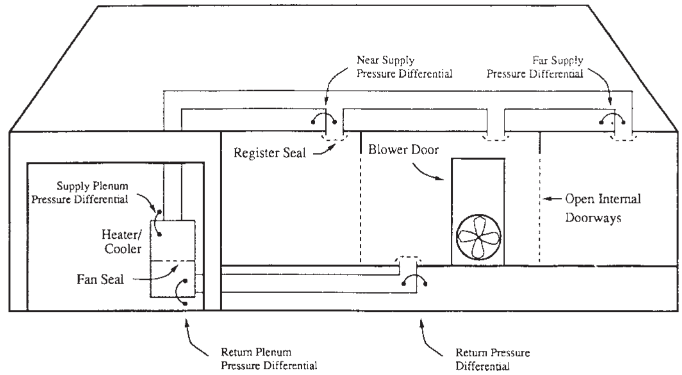


**FIG. 1 Schematic of Major Components and Measurement Set-Up for Test Method A**

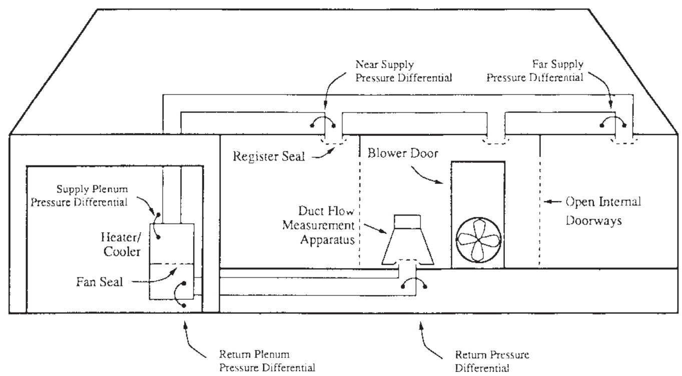


**FIG. 2 Schematic of Major Components and Measurement Set-Up for Test Method B**

5.2 The determination of infiltration energy loads and ventilation rates of residences and small commercial buildings are typically based on the assumption that the principal driving forces for infiltration and ventilation are the wind and indoor/outdoor temperature differences. This can be an inappropriate assumption for buildings that have distribution systems that pass through unconditioned spaces, as the existence of relatively modest leakage from that system has a relatively large impact on overall ventilation rates. The air leakage characteristics of these exterior distribution systems are needed to determine their ventilation, energy, and pollutant-entry implications.

5.3 Air leakage through exterior air distribution systems may be treated in the same manner as air leakage in the building envelope as long as the system is not operating (see Test Method E 779). However, when the distribution-system fan is turned on, the pressures across these leaks are significantly larger than those driving natural infiltration, thereby inducing much larger flows. Thus, it is important to be able to isolate these leaks from building envelope leaks. Also, due to the different impacts of supply-side and return-side distribution-system leaks, these two air leakage pathways shall be measured separately. The leakage of air distribution systems must be measured in the field, as it has been shown that workmanship is often more important than design in determining the leakage of these systems. Also, it is important to distinguish leaks to the conditioned parts of a building from leaks to the outside.

5.4 As an alternative to the fan pressurization method, air infiltration with and without an air distribution system operating may be measured directly using the tracer dilution method (see Test Method E 741). The fan pressurization method provides an indirect way to relate the infiltration rate to the leakage of the building and the air distribution system.

5.5 The fan pressurization method for measuring envelope leakage (Test Method E 779) and the fan pressurization method for measuring the external leakage of air distribution systems have several advantages over the tracer dilution method. The fan pressurization method produces results that characterize the air tightness of the building envelope and the air distribution systems. The fan pressurization method for measuring the external leakage of air distribution systems is used: to compare the relative air tightness of several similar air distribution systems, to identify the leakage sources and rates of leakage from different components of an air distribution system, and to determine the air leakage reduction for individual retrofit measures applied incrementally on an existing air distribution system.

## 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 is permitted. Those items required for Test Method A are labeled (A only), those for Test Method B are labeled (B only), and those for both test methods are labeled (A and B). Most of the components are illustrated in Figs. 1 and 2.

6.2 *Major Components*:

6.2.1 *Air-Moving Equipment* (A and B)—A fan, blower, or blower door assembly that is capable of moving air into and out of the conditioned space at the flow rates required to create the full range of test pressure differences (10 to 60 Pa). The system shall provide constant air flow at each incremental pressure difference at fixed pressure for the period required to obtain readings of air flow rate. The air moving equipment shall be able to accomplish both pressurization and depressurization of the conditioned space and distribution system.

6.2.2 *Air Flow-Regulating System* (A and B)—A device such as a damper, or variable speed motor control, that will regulate and maintain air flow through the air moving equipment (6.2.1) and pressure difference across the leaks within specific limits.

6.2.3 *Duct Flow Measurement Apparatus* (A and B)—A device to measure air flow into or out of an air distribution register within ±6 % of the true value. The calibration of this air flow measuring device shall be performed using a standardized flow measurement technique (for example, ASME MFC-3M) in an installation that is similar in both flow range and entering flow profile to those in which it will be applied in the field. The temperature dependence and range of the calibration shall be explicitly reported.

6.2.4 *Air Flow Measuring Device* (A only)—A device to measure air flow through the air moving equipment (6.2.1) within ±3 % of the true value. The calibration of this air-flow measurement system shall follow Test Method E 1258. The size of the air moving equipment shall be matched to the air flow measuring system so that the linear flow velocity falls within the range of measurement of the air flow meter.

6.2.5 *Pressure-Measuring Device* (A and B)—A manometer or pressure indicator to measure pressure differences with an accuracy of ±0.5 Pa (±0.002 in. $H_2O$).

6.2.6 *Duct Pressure Measuring Probe* (A and B)—A probe to measure the static pressure within a duct under flow conditions (that is, a pressure probe with a small velocity-pressure coefficient).

6.2.7 *Air Temperature Measuring Device* (A and B)—To give an accuracy of ±0.5°C (1°F).

6.2.8 *Wind Speed Measuring Device* (A only)—To give an accuracy within ±0.25 m/s (0.5 mph) at 2.5 m/s (5 mph).

6.2.9 *Simultaneous Pressure and Flow Measurement System* (A only, suggested for B)—A system that provides for essentially simultaneous measurement of building envelope and distribution-system pressures, as well as building envelope and distribution-system flows. Three alternative systems are: a computerized data acquisition system, a multi-channel sample and hold system, and an interleaved multi-point sampling technique (that is, sequential recording of the pressures and flow signals averaged over at least three sets of signal-series samples).

6.3 *Blower Door Assembly*—An accepted variation of air-moving, flow-regulating, and flow-measuring equipment. Issues particular to this assembly are:

6.3.1 The door mount for the fan or blower must be adjustable to fit common door openings.

6.3.2 The fan or blower shall possess a variable-speed motor to accommodate the wide range of required flow rates up to 1.4 $m^3/s$ (3000 $ft^3/min$).

## 7. Hazards

7.1 Glass should not break at the pressure differences normally applied to the building, however, protective eye wear shall be provided to personnel.

7.2 When conducted in the field, safety equipment required for general field work shall be supplied, such as safety shoes, hard hats, etc.

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

7.4 Hearing protection shall be provided for personnel who work close to noises such as those generated by moving air.

7.5 When the blower or fan is operating, a large volume of air is being forced into or out of a building. Plants, pets, occupants, or internal furnishings shall not be damaged due to the influx of cold or warm air. Similar precautions shall be exercised with respect to sucking debris or exhaust gases from fireplaces and flues into the interior of the building.

## 8. Procedure

8.1 *General*—The basic procedure involves pressurization and depressurization of air distribution systems and buildings with concurrent flow and pressure measurements to determine the air leakage of the distribution system. It also includes measurement of distribution-system pressures and recirculating flows during normal distribution-fan operation.

8.1.1 *Test Method A for Air Leakage Determination*—This technique is based upon comparisons of the air leakage rates from three fan pressurization tests: with the entire distribution system in good communication with the building, with the return side of the distribution system sealed from the building and the supply side (at the fan), and with the entire distribution system sealed from the building (see Fig. 1).

8.1.2 *Test Method B for Air Leakage Determination*—This technique is based upon two fan pressurization tests utilizing direct measurement of distribution-system leakage flows: with all but one supply register sealed and all return registers unsealed, and with all but one return register sealed and all supply registers unsealed. Both tests are conducted with the supply side sealed from the return side at the fan (see Fig. 2).

8.1.3 *Choice of Test Method*—In general, Test Method A is subject to higher flow-measurement uncertainties, and Test Method B is subject to higher pressure-measurement uncertainties. The larger flow uncertainties for Test Method A result from the subtraction of total blower-door flows, as compared to the direct measurement of flow through distribution-system leaks with Test Method B. As the entire leakage flow of the distribution system passes through a single register in Test Method B, the larger pressure uncertainties associated with this test method stem from the pressure non-uniformities created by pressure drops across internal distribution-system resistances. Test Method A shall be used for leakier distribution systems (that is, where the flow through the external distribution-system leakage is greater than 15 to 20 % of the building envelope flow), and distribution systems that have significant internal resistance (that is, systems with supply-duct dampers near the supply plenum), whereas Test Method B shall be used for more airtight distribution systems without supply-plenum dampers.

8.1.3.1 Test Method A includes a direct determination of envelope leakage characteristics, whereas Test Method B does not. The user of Test Method B shall include an envelope leakage measurement such as that specified in 8.2.4.1-8.2.4.9, or that specified in Test Method E 779.

8.1.4 *Auxiliary Measurements*—Auxiliary measurements are also required to interpret the air leakage measurements. These include: measurement of the pressures that drive air leakage during normal system operation, and measurement of the recirculating flow through the distribution system. The former involves measurement of characteristic pressure differentials across the distribution-system envelope, and the latter involves measurement of the airflow into the return grill(es) with only the distribution-system fan in operation.

8.2 *Procedure for Test Method A*:

8.2.1 *Environmental Measurements*—At the beginning and the end of each fan pressurization test, measure the wind speed, outdoor temperature, indoor temperature, as well as temperatures in all unconditioned spaces. Preferred test conditions are wind speeds of 0 to 2 m/s (0 to 4 mph) and an outside temperature between 5 and 35°C (41 to 95°F).

8.2.2 *Auxiliary Measurements*:

8.2.2.1 *Distribution-System Operating Pressures*—Install duct pressure measuring probes in the supply plenum, the supply duct closest to the supply plenum, the supply duct furthest from the supply plenum, the return plenum, the return duct closest to the return plenum, and the return duct furthest from the return plenum. Reference the duct-pressure probes to the unconditioned zone in which that duct section is located. Open all interconnecting doors in the conditioned space (except for closet doors, which shall be closed) so that a uniform pressure will be maintained within the conditioned space. If the air handling unit is located in a closet, the closet door shall be closed during testing. Turn on the distribution-system fan, measure each of the specified pressure differentials, and then turn off the distribution-system fan.

8.2.2.2 *Recirculating Flow*—Install a duct air flow measuring device on the return-air register (in the case of multiple return registers, repeat this for each register). Turn on the distribution-system fan and measure the flow rate in cubic metres per second (cubic feet per second) at the local air density into the return register. In the case of multiple return registers, the volumetric flows into each register and their individual indoor air temperatures shall be measured, and any change in velocity at the other return registers due to the installation of the duct air flow measuring device shall be recorded.

8.2.3 *Building Preparation*:

8.2.3.1 *Envelope*—Open all interconnecting doors in the conditioned space (except for closet doors, which shall be closed) so that a uniform pressure will be maintained within the conditioned space to within 10 % of the measured inside/outside pressure difference. Verify this condition by selected differential pressure measurements throughout the building at the highest test pressure. Fireplace and other operable dampers shall be closed. If a significant fraction of the distribution system being measured passes through an unconditioned basement, open the windows or outside door of that basement so as to provide at least 0.3 $m^2$ (3.3 $ft^2$) of open area, or so as to assure that the pressure difference between the basement and outside is less than 5 % of the pressure difference between the conditioned space and outside. Follow the same procedure if the air-handling unit or significant lengths of duct, or both, are located in a relatively airtight garage. If the air handling unit is located in a closet, the closet door shall be closed during testing.

8.2.3.2 *Distribution System*—HVAC-balancing dampers and registers, in general, shall not be adjusted. However, ensure that the return registers are not blocked, and that at least 75 % of the supply registers are not blocked or dampered shut. Remove the return-air filter for the fan pressurization tests.

8.2.4 *Fan Pressurization Measurements*:

8.2.4.1 Connect the air-moving/flow-regulating/flow measurement assembly to the building envelope using a window, door, or vent opening. Seal or tape openings to avoid leakage at these points.

8.2.4.2 If a damper is used to control flow through the air-moving equipment it shall be in a fully closed position at the beginning of a test. Turn on the fan or blower, adjust the damper or air flow regulator to increase the air flow, and take readings of air flow rates and induced pressure differences.

8.2.4.3 When a blower door assembly is used, record the raw data outputs from the air-flow measuring device and use curve fits obtained with Test Method E 1258 to determine flows from that raw data (for example, revolutions per minute or pressure differentials, or both).

8.2.4.4 The range of the induced pressure differences across the building envelope shall be from 10 to 60 Pa (0.04 to 0.24 in. $H_2O$) in increments of 10 Pa (0.04 in. $H_2O$).

8.2.4.5 At each building-envelope pressure differential, measure the air flow rate in cubic metres per second (cubic feet per second) simultaneously with the building-envelope pressure readings and the duct pressure measuring probe readings using one of the measurement techniques described in 6.2.9.

8.2.4.6 Since the capacity of the air handling equipment, the tightness of the building, and the weather conditions affect leakage measurements, the full range of the higher values may not be achievable. In such cases substitute a partial range encompassing at least five data points, with the size of pressure increments suitably adjusted.

8.2.4.7 The maximum variation between the *measured* pressure differential across the building envelope and the *average* pressure differential across the building envelope (due to external influences such as wind, thermal stack effect, or both) shall be no more than 1 Pa. This corresponds to a wind speed of approximately 2 m/s for a single-point outdoor-pressure reference, and a wind speed of approximately 5 m/s for a 4-wall-average outside-pressure reference.

8.2.4.8 When the unconditioned space through which the distribution system (or a part thereof) passes is at a pressure differential relative to outside that is not at least 80 % of the indoor-outdoor pressure differential, the unconditioned zone pressure shall be made to meet this requirement, or that pressure differential shall be separately monitored and reported.

8.2.4.9 For each fan-pressurization test, collect data for both pressurization and depressurization.

8.2.4.10 *Second Fan-Pressurization Test*—Seal all return registers and seal the return side from the supply side at the distribution-system fan.

8.2.4.11 Repeat 8.2.1, 8.2.4.4, 8.2.4.5, and 8.2.4.9.

8.2.4.12 *Third Fan-Pressurization Test*—Unseal the distribution-system fan and seal all return and supply registers.

8.2.4.13 Repeat 8.2.1, 8.2.4.4, 8.2.4.5, and 8.2.4.9.

8.2.4.14 Unseal all return and supply registers, and replace the return air filter.

8.3 *Procedure for Test Method B*:

8.3.1 *Environmental Measurements*—At the beginning and the end of each fan pressurization test, measure the wind speed, outdoor temperature, indoor temperature, as well as temperatures in all unconditioned spaces. Preferred test conditions are wind speeds of 0 to 2 m/s (0 to 4 mph) and an outside temperature between 5 and 35°C (41 to 95°F).

8.3.2 *Auxiliary Measurements*:

8.3.2.1 *Distribution-System Operating Pressures*—Install duct pressure measuring probes in the supply plenum, the supply duct closest to the supply plenum, the supply duct furthest from the supply plenum, the return plenum, the return duct closest to the return plenum, and the return duct furthest from the return plenum. Reference the duct-pressure probes to the unconditioned zone in which that duct section is located. Open all interconnecting doors in the conditioned space (except for closet doors, which shall be closed) so that a uniform pressure will be maintained within the conditioned space. If the air handling unit is located in a closet, the closet door shall be closed during testing. Turn on the distribution-system fan, measure each of the specified pressure differentials, and then turn off the distribution-system fan.

8.3.2.2 *Recirculating Flow*—Install a duct air flow measuring device on the return-air register (in the case of multiple return registers, repeat this for each register). Turn on the distribution-system fan and measure the flow rate in cubic metres per second (cubic feet per second) at the local air density into the return register. In the case of multiple return registers, the volumetric flows into each register and their individual indoor air temperatures shall be measured, and any change in velocity at the other return registers due to the installation of the duct air flow measuring device shall be recorded.

8.3.3 *Building Preparation*:

8.3.3.1 *Envelope*—Open all interconnecting doors in the conditioned space (except for closet doors, which shall be closed) so that a uniform pressure will be maintained within the conditioned space to within a range of less than 10 % of the measured inside/outside pressure difference. Verify this condition by selected differential pressure measurements throughout the building at the highest pressure differential contemplated. Fireplace and other operable dampers shall be closed. If a significant fraction of the distribution system being measured passes through an unconditioned basement, open the windows or outside door of that basement to provide at least 0.3 $m^2$ (3.3 $ft^2$) of open area, or to ensure that the pressure difference between the basement and outside is less than 5 % of the pressure difference between the conditioned space and outside. If the air handling unit is located in a closet, the closet door shall be closed during testing.

8.3.3.2 *Distribution System*—HVAC-balancing dampers shall be in their fully open position during the fan pressurization tests, and their original positions shall be recorded. Remove the return-air filter for the fan pressurization tests. Registers, in general, shall not be adjusted. Seal the return side from the supply side at the distribution-system fan. Seal all registers except one supply and one return. The unsealed supply shall be the one with the highest flow rate during normal operation of the distribution-system fan (often the one that is closest to the supply plenum). The unsealed return shall be the one with the highest flow rate during normal operation of the distribution-system fan (often the one that is closest to the return plenum).

8.3.4 *Fan Pressurization Measurements*:

8.3.4.1 Connect the air-moving/flow-regulation equipment to the building envelope using a window, door, or vent opening.

8.3.4.2 Install a duct air flow measuring device on the unsealed supply register. Install duct pressure measuring probes in the unsealed supply duct, in the supply plenum, and in the supply duct furthest from the supply plenum. Reference the duct-pressure probes to the unconditioned zone in which that duct section is located.

NOTE 1—Supply-side and return-side distribution-system leakage can be measured simultaneously by using two duct air flow measuring devices and two sets of duct pressure measuring probes and also following steps 8.3.4.8 and 8.3.4.9 at this point.

8.3.4.3 Vary the flow through the air-moving equipment installed in the building envelope to create a range of average induced pressure differences across the supply side of the distribution system. The range of this average induced pressure difference shall be from 10 to 60 Pa (0.04 to 0.24 in. $H_2O$) in increments of 10 Pa (0.04 in. $H_2O$).

8.3.4.4 When the full range of induced pressure differences cannot be achieved, substitute a partial range encompassing at least five data points, with the size of pressure increments suitably adjusted.

8.3.4.5 At each supply-side pressure differential, measure the air flow rate through the duct air flow measuring device in cubic metres per second (cubic feet per second) simultaneously with the duct pressure measuring probe readings using one of the measurement techniques described in 6.2.9.

8.3.4.6 A maximum variation of pressure differences across the two different supply duct sections shall be no more than 20 % of the measured average of those pressure differences. When the unconditioned space through which the distribution system (or a part thereof) passes is at a pressure differential relative to outside that is not at least 80 % of the indoor-outdoor pressure differential, the unconditioned zone pressure shall be made to meet this requirement, or that pressure differential shall be separately monitored and reported.

8.3.4.7 Collect data for both pressurization and depressurization.

8.3.4.8 Install a duct air flow measuring device on the unsealed return register. Install duct pressure measuring probes in the unsealed return duct, in the return plenum, and in the return duct furthest from the return plenum. Reference the duct-pressure probes to the unconditioned zone in which that duct section is located.

8.3.4.9 Repeat 8.3.4.3 (substitute return for supply), 8.3.4.5, 8.3.4.6 (substitute return for supply), and 8.3.4.7.

8.3.4.10 Unseal all return and supply registers, as well as the distribution-system fan.

8.3.4.11 Return all HVAC dampers to their original positions, and replace return-air filter.

## 9. Calculation

9.1 *Auxiliary Measurements*:

9.1.1 The pressure differentials measured in step 8.2.2.1 or 8.3.2.1 shall be reported, as shall an average pressure differential, computed as the sum of the three pressure differentials (across the plenum, across the near supply duct, and across the far supply duct) divided by three.

9.1.2 The local flow rates measured in step 8.2.2.2 or 8.3.2.2 shall be converted to equivalent flow rates at an average indoor-air temperature and then summed to yield a total recirculating-air flow rate.

9.2 *Test Method A*:

9.2.1 Convert all the measured air flow rates to cubic metres per second (cubic feet per second) at the condition of the air passing through the envelope and distribution-system leaks. The calibration of the air flow measuring device (or blower door) shall provide the volume flow rate at the density of the air passing through the device. Calculate the volume flow through the leaks from the following equation:

$$Q_{leak} = Q_{device} \frac{T_{leak}}{T_{device}} \tag{1}$$

where:
$Q_{leak}$ = the flow rate through the leaks, $m^3/s$ ($ft^3/s$),
$Q_{device}$ = the flow rate through the fan pressurization device, $m^3/s$ ($ft^3/s$),
$T_{leak}$ = the absolute temperature of the air passing through the leaks, which shall be assumed for pressurization to be the indoor air temperature and for depressurization the duct-area-weighted average temperature of the unconditioned zones through which the ducts pass, K (R), and
$T_{device}$ = the absolute temperature of the air passing through the device, K (R).

Use linear interpolation of before and after temperature measurements if real-time values are not available.

9.2.2 If the air flow rate is not measured directly with a flow meter, then additional calculations are needed to convert, for instance, pitot tube pressure to linear velocity and then to volume flow rate.

9.2.3 Plot the corrected air flow rates (9.2.1) against the corresponding envelope pressure differences on a log-log plot to complete the air leakage graph for both pressurization and depressurization for tests 8.2.4.9, 8.2.4.11, and 8.2.4.13 (see Fig. 3).

9.2.4 *Calculation of Flow Exponent, Flow Coefficient, and Effective Leakage Area*:

9.2.4.1 Use the data as calculated in 9.2.1 to determine the parameters $C$ and $n$ for the three measurement conditions, where:

$$Q_{leak} = C(\Delta P)^n \tag{2}$$

where:
$C$ = flow coefficient, ($m^3/s\ Pa^n$ ($ft^3/s$ (in. $H_2O)^n$)),
$n$ = flow exponent (−), and
$\Delta P$ = differential pressure across the building envelope, (Pa (in. $H_2O$)).

9.2.4.2 Use linear least squares to determine the parameters in Eq 2. This is accomplished by taking the logarithm of both sides of the equation, the resulting equation being:

$$\ln Q_{leak} = \ln C + n \ln (\Delta P) \tag{3}$$

9.2.4.3 Determine the flow exponent, $n$, directly, and determine the flow coefficient, $C$, from the inverse logarithm of the

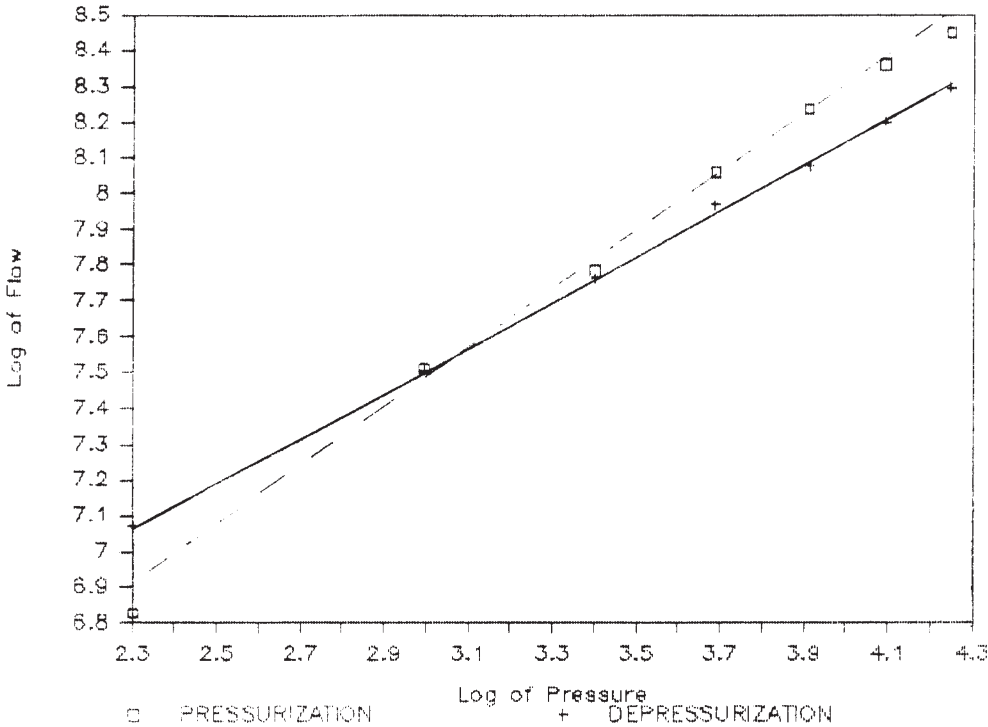


**FIG. 3 Example of Air Leakage Log-Log Plot**

intercept of Eq 3. Calculate and report the coefficient of correlation squared, $R^2$, as well as the standard error of each of the parameters.

9.2.4.4 Calculate the effective leakage area in square metres (square feet), $L$, from the leakage coefficient, $C$, the exponent $n$, a reference pressure, $\Delta P_r$, and the air density ρ at the temperature and pressure of the flow through the leaks as follows:

$$L = C(\Delta P_r)^{(n-1/2)}(\rho/2)^{1/2}A \tag{4}$$

where:

$L$ = effective leakage area, ($m^2$ ($ft^2$)),
ρ = air density in leaks, ($kg/m^3$ ($lbm/ft^3$)), and
$A$ = unit conversion factor, (1 (0.0775)).

The conventional reference pressure for building envelope leaks is 4 Pa, however, the leakage flow at a pressure of 25 Pa is more precisely determined and is more appropriate for air distribution system leaks while the system is operating. The 4-Pa number is appropriate for comparing the size of distribution-system leaks to building envelope leaks, whereas the 25-Pa leakage flow is appropriate for estimating the impacts of distribution-system leakage during system operation. Report the 4 Pa effective leakage area values, as well as the leakage exponents and 25-Pa flows for each of the three tests (all registers open, return registers sealed, and all registers sealed) for both pressurization and depressurization in the report section. In addition, report the density of the air flowing through the leaks for each test.

9.2.4.5 The pressure differentials between the isolated sections of the duct system (that is, those that have been sealed) and their surroundings shall be equal to zero for the second and third fan pressurization tests. If this is not the case, the likely cause is leakage between the building and the sealed portion of the ductwork through improper register or fan seals or leaky duct sections that pass through conditioned spaces. A non-zero pressure differential thus corresponds to a negative bias in the duct leakage being measured.[4] Correct for this bias by multiplying

$$\frac{1}{\left(1 - \left(\frac{\Delta P_{duct}}{\Delta P_{building}}\right)^n\right)} \tag{5}$$

where:

$\Delta P_{duct}$ = pressure differential between the duct and its surrounding zone during the sealed duct test at the maximum pressure differential relative to outside, Pa (in. $H_2O$),
$\Delta P_{building}$ = maximum pressure differential between the building and outside, Pa (in. $H_2O$).

9.2.4.6 Determine the effective leakage area of the return side, $L_{ret}$, and the return leakage flow at 25 Pa, $Q_{ret25}$, from the effective leakage areas and 25-Pa flows obtained by Eq 2 and Eq 4 from the results of the first and second fan pressurization tests, 8.2.4.9 and 8.2.4.11, by means of the following equation (in which $L$ can be replaced by $Q_{25}$):

$$L_{ret} = \frac{(L_{first} - L_{second})}{\left(1 - \left(\frac{\Delta P_{duct(second)}}{\Delta P_{building\ (second)}}\right)^n\right)} \tag{6}$$

where:

[4] Modera, M. P., "Field Comparison of Alternative Techniques for Measuring Air Distribution System Leakage," Lawrence Berkeley Laboratory Report LBL-33126, November 1992.

$L_{first}$ = leakage area computed for the first fan pressurization test (8.2.4.9) using Eq 4 (m$^2$ (ft$^2$)),
$L_{second}$ = leakage area computed for the second fan pressurization test (8.2.4.11) using Eq 4 (m$^2$(ft$^2$)),
$\Delta P_{duct(second)}$ = pressure differential between the duct and its surrounding zone (measured with the return plenum duct pressure measuring probe) during the second pressurization test at the maximum pressure differential between the building and outside (Pa(in $H_2O$)),
$\Delta P_{building(second)}$ = maximum pressure differential between the building and outside during the second pressurization test (Pa(in $H_2O$)).

The reported flow exponents for the return side shall be the averages of the flow exponents determined for the first and second fan pressurization tests.

9.2.4.7 The effective leakage area of the supply side, $L_{sup}$, and the supply leakage flow at 25 Pa, $Q_{sup25}$, shall be determined from the effective leakage areas and 25-Pa flows obtained by Eq 2 and Eq 4 from the results of the first and third fan pressurization tests, 8.2.4.9 and 8.2.4.13, as well as the return-duct leakage computed with Eq 6. The leakage area and 25-Pa leakage flow of the supply ducts shall be determined by means of the Eq 7 (in which $L$ can be replaced by $Q_{25}$). If $L_{ret}$ or $Q_{ret25}$ is less than zero, they shall be set to zero in Eq 7.

$$L_{sup} = \frac{(L_{first} - L_{third})}{\left(1 - \left(\frac{\Delta P_{duct(third)}}{\Delta P_{building\ (third)}}\right)^n\right)} - L_{ret} \quad (7)$$

where:
$L_{first}$ = leakage area computed for the first fan pressurization test (Section 8.2.4.9) using Eq 4 (m$^2$ (ft$^2$)),
$L_{third}$ = leakage area computed for the third fan pressurization test (Section 8.2.4.13) using Eq 4 (m$^2$ (ft$^2$)),
$\Delta P_{duct(third)}$ = pressure differential between the duct and its surrounding zone (measured with the return plenum duct pressure measuring probe) during the third pressurization test at the maximum pressure differential between the building and outside (Pa (in. $H_2O$)),
$\Delta P_{building(third)}$ = maximum pressure differential between the building and outside during the third pressurization test (Pa (in. $H_2O$)).

The reported flow exponents for the supply side shall be the averages of the flow exponents determined for the first and third fan pressurization tests.

9.2.4.8 The flow coefficients for the supply and return sides, $C_{sup}$, and $C_{ret}$, shall be computed using the following equation:

$$C = \frac{L}{(\Delta P_r)^{(n-1/2)}(\rho/2)^{1/2}A} \quad (8)$$

where:
$L$ = computed leakage area of the supply or return side (m$^2$ (ft$^2$)),
$n$ = computed flow exponent of the supply or return side (m$^2$ (ft$^2$)),
$\Delta P_r$ = pressure differential at which the leakage area was computed (Pa (in. $H_2O$)),
$\rho$ = air density in leaks (kg/m$^3$ (lbm/ft$^3$)), and
$A$ = unit conversion factor (1 (0.0775)).

9.3 *Test Method B*:

9.3.1 Convert all the measured air flow rates to cubic metres per second (cubic feet per second) at the condition of the air passing through the envelope and distribution-system leaks. The calibration of the duct flow measurement apparatus shall provide the volume flow rate at the density of the air passing through the device. Calculate the volume flow through the leaks from the following equation:

$$Q_{leak} = Q_{device}\frac{T_{leak}}{T_{device}} \quad (9)$$

where:
$Q_{leak}$ = the flow rate through the leaks, m$^3$/s (ft$^3$/s),
$Q_{device}$ = the flow rate through the duct flow measurement apparatus, m$^3$/s (ft$^3$/s),
$T_{leak}$ = the absolute temperature of the air passing through the leaks, which shall be assumed for pressurization to be the indoor air temperature (that is, $T_{device}$), and for depressurization the duct-area-weighted average temperature of the unconditioned zones through which the ducts pass, K (R), and
$T_{device}$ = the absolute temperature of the air passing through the device, K (R).

Use linear interpolation of before and after temperature measurements if real-time values are not available.

9.3.2 If the air flow rate is not measured directly with a flow meter, then additional calculations are needed to convert, for instance, pitot tube pressure to linear velocity and then to volume flow rate.

9.3.3 Plot the corrected distribution-system leakage air flow rates (9.3.1) against the corresponding distribution-system pressure differences (average of far-supply and supply plenum, or average of (far-)return and return plenum) on a log-log plot to complete the air leakage graph for both pressurization and depressurization for 8.3.4.7 and 8.3.4.9 (see Fig. 3).

9.3.4 *Calculation of Flow Exponent, Flow Coefficient, and Effective Leakage Area*:

9.3.4.1 Use the data as calculated in Eq 6 to determine the parameters $C$ and $n$ for both the supply and return, where:

$$Q_{leak} = C(\Delta P)^n \quad (10)$$

where:
$C$ = flow coefficient, (m$^3$/s Pa$^n$ (ft$^3$/s (in. $H_2O$)$^n$)),
$n$ = flow exponent (−), and

$\Delta P$ = differential pressure across the distribution system (see 9.3.3), (Pa (in. $H_2O$)).

9.3.4.2 Use linear least squares to determine the parameters in Eq 7. This is accomplished by taking the logarithm of both sides of the equation, resulting equation being:

$$\ln Q_{leak} = \ln C + n \ln (\Delta P) \tag{11}$$

9.3.4.3 The flow exponent, *n*, is determined directly, and the flow coefficient, *C*, is determined from the inverse logarithm of the intercept of Eq 8. Calculate and report the coefficient of correlation squared, $R^2$, as well as the standard error of each of the parameters.

9.3.4.4 Calculate the effective leakage area in square metres, *L*, from the leakage coefficient, *C*, the exponent *n*, a reference pressure, $\Delta P_r$, and the air density ρ at the temperature and pressure of the flow through the leaks as follows:

$$L = C(\Delta P_r)^{(n-1/2)}(\rho/2)^{1/2}A \tag{12}$$

where:
$L$ = effective leakage area, ($m^2$ ($ft^2$)),
$\rho$ = air density in leaks, ($kg/m^3$ ($lbm/ft^3$)), and
$A$ = unit conversion factor, 1 (0.0775).

The conventional reference pressure for building envelope leaks is 4 Pa; however, the leakage flow at a pressure of 25 Pa is more precisely determined and is more appropriate for air distribution system leaks while the system is operating. The 4-Pa number is appropriate for comparing the size of distribution-system leaks to building envelope leaks, whereas the 25-Pa leakage flow is appropriate for estimating the impacts of distribution-system leakage during system operation. Report the effective leakage area values, as well as the leakage exponents and 25-Pa flows computed with Eq 7, for the supply and return sections for both pressurization and depressurization. In addition, report the density of the air flowing through the leaks for each test.

## 10. Report

10.1 Report at least the following information:

10.1.1 *Building Description*:

10.1.1.1 *Location and Construction*:

(*a*) Date built (estimate if unknown),

(*b*) Floor area of conditioned space, attic, basement, and crawlspace.

(*c*) Volume of conditioned space, attic, basement, and crawlspace.

10.1.1.2 *Condition of Openings in Exterior Shell*:

(*a*) Doors (including storm doors),

(*b*) Windows (including storm windows), latched or unlatched,

(*c*) Ventilation openings, dampers closed or open,

(*d*) Chimneys, dampers closed or open, and

(*e*) Condition of openings during test (for example, broken windows, HVAC-louver settings, etc.).

10.1.1.3 *HVAC System*:

(*a*) Furnace/Air-conditioner/Heat-pump type and capacity,

(*b*) Indicated blower capacity (most likely just pressure and horsepower),

(*c*) Measured recirculating-air flow rate from 9.1.1,

(*d*) All measured characteristic leakage pressures for return and supply sides of the distribution system $\Delta P_{retplen}$, $\Delta P_{retnear}$, $\Delta P_{retfar}$, $\Delta P_{supplen}$, $\Delta P_{supnear}$, and $\Delta P_{supfar}$ (from 9.1.2), and

(*e*) Distribution system location (supplies, returns, plenums and air-handling unit).

10.1.2 *Pressurization Measurements*:

10.1.2.1 Technique employed (that is, Test Method A or Test Method B),

10.1.2.2 Equipment used,

10.1.2.3 Calibration of air flow meter, and

10.1.2.4 Measurement results.

10.1.3 *Weather*:

10.1.3.1 Off-site conditions (nearby weather station),

10.1.3.2 On-site conditions (height and position of weather tower),

10.1.3.3 Measurement apparatus,

10.1.3.4 Wind speed,

10.1.3.5 Temperature (indoor, outdoor, and unconditioned spaces) before and after each fan pressurization test, as well as before and after auxiliary measurements,

10.1.3.6 Humidity (indoor and outdoor) and barometric pressure (optional), and

10.1.3.7 Altitude.

10.1.4 *Air Leakage Data*:

10.1.4.1 Tabular listing of all air leakage data (including time, flows and all pressures).

10.1.4.2 Plots of air leakage data (see Fig. 3).

10.1.5 *Air Leakage Results*:

10.1.5.1 Supply-side and return-side distribution-system leakage flow coefficients and exponents for both pressurization and depressurization in accordance with 9.2.4.8 or 9.3.4.3. For Test Method A, also report the flow coefficients and exponents for each fan pressurization test (in accordance with 9.2.4.3) and any correction factors (in accordance with 9.2.4.5).

10.1.5.2 Supply-side and return-side distribution-system leakage flows at 25 Pa based upon determined leakage coefficients and exponents (in accordance with 9.2.4.6, 9.2.4.7, or 9.3.4.4). If extrapolations outside of the measurement range are made, include an estimate of the extrapolation error. For Test Method A, also report the flows at 25 Pa from each fan pressurization test (in accordance with 9.2.4.1) and any correction factors (in accordance with 9.2.4.4).

10.1.5.3 The effective leakage areas of supply and return sides for both pressurization and depressurization, as well as the average (in accordance with 9.2.4.5 or 9.3.4.4). For Test Method A, also report the effective leakage areas from each fan pressurization test (in accordance with 9.2.4.4).

10.1.5.4 Correlation coefficient squared, $R^2$, and standard error or flow coefficient and exponent for each fit to Eq 3 or Eq 8 for both pressurization and depressurization.

10.1.6 *Test Identification*:

10.1.6.1 Date the test was performed.

10.1.6.2 Name and address of organization performing the test.

10.1.6.3 Name(s) of individual(s) performing the test.

## 11. Precision and Bias

11.1 *Precision*—At present, the precision and bias of these test methods is largely dependent on the instrumentation and apparatus used and on the ambient conditions under which the data are taken. For Test Method A, the precision is based principally upon the fraction of the fan-pressurization flow passing through the ducts. A fan pressurization test following the procedures outlined in these test methods with well-calibrated equipment at reasonable windspeeds should produce effective leakage area results that are repeatable within 2 to 9 %. As an example, the measurement of supply-side or return-side leakage area that represents 10 % of the overall leakage area, would have an uncertainty of $\sqrt{2^* (0.02\ to\ 0.09)^2}/0.1 = 28$ to 127 %. The uncertainty in the flow at 25 Pa is approximately one third of that at 4 Pa, corresponding to an uncertainty range of 9 to 42 % for the same example. The uncertainty for Test Method B will in general be considerably lower than that for Test Method A, however, careful attention needs to be paid to the pressure nonuniformities in the ducts, as such nonuniformities can create biased results. A more complete precision and bias statement is currently being developed.

11.2 It is more precise to take data at higher pressure differences than at lower differences. Therefore, exercise special care when measurements are taken at low pressure differences.

11.3 *Bias*—Both Test Method A and Test Method B will be negatively biased by leaks between the air distribution system and the conditioned space. For Test Method A, the flow through those leaks is elevated when the distribution system is sealed from the building, thereby reducing the calculated flow through the leaks between the distribution system and unconditioned spaces. The correction procedure outlined in 9.2.4.6 helps to reduce this bias. Test Method B essentially assumes that all of the flow passing through leaks between the distribution system and unconditioned spaces (external leaks) is passing through the duct air flow measurement device, which is not the case when there are distribution-system leaks to the conditioned space. There is no correction factor for Test Method B, however, the magnitude of the uncorrected bias is much less than that associated with Test Method A.

## 12. Keywords

12.1 air distribution; air leakage; ducts; field method