BSR/ASHRAE Standard 130-2016R

Public Review Draft

Laboratory Methods of Testing Air Terminal Units

First Public Review (January 2025)
(Complete Draft for Full Review)

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FOREWORD

First published in 1996 and reaffirmed in 2006, Standard 130 specifies instrumentation, test installation methods, and procedures for determining the capacity and related performance in a laboratory-controlled environment of constant-volume and variable-volume air terminal units. The standard is classified as an ASHRAE standard method of measurement. This standard is required for compliance with AHRI Standards 880 (I-P) and 881 (SI) "Performance Rating of Air Terminals".

The 2016 revision of the standard included updates and revisions to all parts of the standard, including its title, purpose, and scope. It updated definitions, redefined airflow sensor performance testing, and added a method to determine terminal-unit total pressure loss coefficients and the relationship between terminal-unit casing leakage and pressure.

The 2025 revision of the standard again includes updates and revisions to all parts of the standard. Key updates include:
- *uses relative humidity measurements rather than wet-bulb temperature measurements to determine air densities,*
- *redefines the test in Section 5.5 to more accurately determine the casing leakage of terminal units, based in part on airflow adjustments and regression calculations in CAN/CGSB 149.10-2019 "Determination of the Airtightness of Building Envelopes by the Fan Depressurization Method",*
- *expands the casing leakage test to determine leakage with and without the backdraft damper sealed for parallel-flow fan-powered terminal units,*
- *provides informative appendices to explain equation derivations for air density and leakage parameter calculations.*
- *the sound test section now refers to AHRI 220 for determining sound power and adds corresponding definitions and language to describe the various test configurations required, including a new appendix with examples*
- *eliminates modulating diffuser sound test setup Figure 24 and refers to ASHRAE Standard 70.*

1. PURPOSE

The standard specifies instrumentation, test installation methods, and procedures for measuring the capacity and related performance of constant-volume, variable-volume, and modulating integral diffuser air terminals.

2. SCOPE

2.1 The methods of test in this standard apply to air control devices used in air distribution systems. These devices provide control of air volume with or without temperature change by one or more of the following means and with or without a fan:

a. Fixed or adjustable directional vanes (i.e., bypass terminal)
b. Pressure-dependent volume dampers or valves (including air induction nozzles and dampers)
c. Pressure-independent volume dampers or valves (including air induction nozzles and dampers)
d. Integral heat exchanger
e. On/off fan control
f. Variable-speed fan control
g. Modulating integral diffuser terminals

2.2 This standard covers test methods for use in determining the following performance characteristics:

a. Sound
b. Temperature mixing and stratification
c. Minimum operating pressure
d. Air leakage
e. Induced airflow
f. Fan performance
g. Condensation
h. Airflow sensor performance
i. Pressure independence

2.3 This standard shall not be used for field testing.

3. DEFINITIONS AND SYMBOLS

3.1 Definitions

accuracy: degree of conformity of an indicated value to an accepted standard value, or true value. The degree of inaccuracy is known as "total measurement error" and is the sum of bias error and precision error.

acoustically isolated duct: ductwork for which, in all frequency bands of interest, the breakout sound level is at least 10 dB less than the transmitted sound level of the terminal unit under test. Refer to Informative Appendix H for a detail of an acoustically isolated duct.

air terminal unit: device that automatically controls the volume of air delivered to or removed from a defined space.

amplification factor (F): ratio of sensor output (p_{sensor}) to velocity pressure (p_v) as defined by Equation 1:

$$F = \frac{p_{sensor}}{p_v} \qquad (1)$$

where

F = amplification factor, dimensionless
p_{sensor} = sensor output, in. of water (Pa)
p_v = velocity pressure at sensor location, in. of water (Pa)

Example: a sensor with a reading of 1.0 in. of water (250 Pa) pressure at a velocity pressure of 0.43 in. of water (108 Pa) has an amplification factor of 2.3.

background noise: the cumulative sound present during a terminal unit sound test that is not directly created by the unit under test. This includes but is not limited to ambient noise from outside the laboratory, laboratory fan system operation, building system components unrelated to the sound tests, and others. This standard assumes that the background noise is relatively constant and does not change significantly in level. Corrections for background noise are included in the sound test method.

bias error: the difference or offset between the true value to be measured and the mean indicated value from the measuring system that persists and is usually due to the particular instrument or technique of measurement. This error is determined or minimized through calibration. A positive bias error means that the measured value is greater than the true value and so the bias error is subtracted from the measured value. A negative bias error means that the measured value is less than the true value, and so the bias error is added to the measured value (because a double negative results in a positive).

bypass terminal unit: a terminal unit that uses a method of volume modulation whereby airflow is varied by distributing the volume required to meet the space requirements, the balance of supply/exhaust air being diverted away from the space.

confidence level: the probability that a stated interval will include the true value. In analyzing measured data, a confidence level of 95% (approximately two standard deviations) is often used. The level used in this standard for error analyses is one standard deviation (approximately 68%).

discharge sound power level: sound power that is transmitted from the terminal outlet.

dual-duct terminal unit: air terminal that controls varying portions of two independent sources of primary air.

equivalent diameter: diameter of a circular-duct equivalent that has a cross-sectional area equal to a particular rectangular duct. Equivalent diameter is calculated using the following equation:

$$D_e = \left(\frac{4A}{\pi}\right)^{0.5} \tag{2}$$

where

A = cross-sectional area, in^2 (mm^2)

D_e = equivalent duct diameter, in (mm)

error: the difference between the true value of the quantity measured and an observed value. All experimental errors can be classified as one of two types: *bias error* or *precision error*.

exhaust sound power level: sound power that is transmitted from an exhaust terminal inlet back to the room (counter to the airflow).

exhaust terminal unit: terminal unit for regulating exhaust or return airflow.

exhaust terminal-unit total leakage: total amount of the air in cfm (L/s) drawn through the casing and a fully closed damper/valve into the airstream of an exhaust terminal unit at a given outlet pressure.

fan-powered terminal unit

parallel-flow fan-powered terminal unit: a type of induction terminal unit in which the primary air inlet is in parallel to an integral fan, thus allowing the supply air to bypass the fan. The fan induces air from the induction port, which has a backdraft damper intended to prevent reverse flow through the port when the fan is not operating.

series-flow fan-powered terminal unit: a type of induction terminal unit where the primary air inlet is in series with an integral fan, and where all air flows through the fan.

fan-powered terminal unit efficiency: ratio of the total power consumed (W) to delivered fan air volume, W per cfm (W per L/s).

flow coefficient (K): the flow coefficient of terminal units is calculated from test data using Equation 3.

$$K = \frac{Q}{p_{sensor}^{0.5}} \tag{3}$$

where

K = flow coefficient, cfm per (in. of water)$^{0.5}$ [L/s per Pa$^{0.5}$]
Q = actual terminal-unit airflow, cfm (L/s)
p_{sensor} = sensor output, in. of water (Pa)

induced airflow: air that is drawn into a terminal by means of induction and discharged through the terminal outlet

induction terminal unit: a terminal unit, typically having more than one inlet, that supplies varying proportions of primary and induced air. This type of terminal excludes fan-powered terminal units.

integral diffuser air terminal: diffuser with the features of an air terminal. Air is modulated by outlet or inlet dampers.

loss coefficient: a dimensionless fluid resistance coefficient having the same value in dynamically similar streams (i.e., streams with geometrically similar stretches, equal Reynolds numbers, and equal values of other criteria necessary for dynamic similarity). The loss coefficient represents the ratio of total pressure loss to velocity pressure at the referenced cross section:

$$C_{loss,i} = \frac{\Delta p_t}{p_{vi}} \tag{4}$$

where

$C_{loss,i}$ = total pressure loss coefficient, dimensionless
Δp_t = total pressure loss, in. of water (Pa)
p_{vi} = velocity pressure at referenced cross section i, in. of water (Pa)

minimum operating pressure: the static or total pressure drop through a terminal at a given airflow rate with the damper/valve placed in its full-open position by its actuator while the terminal is operating under steady-state control.

TABLE 1 Upper, Lower, and Center Frequencies for the Preferred Series of Octave and One-Third Octave Bands

Octave Band	Octave Bands, Hz	One-Third Octave Bands, Hz		
		Lower	Center (f)	Upper
1	63	45	50	56
		56	63	71
		71	80	90
2	125	90	100	112

		112	125	140
		140	160	180
3	250	180	200	224
		224	250	280
		280	315	355
4	500	355	400	450
		450	500	560
		560	630	710
5	1000	710	800	900
		900	1000	1200
		1200	1250	1400
6	2000	1400	1600	1800
		1800	2000	2240
		2240	2500	2800
7	4000	2800	3150	3550
		3550	4000	4500
		4500	5000	5600
8	8000	5600	6300	7100
		7100	8000	9000
		9000	10,000	11,200

modulating diffuser terminal unit: diffuser with features of an air terminal unit and with an integral airflow control device.

octave band: a frequency band with an upper frequency limit twice that of its lower frequency limit. Octave and one-third octave bands are identified by their center frequencies, which are the geometric means of the upper and lower band limits: $f_c = \sqrt{f_{upper} f_{lower}}$. Three one-third octave bands make up one octave band. Table 1 lists the upper, lower, and center frequencies for the preferred series of octave and one-third octave bands.

precision error: a statistical error that is caused by chance or by stochastic temporal or spatial variations of factors affecting the measurement process and is not necessarily recurring. It causes readings to take varying values on either side of the mean value. This error can often be reduced by increasing the number of observations.

pressure-compensating control system: see *pressure-independent control system*.

pressure-dependent control system: a control system in which the airflow through the air terminal varies with system pressure.

pressure-independent control system: control system in which the airflow through the air terminal is independent of system pressure. Also known as “pressure-compensated.”

primary air: treated supply air to a terminal unit.

quiet air: airflow generated by a laboratory fan system whose associated sound levels as measured in the reverberation room without a terminal unit under test are at least 6 dB less than the sound levels measured with a terminal unit under test in all one-third octave bands and at least 10 dB less in the one-third octave bands from 400 to 5000 Hz inclusive.

NOTE: this definition of “quiet air” is based on background noise limits established in AHRI 220 for the purpose of calculating corrected sound levels. Each test configuration and flow rate may produce different background noise levels in the reverberation room, and so the condition of “quiet air” only applies to a specific configuration and flow rate. The presence of “quiet air” cannot be assumed at other flow rates and configurations.

radiated sound power level: sound power that radiates from terminal unit casings and induction ports.

reheat: the application of sensible heat to supply air that has been previously cooled below the temperature desired for maintaining the temperature of the conditioned space.

resolution: smallest change in input that produces a detectable change in instrument output.

single-duct terminal unit: a terminal unit supplied with one source of supply/exhaust air. This type of terminal excludes fan-powered terminal units.

sound power level (Lw): a level of sound power that is ten times the logarithm to the base 10 of the ratio of the sound power generated by the source to a reference sound power. The reference sound power is 10^{-12} W.

standard air: air that has a mass density of 0.075 $\text{lb}_\text{m}/\text{ft}^3$ (1.204 kg/m^3).

static pressure: in fluid flow, the actual pressure of the fluid, which is associated not with its motion but with its state. The pressure is exerted uniformly throughout the entire fluid and is the portion of fluid pressure that exists by virtue of the degree of compression only. If expressed as gage pressure, it may be negative or positive. In a dynamic system, static pressure is the total pressure minus the velocity pressure, expressed in units of in. of water (Pa).

terminal-unit casing leakage: air in cfm (L/s) leaking across the terminal unit casing. For parallel-flow fan-powered supply terminal units, the leakage test is carried out with the backdraft damper unsealed and then sealed, so that the backdraft damper leakage can be excluded during normal operation when the box fan is operating and flow is inward through the backdraft damper opening.

terminal-unit damper leakage: air in cfm (L/s) leaking through a fully closed damper/valve of a supply/exhaust terminal unit.

thermal equilibrium: less than 1°F (0.6°C) change over a five-minute period.

total pressure: in fluid flow, the pressure that exists by virtue of the degree of compression and the rate of motion. It is the algebraic sum of the velocity pressure and the static pressure at a point (Equation 5). Thus, if the fluid is at rest, the total pressure will equal the static pressure.

$$p_t = p_s + p_v \tag{5}$$

where

p_t = total pressure, in. of water (Pa)
p_s = static pressure, in. of water (Pa)
p_v = velocity pressure, in. of water (Pa)

uncertainty: a measure of the dispersion of potential error relative to the true value. It reflects doubt in a measurement to a specified confidence level. Although uncertainty is the result of both bias and precision errors, only precision errors are treated by statistical methods. Bias errors correspond to a mean error and can be minimized through calibration. In this standard, instrument readings are corrected by subtracting mean bias errors, and uncertainty is specified only as a precision error.

velocity pressure: the kinetic energy per unit volume of a fluid particle. Static pressure is the actual thermodynamic pressure (force/area) that would be sensed if a probe moved along with the fluid flow, and is equal in all directions if the fluid is not moving. The velocity pressure (also called "dynamic pressure") is the additional pressure that would be sensed if the flow was brought to rest isentropically, i.e., without friction or heat transfer. In that sense, the dynamic pressure is equal to the total pressure minus the static pressure. Velocity pressure is a function of air density and velocity, expressed as follows:

$$p_v = \rho\left(\frac{V}{1097}\right)^2 \tag{6 I-P}$$

$$p_v = \frac{\rho V^2}{2} \tag{6 SI}$$

where

p_v = velocity pressure, in. of water (Pa)
ρ = air density, lb_m/ft^3 (kg/m^3)
V = air velocity, ft/min (m/s)

3.2 Symbols and Subscripts

3.2.1 Symbols

Symbol	Description	Units
A	Duct area	in^2 (mm^2)
A_n	Orifice or nozzle exit area	ft^2 (m^2)
$C_{loss,i}$	Total pressure loss coefficient	Dimensionless
C_n	Nozzle discharge coefficient	Dimensionless
D_e	Equivalent diameter	in. (mm)
f	One-third octave band center frequency	Hz
$\dot{m}$	Mass flow rate	lb_m/s (kg/s)
p_{bo}	Barometric pressure	in. of mercury (kPa)
p_s	Static pressure	in. of water (Pa)
p_t	Total pressure	in. of water (Pa)
p_v	Velocity pressure	in. of water (Pa)
Q	Volumetric flow rate	cfm (L/s)
Q_{leak}	Damper or casing leakage	cfm (L/s)
t	Dry-bulb temperature	°F (°C)
V	Velocity	ft/min (m/s)
Y_n	Nozzle expansion factor	dimensionless
Δp_s	Static pressure loss	in. of water (Pa)
Δp_t	Total pressure loss	in. of water (Pa)
$\Delta p_{s,5-6}$	Static pressure differential across nozzle	in. of water (Pa)
β	Ratio of nozzle exit diameter to approach diameter	dimensionless
φ	Relative humidity	%
ρ	Air density	lb_m/ft^3 (kg/m^3)

3.2.2 Subscripts

Subscript	Description
o	Ambient
c	Cold-deck
h	Hot-deck
d	Downstream
u	Upstream
Plane 1: terminal-unit inlet	
Plane 2: terminal-unit outlet	
Plane 5: upstream of airflow measuring station nozzle	
Plane 6: downstream of airflow measuring station nozzle	
Plane 7: upstream of terminal unit	
Plane 8: downstream of terminal unit	

4. INSTRUMENTATION

4.1 Calibration Requirements. Measurements from the instruments shall be traceable to primary or secondary standards calibrated by the National Institute of Standards and Technology (NIST) or to the Bureau International des Poids et Mesures (BIPM) if a National Metrology Institute (NMI) other than NIST is used. Instruments shall be calibrated on a regular schedule that is appropriate for each instrument. Calibration records shall be maintained. Instrument bias and precision errors shall be determined by means of a previous calibration.

4.2 Bias Error. Mean bias errors for airflows shall be stated at standard air density as a fractional value of the measured airflow adjusted to standard air density or as an absolute value, whichever is applicable. Mean bias errors for other measuring instruments shall be stated as a fractional value of the measured value or as an absolute value, whichever is applicable.

4.3 Precision Error. The required precision with a 95% confidence level for the instruments used shall be as follows:

a. Volumetric airflow instruments shall have a precision equal to or better than 2 cfm (1 L/s) or 3% of measured flow, whichever is greater. Precision shall be stated at standard air density: 0.075 lb_m/ft^3 (1.204 kg/m^3).

b. Temperature instruments shall have a precision equal to or better than 1°F (0.6°C).

c. Static pressure instruments shall have a precision equal to or better than 2% of measured pressure or 0.004 in. of water (1 Pa), whichever is greater.

d. Barometric pressure instruments shall have a precision equal to or better than 0.5% of measured pressure or 0.148 in. of mercury (500 Pa), whichever is greater.

e. Relative humidity instruments shall have an absolute precision equal to or better than 7%.

f. Voltmeters shall have a precision equal to or better than 2% of measured voltage.

g. Ammeters shall have a precision equal to or better than 2% of measured current.

h. Wattmeters shall have a precision equal to or better than 2% of measured power.

i. Instrumentation used for measuring sound shall meet the precision requirements of AHRI 220.

4.4 Accuracy. When instrument "accuracy" is reported without separating out the precision and bias error components, it shall be assumed that accuracy means a precision error at a 95% confidence level and the bias error is zero.

4.5 Airflow Measuring Instruments

4.5.1 Airflow measuring instruments shall meet the precision requirements of Section 4.3(a). They shall also conform to the ducted nozzle in ASHRAE Standard 120[1], the multiple nozzle chamber in ASHRAE Standard 41.2[2], the ducted orifice plate in ASME MFC-3M-2004 (R2017)[3], or the rotating vane anemometer flow measuring system shown in Normative Appendix A, whichever is applicable. Unless otherwise specified in a test procedure in Section 5, other flow measuring devices are acceptable for use, but only after they have been calibrated to traceable standards as described in Section 4.1. Fans shall be located as shown in the test setups for each test method.

4.5.2 The ducted nozzle in ASHRAE Standard 120[1] is considered a reference flow measuring device and therefore does not need calibration.

4.5.3 The multiple-nozzle chamber in ASHRAE Standard 41.2[2] does not need calibration. The flow-settling screens' effectiveness must meet the requirements of AMCA Standard 210[4] (Normative Annex A).

4.5.4 Leakage between the airflow measuring means and the test device shall meet the requirement of AMCA Standard 210[4], Section 5.1.3. A leakage test shall be performed prior to initial use and annually thereafter.

Informative Note: Informative Annex B in Standard 210[4] provides recommended leakage test procedures.

4.6 Temperature Measuring Instruments

4.6.1 Temperature measuring instruments shall meet the precision requirements of Section 4.3(b), as well as the requirements of ASHRAE Standard 41.1[5].

4.7 Pressure Measuring Instruments

4.7.1 Static pressure measuring instruments shall meet the precision requirements of Section 4.3(c). Barometric pressure measuring instruments shall meet the precision requirements of Section 4.3(d). All pressure measuring instruments shall also meet the requirements of ASHRAE Standard 41.3[6].

4.7.2 Piezometer rings complying with Standard 120[1] (Figure 4) shall be used to measure static pressure.

4.7.3 The barometric pressure shall be obtained by means of a barometer located in the test area.

4.8 Humidity Measuring Instruments

4.8.1 Humidity measuring instruments shall meet the precision requirements of Section 4.3(e), as well as the requirements of ASHRAE Standard 41.6[7].

4.9 Electrical Measuring Instruments

4.9.1 Voltmeters, ammeters, and wattmeters shall be true root-mean-square (RMS), high-impedance types and shall meet the precision requirements of Section 4.3(f), Section 4.3(g), and Section 4.3(h), respectively.

4.10 Acoustical Measuring Instruments

4.10.1 Acoustical instruments shall comply with AHRI Standard 220[8].

5. TEST METHODS

5.1 General Requirements

5.1.1 Instrumentation that conforms to the requirements of Section 4 shall be installed or applied to the device under test in accordance with applicable requirements specified in the tests described in Section 5.

5.1.2 Data collection for the tests shall be performed with the device under test configured to and operated according to applicable requirements specified in the tests described in Section 5.

5.2 List of Tests

Table 2 identifies tests applicable for various types of air terminals.

TABLE 2 Test Applicability for Various Types of Air Terminals

		Terminal Unit Type										
		Single-Duct		Induction	Bypass	Dual-Duct	Fan-Powered		Integral	Modulating	Mechanically-Regulated	
Section	Test	Supply	Exhaust	All	All	All	Series-Flow	Parallel-Flow	Diffuser	Diffuser	Supply	Exhaust
5.3	Minimum Operating Pressure and Loss Coefficient	X	X	X	X	X	X	X	X	X	-	-
5.4	Mechanical Regulator Minimum Operating Pressure	-	-	-	-	-	-	-	-	-	X	X
5.5	Pressure-Compensating Controller Performance	X	X	X	X	X	X	X	X	X	X	X
5.6	Casing Leakage	X	X	-	X	X	-	X	X	-	X	X
5.7	Supply Inlet Damper/Valve Leakage	X	X	X	X	X	X	X	-	-	X	X
5.8	Exhaust Total Leakage	-	X	-	-	-	-	-	-	-	-	X
5.9	Dynamic Leakage (Parallel-Flow Fan-Powered)	-	-	-	-	-	-	X	-	-	-	-
5.10	Airflow Sensor Amplification Factor	X	X	X	X	X	X	X	-	-	-	-
5.11	Airflow Sensor Performance - Inlet Conditions	X	X	X	X	X	X	X	-	-	-	-
5.12	Temperature Mixing	-	-	X	-	X	X	X	-	-	-	-
5.13	Temperature Stratification	X	-	X	X	-	X	X	-	-	X	-
5.14	Condensation Determination	X	X	X	X	X	X	X	X	X	X	X
5.15	Sound	X	X	X	X	X	X	X	X	X	X	X
5.16	Fan Curve - No Primary Air	-	-	-	-	-	X	X	-	-	-	-
5.17	Fan Curve - Fan Plus Primary Air	-	-	-	-	-	X	X	-	-	-	-

5.3 Minimum Operating Pressure Differential and Loss Coefficient

5.3.1 Test Purpose. This test determines the minimum operating pressure differential and total pressure loss coefficient for terminal units.

5.3.2 Test Setup

5.3.2.1 The single-duct terminal unit shall be set up as shown in Figure 1 (supply) and Figure 2 (return/exhaust).

5.3.2.2 The induction and bypass terminal units shall be setup as shown in Figure 1. The induction opening of the induction terminal unit and the bypass opening of the bypass terminal shall be sealed.

5.3.2.3 Dual-duct terminal units shall be setup as shown in Figure 1. Each inlet (duct) of the terminal unit shall be tested.

5.3.2.4 The series-flow fan-powered terminal unit shall be setup as shown in Figure 3; the terminal-unit fan shall operate, and the induction port shall be open.

5.3.2.5 The parallel-flow fan-powered terminal unit shall be setup as shown in Figure 1. The fan shall not operate, and the backdraft damper shall be sealed.

5.3.2.6 Modulating and integral diffuser terminals shall be setup as shown in Figure 4.

5.3.2.7 Seal all transverse joints and longitudinal seams upstream and downstream of the terminal unit.

5.3.3 Test Procedure

5.3.3.1 Terminal-unit primary air dampers shall be full open.

5.3.3.2 The series-flow terminal-unit fan shall match the primary airflow rate.

5.3.3.3 Vary primary airflow from minimum to maximum values in increments not exceeding 10% of maximum airflow.

5.3.4 Test Data. Measure and record the following data after equilibrium has been established.

5.3.4.1 Ambient air conditions in the test area: dry-bulb temperature (t_o), relative humidity (φ_o), and barometric pressure at the same elevation as the airflow measurement (p_{bo}).

5.3.4.2 Mass flow measurements.

a. Single-duct, induction, bypass, parallel-flow fan-powered, modulating, and integral diffuser (t_5, p_{s5}, $\Delta p_{s,5\text{–}6}$).
b. Series-flow fan-powered terminal unit ([$t_{5(u)}$, $p_{s5(u)}$, $\Delta p_{s,5\text{–}6(u)}$] and [$t_{5(d)}$, $p_{s5(d)}$, $\Delta p_{s,5\text{–}6(d)}$]).

5.3.4.3 Static pressure loss across terminal units.

a. Single-duct, induction, bypass, and fan-powered ($\Delta p_{s,7\text{–}8}$).
b. Modulating and integral diffuser terminal (p_{s7}).

5.3.4.4 Electrical measurements (fan-powered terminal units).

a. Amperes
b. Voltage
c. Watts

5.3.5 Calculations

5.3.5.1 Air Density. The air density (ρ_{act}) in the general test area shall be calculated using Normative Appendix J.

5.3.5.2 Airflow. Volumetric airflow rates shall be calculated using Equations B-1 or B-2, whichever is applicable, and then Equation B-3.

5.3.5.3 Air Velocity and Velocity Pressure. Air velocity and velocity pressure at a measurement plane shall be calculated using Equations B-4 and B-5, respectively.

5.3.5.4 Specific Power. Calculate power per unit airflow (W per cfm [W per L/s]).

5.3.5.5 Terminal-Unit Total Pressure Loss

a. **All Terminal Units, Except Modulating and Integral Diffusers.** The total pressure loss for each data point shall be calculated using Equation 7.

$$\Delta p_t = \Delta p_{s,7-8} + \left(p_{v7} - p_{v8}\right) \tag{7}$$

b. **Modulating and Integral Diffusers.** The total pressure loss for each data point shall be calculated using Equation 8.

$$\Delta p_t = \Delta p_{s7} + p_{v7} \tag{8}$$

5.3.5.6 Loss Coefficient

a. Plot data points on a Δp_t versus p_{v1} chart.
b. Fit the data using least-squares regression, where $C_{loss,1}$ is the total pressure loss coefficient for the terminal unit referenced to Plane 1.

5.3.5.7 Test Example. Refer to Informative Appendix C for an example of a minimum operating pressure differential and loss coefficient test for a single-duct terminal unit, using a chamber nozzle airflow measuring device.

5.4 Mechanical Regulator Minimum Operating Pressure Differential

5.4.1 Test Purpose. This test determines the minimum pressure differential required to operate supply and exhaust mechanically regulated air terminal units.

5.4.2 Test Setup

5.4.2.1 The air terminal unit to be tested shall be set up as shown in Figure 1 (supply) or Figure 2 (exhaust).

5.4.2.2 Seal all transverse joints and longitudinal seams upstream and downstream of the air terminal unit.

5.4.3 Test Procedure

5.4.3.1 Set the mechanically regulated terminal unit to the desired airflow rate.

5.4.3.2 Increase system resistance (fan speed) until the air terminal unit is controlling; then decrease the fan speed until the air terminal unit is not controlling.

5.4.3.3 Increase the fan speed and identify the static pressure where the air terminal starts to control.

5.4.4 Test Data. Measure and record the following data.

5.4.4.1 Ambient air conditions in the test area: dry-bulb temperature (t_o), relative humidity (φ_o), and barometric pressure at the same elevation as the airflow measurement (p_{bo}).

5.4.4.2 Mass flow measurements (t_5, p_{s5}, $\Delta p_{s,5\text{–}6}$).

5.4.4.3 Static pressure upstream (p_{s7}) and downstream (p_{s8}) of the air terminal unit.

5.4.5 Calculations

5.4.5.1 Air Density. The air density (ρ_{act}) in the test area shall be calculated using Normative Appendix J.

5.4.5.2 Airflow. Volumetric airflow rate shall be calculated using Equations B-1 or B-2, whichever is applicable, and then Equation B-3.

5.4.5.3 Minimum Operating Pressure

a. **Supply Terminal Unit.** Minimum operating pressure is p_{s8}.
b. **Exhaust Terminal Unit.** Minimum static pressure is p_{s7}.

5.5 Pressure-Compensating Volume Controller Performance

5.5.1 Test Purpose. This test evaluates the performance (change in airflow caused by variations in the inlet static pressure) of pressure-compensating terminal units with resettable or preset volume controllers.

5.5.2 Test Setup

5.5.2.1 The air terminal unit to be tested shall be set up as shown in Figure 1 (for single-duct units, dual-duct units, modulating and integral diffusers, and mechanically regulated units) or Figure 3 (for induction, bypass, and fan-powered units).

5.5.2.2 Seal all transverse joints and longitudinal seams upstream and downstream of the terminal unit.

5.5.3 Test Procedure

The airflow through and static pressure difference across the terminal unit shall be determined for each step.

5.5.3.1 Minimum Static Pressure Test. At the desired (rated) airflow, determine the minimum static pressure drop across the terminal unit ($\Delta p_{s,7\text{-}8}$).

a. Refer to Section 5.2 or 5.3 as applicable. Section 5.2 provides procedures for determining the minimum operating pressure differential for terminal units, other than mechanically regulated units. Section 5.3 provides procedures for mechanically regulated terminal units.

b. Record $\Delta p_{s,7\text{–}8}$. The airflow corresponding to this minimum pressure difference is Q_1.

5.5.3.2 Pressure-Compensating Volume Controller Performance Test

a. Increase the static pressure across the terminal unit to 0.75 in. of water (187 Pa) above the minimum static pressure ($\Delta p_{s,7\text{–}8}$) determined in Section 5.4.3.1. The airflow corresponding to this elevated pressure difference is Q_2.

b. The static pressure across the terminal unit shall then be *increased* in equal increments to the desired maximum static pressure across the terminal unit. The airflow corresponding to this maximum pressure difference is Q_3.

c. The static pressure across the terminal unit shall then be *decreased* in equal increments to the minimum static pressure across the terminal unit. The airflow corresponding to this minimum pressure difference is Q_4.

5.5.4 Calculations

5.5.4.1 Air Density. The air density (ρ_{act}) in the general test area shall be calculated using Normative Appendix J.

5.5.4.2 Airflow. The volumetric airflow rates Q_1, Q_2, Q_3, and Q_4 shall each be calculated using Equations B-1 or B-2, whichever is applicable, and then Equation B-3.

5.5.4.3 Calculate Volume Controller Performance. The changes in airflow (ΔQ_{up} and ΔQ_{down}) caused by increasing and decreasing variations in the inlet static pressure of the terminal-unit/controller combination, respectively, are calculated using Equations 9 and 10.

$$\Delta Q_{up} = 100\left(\frac{Q_3 - Q_1}{Q_1}\right) \tag{9}$$

$$\Delta Q_{down} = 100\left(\frac{Q_4 - Q_3}{Q_1}\right) \tag{10}$$

5.5.4.4 Test Example. Refer to Informative Appendix N for an example of a pressure-compensating volume controller performance test.

5.6 Casing Leakage Test

5.6.1 Test Purpose. This test determines the casing leakage of supply and return/exhaust terminal units and mechanically regulated terminal units. For parallel-flow fan-powered supply terminal units, the test is carried out with the backdraft damper unsealed and then sealed, so that the backdraft damper leakage can be excluded during normal operation when the box fan is operating and flow is inward through the backdraft damper opening.

5.6.2 Test Setup

5.6.2.1 The terminal unit shall be set up as shown in Figure 5 (supply) and Figure 6 (return/exhaust).

5.6.2.2 The leakage airflow measuring device shall be (a) a calibrated orifice plate with a blower or (b) a calibrated flowmeter with an integral fan.

5.6.2.3 The test setup ductwork, inlets for return/exhaust terminal units, and outlets for supply terminal units shall be sealed. For parallel-flow fan-powered supply terminal units, the terminal unit fan shall not operate, and the test shall be carried out with the backdraft damper unsealed and then sealed.

5.6.3 Test Procedure

5.6.3.1 The inlet control damper or modulating diffuser shall be fully open.

5.6.3.2 The terminal-unit casing shall be leak-tested from the minimum to maximum pressure differences specified by the user of this standard in at least four equal increments.

5.6.4 Test Data. Measure and record the following data for each leakage test pressure difference $\Delta p_{s,i}$.

5.6.4.1 Ambient air conditions in the test area: dry-bulb temperature ($t_{o,i}$), relative humidity ($\varphi_{o,i}$), and barometric pressure at the same elevation as the airflow measurement ($p_{bo,i}$).

5.6.4.2 Leakage test pressure difference across the casing ($\Delta p_{s,i}$), referenced to the ambient air pressure in the test area. For supply terminal unit tests, $\Delta p_{s,i} \geq 0$. For return/exhaust terminal unit tests, $\Delta p_{s,i} \leq 0$.

5.6.4.3 Airflow through the flow measuring instrument ($Q_{meas,i}$), as determined using the instrument's calibration.

5.6.5 Calculations

Calculate the following data for each leakage test pressure difference $\Delta p_{s,i}$.

5.6.5.1 Air Density. The actual density of air entering the flow measuring device ($\rho_{act,i}$) shall be calculated using Normative Appendix J.

5.6.5.2 Leakage Airflows at Actual Air Density. When an orifice plate type of device is used to measure airflow, the actual air density calculated in Section 5.5.5.1 ($\rho_{act,i}$) and the flow measurement instrument's calibration air density (ρ_{calib}) shall be used to convert each "measured" airflow ($Q_{meas,i}$) to leakage airflow at actual conditions ($Q_{act,i}$) as follows:

$$Q_{act,i} = Q_{meas,i}\sqrt{\frac{\rho_{calib}}{\rho_{act,i}}} \tag{11}$$

The derivation of Equation 11 is shown in Informative Appendix L.

For other types of flow measurement devices, the device manufacturer's instructions shall be used to convert the measured airflows to actual conditions.

5.6.5.3 Leakage Parameters. The following equation defines the volumetric leakage flow at actual conditions as a function of the pressure difference across the leaks:

$$Q_{act,i} = C\left|\Delta p_{s,i}\right|^{n} \tag{12}$$

where

$Q_{act,i}$ = volumetric airflow through airflow meter at actual air density, cfm [L/s]
C = leakage flow coefficient, cfm per (in. of water)^n [L/s per Pa^n]
$\Delta p_{s,i}$ = static pressure difference across leaks, in. of water [Pa]
n = leakage pressure exponent, dimensionless

The parameters *C* and *n*, as well as the correlation coefficient (*r*), shall be determined using the equations listed in Normative Appendix M. An iterative least-squares fit using log transforms of $Q_{act,i}$ and $\Delta p_{s,i}$ shall not be used to determine the leakage parameters *C* and *n*.

The leakage test shall be repeated if:

- the pressure exponent *n* is beyond the expected bounds: less than 0.5 or greater than 1.0,
- the correlation coefficient *r* is less than 0.99, or
- the relative error in flow $100\left(\frac{\left|Q_{fit\_act,i} - Q_{act,i}\right|}{Q_{act,i}}\right)$ is greater than 5% for any data point.

where $Q_{fit\_act,i} = C\left|\Delta p_{s,i}\right|^{n}$, cfm [L/s]

5.6.6 Test Example

Informative Appendix D provides an example of a terminal-unit leakage test and leakage parameter calculations.

5.6.7 Report

5.6.7.1 The calculated leakage flow coefficient *C* (cfm per (in. of water)^n [L/s per Pa^n]) and leakage pressure exponent *n* (dimensionless) from the test shall be reported along with the average actual air density ρ_{act} (lb$_m$/ft^3 (kg/m^3)) averaged over all of the tests, the correlation coefficient *r*, and the maximum relative error in fitted leakage flow (%) for all data points.

5.6.7.2 The terminal unit leakage volumetric airflow $Q_{act,\,ref}$ at the reference static pressure difference $\Delta p_{s,ref}$ specified by the user of this standard and calculated using Equation 12 shall be reported in units of cfm [L/s] along with the average actual air density ρ_{act} (lb$_m$/ft^3 (kg/m^3)) averaged over all of the tests.

5.6.7.3 To convert the terminal unit volumetric leakage airflow $Q_{act,ref}$ at the reference static pressure difference $\Delta p_{s,ref}$ from *actual* air density (at the flow meter inlet) to the volumetric airflow $Q_{std,ref}$ at *standard* air density (ρ_{std}), the following equation shall be used:

$$Q_{std,ref} = Q_{act,ref}\left(\frac{\rho_{act}}{\rho_{std}}\right)^{(1-n)} \tag{13}$$

Equation 13 is derived from the flow coefficient correction described by Carrié (2014)[9], with temperature-difference-related air viscosity dependencies excluded.

The volumetric airflow $Q_{std,ref}$ calculated using Equation 13 shall be reported in units of cfm [L/s].

5.6.7.4 For parallel-flow fan-powered supply terminal units, all of the values described in Sections 5.6.7.1 and 5.6.7.2 for tests with the backdraft damper unsealed and then sealed shall be reported.

5.7 Supply Inlet Damper/Valve Leakage

5.7.1 Test Purpose. This test determines the air leakage of the supply air terminal unit inlet damper/valve in the shut-off position. It excludes the leakage of the terminal unit downstream of the inlet damper/valve. This test is applicable for (a) single-duct, dual-duct, series, and parallel-flow fan-powered terminals and (b) mechanically regulated terminal units.

5.7.2 Test Setup

5.7.2.1 The terminal unit to be tested shall be set up as shown in Figure 7.

5.7.2.2 The leakage airflow measuring means shall be (a) a calibrated orifice tube with a blower or (b) a calibrated flowmeter with an integral fan.

5.7.2.3 The test setup ductwork between the airflow measuring means and the terminal unit shall be sealed. The terminal unit outlet and the downstream ductwork shall be open to the ambient air conditions in the test area.

5.7.3 Test Procedure

5.7.3.1 Both inlet dampers of dual-unit air terminals shall be tested individually.

5.7.3.2 The fan of a series- and parallel-flow fan-powered terminal unit shall not be operating.

5.7.3.3 The test pressures shall be specified by the user of this standard.

5.7.3.4 The terminal-unit inlet damper/valve shall be operational or manually adjusted during tests.

5.7.3.5 The air pressure shall be increased to the maximum test pressure of interest with the inlet damper/valve closed, and then the damper/valve shall be modulated to the open position and returned to the closed position. After the damper/valve is closed and equilibrium is established, the air pressure shall be adjusted to the minimum test pressure of interest in at least four equal increments.

5.7.4 Test Data. Measure and record the following data.

5.7.4.1 Ambient air conditions in the test area: dry-bulb temperature (t_o), relative humidity (φ_o), and barometric pressure at the same elevation as the airflow measurement (p_{bo}).

5.7.4.2 Leakage test pressure (Δp_1).

5.7.4.3 Leakage airflow rate (Q_{leak}).

5.7.5 Calculations

5.7.5.1 Air Density. The air density (ρ_{act}) in the test area shall be calculated using Normative Appendix J.

5.7.6 Report. The terminal-unit inlet damper/valve leakage shall be reported as Q_{leak} cfm (L/s) at Δp_1 in. of water (Pa) inlet static pressure with the air density = ρ_{act} lb_m/ft^3 (kg/m^3).

5.8 Exhaust Total Leakage

5.8.1 Test Purpose. This test determines the exhaust damper/valve and casing leakage under negative pressure with the control damper/valve closed. This test is applicable to single-duct and mechanically regulated terminal units.

5.8.2 Test Setup

5.8.2.1 The terminal unit to be tested shall be installed as shown in Figure 8.

5.8.2.2 The leakage airflow measuring means shall be (a) a calibrated orifice tube with a blower or (b) a calibrated flowmeter with an integral fan.

5.8.2.3 The test setup ductwork between the terminal unit and the airflow measurement means shall be sealed.

5.8.3 Test Procedure

5.8.3.1 The test pressures shall be specified by the user of this standard.

5.8.3.2 The control damper/valve actuator shall be operational during the damper/valve leakage tests.

5.8.3.3 The air pressure shall be decreased to the minimum test static pressure with the control damper/valve closed, and then the damper/valve shall be modulated to the open position and returned to the closed position.

5.8.3.4 After the damper/valve is closed and equilibrium is established, the air pressure shall be adjusted to the maximum test pressure of interest in at least four equal increments.

5.8.4 Test Data. Measure and record the following data.

5.8.4.1 Ambient air conditions in the test area: dry-bulb temperature (t_o), relative humidity (φ_o), and barometric pressure at the same elevation as the airflow measurement (p_{bo}).

5.8.4.2 Leakage test pressure (Δp_{s2}).

5.8.4.3 Leakage airflow rate (Q_{leak}).

5.8.5 Calculations

5.8.5.1 Air Density. The air density (ρ_{act}) in the test area shall be calculated using Normative Appendix J.

5.8.6 Report. The terminal-unit total leakage shall be reported as Q_{leak} cfm (L/s) at Δp_{s2} in. of water (Pa) inlet static pressure with the air density = ρ_{act} lb_m/ft^3 (kg/m^3).

5.9 Dynamic Leakage (Parallel-Flow Fan-Powered)

5.9.1 Test Purpose. This test determines the leakage through the casing and backdraft damper of parallel-flow fan-powered terminal units with the primary air system operating and the terminal fan not operating.

5.9.2 Test Setup

5.9.2.1 The terminal unit to be tested shall be installed as shown in Figure 3.

5.9.2.2 Seal the entire setup, not including the terminal unit and induction port.

5.9.3 Test Procedure

5.9.3.1 The test conditions (terminal-unit airflow and upstream and downstream static pressure) shall be specified by the user of this standard.

5.9.3.2 The system fan and the terminal-unit damper shall be set to the specified terminal airflow and inlet static pressure. The downstream static pressure shall be set to the specified value. Airflow and pressure shall be within ±5% of test values.

5.9.4 Test Data. Measure and record the following data.

5.9.4.1 Ambient air conditions in the test area: dry-bulb temperature (t_o), relative humidity (φ_o), and barometric pressure at the same elevation as the airflow measurement (p_{bo}).

5.9.4.2 Terminal-unit inlet static pressure (p_{s7}).

5.9.4.3 Terminal-unit downstream static pressure (p_{s8}).

5.9.4.4 Terminal-unit inlet airflow [t_5, p_{s5}, $\Delta p_{s,5\text{–}6}$ (upstream airflow measuring means)].

5.9.4.5 Terminal-unit outlet airflow [t_5, p_{s5}, $\Delta p_{s,5\text{–}6}$ (downstream airflow measuring means)].

5.9.5 Calculations

5.9.5.1 Air Density. The air density (ρ_{act}) in the test area shall be calculated using Normative Appendix J.

5.9.5.2 Inlet Airflow. The upstream volumetric airflow rate shall be calculated using Equations B-1 or B-2, whichever is applicable, and then Equation B-3.

5.9.5.3 Downstream Airflow. The downstream volumetric airflow rate shall be calculated using Equations B-1 or B-2, whichever is applicable, and then Equation B-3.

5.9.5.4 Dynamic Leakage. The air leakage of the terminal-unit casing and backdraft damper shall be calculated as follows.

$$Q_{leak} = Q_{in} - Q_{out} \tag{14}$$

where

Q_{leak} = parallel-flow fan-powered terminal-unit dynamic leakage, cfm (L/s)
Q_{in} = terminal-unit inlet airflow, cfm (L/s)
Q_{out} = terminal-unit outlet airflow, cfm (L/s)

5.9.6 Report. The dynamic leakage shall be reported as Q_{leak} cfm (L/s) at the following conditions: air density ρ_{act} (lb$_m$/ft^3 [kg/m^3]); terminal-unit size (in. [mm]); terminal airflow Q_{in} (cfm [L/s]); inlet static pressure of terminal unit p_{s7} (in. of water [Pa]); and downstream static pressure of terminal unit p_{s8} (in. of water [Pa]).

5.10 Airflow Sensor Amplification Factor

5.10.1 Test Purpose. This test determines the controlled terminal-unit airflow sensor output (amplification factor) at various airflows. This test is applicable for single-duct, induction, bypass, dual-duct, and fan-powered terminal units.

5.10.2 Test Setup. The terminal unit to be tested shall be set up as shown in Figure 1.

5.10.3 Test Procedure

5.10.3.1 Vary airflow from minimum to maximum values in increments not exceeding 10% of the maximum value with the damper fully open**.**

5.10.4 Test Data. Measure and record the following data after equilibrium has been established.

5.10.4.1 Ambient air conditions in the test area: dry-bulb temperature (t_o), relative humidity (φ_o), and barometric pressure at the same elevation as the airflow measurement (p_{bo}) (t_o, t'_o, p_b).

5.10.4.2 Mass flow measurements (t_5, p_{s5}, $\Delta p_{s,5\text{–}6}$).

5.10.4.3 Terminal-unit inlet static pressure (p_{s7}).

5.10.4.4 Airflow sensor output, p_{sensor} (in. of water [Pa]).

5.10.5 Calculations

5.10.5.1 Air Density. The air density (ρ_{act}) in the test area shall be calculated using Normative Appendix J.

5.10.5.2 Airflow. Volumetric airflow rate (Q_o) shall be calculated using Equations B-1 or B-2, whichever is applicable, and then Equation B-3.

5.10.5.3 Velocity Pressure. The terminal-unit inlet velocity pressure shall be calculated using Equation B-5, where the inlet velocity is calculated by Equation B-4.

5.10.5.4 Amplification Factor. The amplification factor (F) shall be calculated using Equation 1.

5.10.5.5 Flow Coefficient. The flow coefficient (K) shall be calculated using Equation 4.

5.10.6 Refer to Informative Appendix E for a test to determine the effect of the partially closed control damper on airflow sensor performance.

5.11 Airflow Sensor Performance—Inlet Conditions

5.11.1 Test Purpose. This test measures the change in airflow caused by variations in inlet configurations.

5.11.2 Test Setup

5.11.2.1 Sensor performance shall first be measured under straight inlet conditions in accordance with Figure 1.

5.11.2.2 Sensor performance shall then be measured under non-straight inlet conditions in accordance with Figure 9.

5.11.3 Test Procedure

5.11.3.1 Straight Inlet Conditions. Adjust the airflow to obtain the desired sensor output and inlet static pressure with straight inlet conditions.

5.11.3.2 Non-straight Inlet Conditions. Change the setup to the non-straight inlet condition (Figure 9). Adjust the airflow and terminal-unit throttling device to obtain the same airflow sensor output and duct static pressure recorded with the straight inlet condition.

5.11.4 Test Data. Measure and record the following data after equilibrium has been established.

5.11.4.1 Ambient air conditions in the test area: dry-bulb temperature (t_o), relative humidity (φ_o), and barometric pressure at the same elevation as the airflow measurement (p_{bo}).

5.11.4.2 Straight Inlet Conditions

a. Mass flow measurements (t_5, p_{s5}, $\Delta p_{s,5\text{–}6}$).
b. Terminal-unit inlet static pressure (p_{s7}).
c. Airflow sensor output, p_{sensor} (in. of water [Pa]).

5.11.4.3 Non-Straight Inlet Conditions

a. Mass flow measurements (t_5, p_{s5}, $\Delta p_{s,5\text{–}6}$).
b. Terminal-unit inlet static pressure (p_{s7}).
c. Airflow sensor output, p_{sensor} (in. of water [Pa]).

5.11.5 Calculations

5.11.5.1 Straight Inlet Conditions with Damper/Valve Open

a. **Air Density.** The air density (ρ_{act}) in the test area shall be calculated using Normative Appendix J.

b. **Airflow.** Volumetric airflow rate (Q_{st}) shall be calculated using Equations B-1 or B-2, whichever is applicable, and then Equation B-3.

c. **Velocity Pressure.** The terminal-unit inlet velocity pressure shall be calculated using Equation B-5, where the inlet velocity is calculated using Equation B-4.

d. **Amplification Factor.** The amplification factor (F) shall be calculated using Equation 1. Mechanical regulated terminal units exempt from this calculation.

e. **Flow Coefficient.** The flow coefficient (K) shall be calculated using Equation 3. Mechanical regulated terminal units exempt from this calculation.

5.11.5.2 Inlet with Non-straight Inlet Conditions, Damper/Valve Open

a. **Airflow Rate.** Calculate the airflow rate ($Q_{non\text{-}st}$) using Equations B-1 or B-2, whichever is applicable, and then Equation B-3.

5.11.6 Report

5.11.6.1 Provide a detailed description of the non-straight inlet conditions to the terminal unit. Description shall include type of fitting, angle, and distance from the terminal-unit inlet.

5.11.6.2 The change in volumetric airflow shall be reported as the percent difference between the straight inlet condition and the non-straight inlet condition (Equation 15).

$$\%\text{change} = \frac{100\left(Q_{st} - Q_{non-st}\right)}{Q_{st}} \tag{15}$$

where

Q_{st} = test conditions with straight inlet flow to terminal unit, cfm (L/s)
$Q_{non\text{-}st}$ = test conditions with non-straight inlet flow to terminal unit, cfm (L/s)

5.12 Temperature Mixing

5.12.1 Test Purpose. This test measures the efficiency for mixing (a) the primary and induced air of induction terminal units and fan-powered terminal units and (b) the hot and cold decks of dual-duct terminal units.

5.12.2 Test Setup. The equipment to be tested shall be set up as shown in Figure 10 (non-dual-duct terminal units) or Figure 11 (dual-duct terminal unit).

5.12.3 Test Procedure. Tests shall be conducted as follows.

5.12.3.1 The supply air temperatures shall be measured at the duct centerline immediately upstream of the terminal unit inlets (Plane 1).

5.12.3.2 The induced air temperature shall be measured adjacent to the air inlet.

5.12.3.3 For each row of temperature measurement at Plane 8, the end points shall be 1.0 in. (25 mm) from wall surfaces. The remaining temperature measuring points shall be uniformly located throughout the remaining area. The minimum number of temperature measuring points shall be per Table 3.

5.12.3.4 Prior to each test, the system shall be stabilized within 0.2°F (0.1°C) of all temperature measurement planes by running isothermal air at room temperature through the system.

5.12.3.5 Adjust the terminal airflow control devices and supply air temperatures until the desired airflows, inlet and outlet static pressures, and supply air temperatures are obtained.

5.12.3.6 Monitor the supply and discharge air temperatures until thermal equilibrium (see Section 3.1) is obtained.

5.12.4 Test Data. Measure and record the following data after equilibrium has been established.

5.12.4.1 Ambient air conditions in the test area: dry-bulb temperature (t_o), relative humidity (φ_o), and barometric pressure at the same elevation as the airflow measurement (p_{bo}).

5.12.4.2 Inlet mass flow measurements ($t_{5(u)}$, $p_{s5(u)}$, $\Delta p_{s,5-6(u)}$).

5.12.4.3 Discharge mass flow measurements ($t_{5(d)}$, $p_{s5(d)}$, $\Delta p_{s,5-6(d)}$).

5.12.4.4 Inlet static pressure.

a. Non-dual-duct terminal (p_{s7}).
b. Dual-duct terminal: cold-deck ($p_{s,7c}$); hot-deck ($p_{s,7h}$).

5.12.4.5 Discharge static pressure (p_{s8}).

5.12.4.6 Supply air temperature.

a. Non-dual-duct terminal (t_1).
b. Dual-duct terminal: cold-deck (t_{1c}); hot-deck (t_{1h}).

TABLE 3 Minimum Number of Temperature Measuring Points

Test Duct Cross-Sectional Area, ft^2 (m^2)	Minimum Number of Temperature Points
0.25 (0.025)	4
0.50 (0.05)	6
1.00 (0.1)	9
1.50 (0.15)	12
2.00 (0.2)	15
3.00 (0.3)	20
>3.00 (>0.3)	25

5.12.4.7 Induced air temperature (t_o).

5.12.4.8 Discharge air temperatures (t_8).

5.12.5 Calculations

5.12.5.1 Air Density. The air density (ρ_{act}) in the test area shall be calculated using Normative Appendix J.

5.12.5.2 Supply Airflow. The supply volumetric airflow rates shall be calculated using Equations B-1 or B-2, whichever is applicable, and then Equation B-3.

5.12.5.3 Discharge Airflow. The discharge volumetric airflow rate shall be calculated using Equations B-1 or B-2, whichever is applicable, and then Equation B-3.

5.12.5.4 Induced Airflow

a. For non-dual-duct terminal units, calculate the induced airflow using Equation 16.

$$Q_i = Q_{5d} - Q_{5u} \tag{16}$$

where

Q_{5d} = discharge airflow, cfm (L/s)
Q_{5u} = primary airflow, cfm (L/s)
Q_i = induced airflow, cfm (L/s)

b. For dual-duct terminal units, calculate the hot-deck airflow rate using Equation 17.

$$Q_{5h} = Q_{5d} - Q_{5c} \tag{17}$$

where

Q_{5c} = cold-deck airflow, cfm (L/s)
Q_{5h} = hot-deck airflow, cfm (L/s)
Q_{5d} = discharge airflow cfm (L/s)

5.12.5.5 Difference between the highest and lowest discharge air temperature is calculated using Equation 18.

$$\Delta t_x = t_{8,\max} - t_{8,\min} \tag{18}$$

where

Δt_x = min-max air temperature difference at Plane 8, °F (°C)
$t_{8,max}$ = max air temperature at Plane 8, °F (°C)
$t_{8,min}$ = min air temperature at Plane 8, °F (°C)

5.12.6 For induction and fan-powered terminal units, the difference between the primary and induced air temperatures is calculated using Equation 19. For dual-duct units, the difference between the hot and cold decks is calculated using Equation 20.

$$\Delta t_y = t_1 - t_0 \tag{19}$$

$$\Delta t_y = t_{1h} - t_{1o} \tag{20}$$

where

Δt_y = temperature difference between primary and induced airstreams, °F (°C)
t_1 = primary air temperature, °F (°C)
t_{1c} = cold-deck temperature, °F (°C)
t_{1h} = hot-deck temperature, °F (°C)
t_{1o} = induced air temperature, °F (°C)

5.12.7 Report

5.12.7.1 Induction and Fan-Powered Terminal Units. The efficiency of mixing shall be reported as Δt_x°F (°C) with the primary and induced air temperatures at t_1°F (°C) and t_o°F (°C), respectively, (Δt_y differential) with test conditions as follows.

5.12.7.1.1 Upstream. Q_{5u} cfm (L/s) at p_{s7} in. of water (Pa).

5.12.7.1.2 Downstream. Q_{5d} cfm (L/s) at p_{s8} in. of water (Pa).

5.12.7.2 Dual-Duct Terminal Units. The efficiency of temperature shall be reported as Δt_x°F (°C) with the hot- and cold-deck temperatures air at t_{1h}°F (°C) and t_{1c}°F (°C), respectively, (Δt_y differential) with test conditions as follows.

a. **Upstream, Hot-Deck.** Q_{5h} cfm (L/s) at $p_{s,7h}$ in. of water (Pa).
b. **Upstream, Cold-Deck.** Q_{5C} cfm (L/s) at $p_{s,7c}$ in. of water (Pa).

5.12.8 Test Example. Refer to Informative Appendix F for mixing efficiency test examples for a series-flow fan-powered terminal unit and a dual-duct terminal unit.

5.13 Temperature Stratification

5.13.1 Test Purpose. This test determines the degree of stratification for the following terminal units with reheat coils: (a) single-duct, induction, bypass, series-flow fan-powered, and parallel-flow fan-powered and (b) mechanically regulated.

5.13.2 Test Setup. The terminal units to be tested shall be set up as shown in Figure 12 (single-duct) and Figure 10 (fan-powered, induction, and bypass). The source of cooling and heating is not shown on the test setups.

5.13.3 Test Procedure. The test shall be conducted as follows.

5.13.3.1 The supply air temperature shall be measured at the duct centerline immediately upstream of the terminal-unit inlet (Plane 1).

5.13.3.2 For each row of temperature measurement at Plane 8, the end points shall be 1.0 in. (25 mm) from wall surfaces. The remaining temperature measuring points shall be uniformly located throughout the remaining area. The minimum number of temperature measuring points shall be per Table 3 (Section 5.12.3.3).

5.13.3.3 Prior to each test, the system shall be stabilized within 0.2°F (0.1°C) of all temperature measurement planes by running isothermal air at room temperature through the system.

5.13.3.4 Adjust the terminal airflow control devices and supply (reheat) air temperature until the desired airflows, inlet and outlet static pressures, and supply air temperatures are obtained.

5.13.3.5 Monitor the supply and discharge air temperatures until thermal equilibrium (see Section 3.1) is obtained.

5.13.4 Test Data. Measure and record the following data after equilibrium has been established.

5.13.4.1 Ambient air conditions in the test area: dry-bulb temperature (t_o), relative humidity (φ_o), and barometric pressure at the same elevation as the airflow measurement (p_{bo}).

5.13.4.2 Single-duct terminal unit (t_5, p_{s5}, $\Delta p_{s,5-6}$).

5.13.4.3 Fan-powered, induction, and bypass terminal units: Inlet and discharge mass flow measurements [$t_{5(u)}$, $p_{s5(u)}$, $\Delta p_{s,5-6(u)}$ and $t_{5(d)}$, $p_{s5(d)}$, $\Delta p_{s,5-6(d)}$].

5.13.4.4 Inlet static pressure (p_{s7}).

5.13.4.5 Discharge static pressure (p_{s8}).

5.13.4.6 Supply air temperature (t_1).

5.13.4.7 Discharge air temperature (t_8) profile per Section 5.12.3.3.

5.13.5 Calculations

5.13.5.1 Air Density

a. **Ambient.** The air density (ρ_{act}) in the test area shall be calculated using Normative Appendix J.

b. **Downstream.** The downstream air density ($\rho_{5,d}$) shall be calculated using Normative Appendix J. Subscript 5,d is the temperature measurement plane within the downstream airflow measurement means.

5.13.5.2 Airflow

a. **Supply.** The supply volumetric airflow rate (Q_{5u}) shall be calculated using Equations B-1 or B-2, whichever is applicable, and then Equation B-3.

b. **Discharge.** The discharge volumetric airflow rate (Q_{5d}) shall be calculated using Equations B-1 or B-2, whichever is applicable, and then Equation B-3 at two conditions: upstream air density (ρ_{5u}) and downstream air density (ρ_{5d}). Assume $\rho_{5u} = \rho_{act}$.

c. **Induced.** For induction and fan-powered terminal units, calculate the induced airflow using Equation 21.

$$Q_i = Q_{5d}^{'} - Q_{5u} \tag{21}$$

where

Q_i = induced airflow, cfm (L/s)

$Q_{5d}^{'}$ = discharge airflow at ambient air density (ρ_{act}), cfm (L/s)

Q_{5u} = primary airflow, cfm (L/s)

d. **Bypass.** For bypass terminal units, calculate the exhaust airflow rate using Equation 22.

$$Q_{ex} = Q_{5d}^{'} - Q_{5u} \tag{22}$$

where

Q_{ex} = induced airflow, cfm (L/s)
$Q_{5d}^{'}$ = discharge airflow at ambient air density (ρ_{act}), cfm (L/s)
Q_{5u} = primary airflow, cfm (L/s)

5.13.6 Report

5.13.6.1 Single-Duct Terminal Unit. The stratification shall be reported as Δt_x°F (°C) horizontal and Δt_y°F (°C) vertical with a temperature rise Δt_z°F (°C) and test conditions as follows:

a. **Upstream.** Q_{5u} cfm (L/s) at p_{s7} in. of water (Pa).
b. **Downstream.** Q_{5d} cfm (L/s) p_{s8} in. of water (Pa).

where

Δt_x = at Plane 8, the maximum temperature difference between horizontal end points at any horizontal plane (row), °F (°C).
Δt_y = at Plane 8, the maximum temperature difference between vertical end points at any vertical plane (column), °F (°C).
Δt_z = difference between arithmetic average at Plane 8 and the supply air temperature (t_1), °F (°C).

5.13.6.2 Induction and Fan-Powered Terminal Units. The stratification shall be reported as Δt_x°F (°C) horizontal and Δt_y°F (°C) vertical with a temperature rise Δt_z°F (°C) and test conditions as follows:

a. **Upstream.** Q_{5u} cfm (L/s) at p_{s7} in. of water (Pa).
b. **Downstream.** Q_{5d} cfm (L/s) at p_{s8} in. of water (Pa).

where

Δt_x = maximum temperature difference between horizontal end points at any horizontal plane (row), °F (°C).
Δt_y = maximum temperature difference between vertical end points at any vertical plane (column), °F (°C).
Δt_z = difference between arithmetic average at Plane 8 and the induced air temperature (t_o), °F (°C).

Refer to Informative Appendix G for a temperature stratification test of a fan-powered terminal unit with reheat coil.

5.13.6.3 Bypass Terminal Units. The stratification shall be reported as Δt_x°F (°C) horizontal and Δt_y°F (°C) vertical with a temperature rise Δt_z°F (°C) and test conditions as follows:

a. **Upstream.** Q_{5u} cfm (L/s) at p_{s7} in. of water (Pa).
b. **Downstream.** Q_{5d} cfm (L/s) at p_{s8} in. of water (Pa).

where

Δt_x = maximum temperature difference between horizontal end points at any horizontal plane (row), °F (°C).
Δt_y = maximum temperature difference between vertical end points at any vertical plane (column), °F (°C).
Δt_z = difference between arithmetic average at Plane 8 and the primary air temperature (t_1), °F (°C).

5.14 Condensation Determination

5.14.1 Test Purpose. This test determines the condensation potential of terminal units.

5.14.2 Test Setup. The terminal unit to be tested shall be set up as shown in Figure 1 (single-duct, induction, dual-duct, modulating and integral diffusers, mechanically regulated) and Figure 3 (bypass, fan-powered)

5.14.3 Test Procedure

5.14.3.1 Terminal units shall be operated at rated conditions.

5.14.3.2 Primary air and ambient air conditions shall be selected by the user of this standard.

5.14.3.3 Prior to each test, the system shall be stabilized within 0.2°F (0.1°C) of all temperature measurement planes by running isothermal air at room temperature through the system.

5.14.3.4 The terminal unit shall be operated at the selected test conditions for one hour, minimum, at steady-state conditions. After this period, the terminal unit shall be inspected for condensation.

5.14.4 Test Data. Measure and record the following data after equilibrium has been established.

5.14.4.1 Ambient air conditions in the test area: dry-bulb temperature (t_o), relative humidity (φ_o), and barometric pressure at the same elevation as the airflow measurement (p_{bo}).

5.14.4.2 Supply air conditions in the test area: dry-bulb temperature (t_1) and relative humidity (φ_1).

5.14.4.3 Mass flow measurements—single-duct, induction, and dual-duct terminal units; modulating and integral diffusers (t_5, p_{s5}, $\Delta p_{\text{s},5\text{–}6}$).

5.14.4.4 Mass Flow Measurements (Bypass and Fan-Powered Terminal Units)

a. Inlet ($t_{5(u)}$, $p_{s5(u)}$, $\Delta p_{\text{s},5\text{–}6(u)}$).
b. Discharge [$t_{5(d)}$, $p_{s5(d)}$, $\Delta p_{\text{s},5\text{–}6(d)}$].

5.14.4.5 Inlet static pressure (p_{s7}).

5.14.4.6 Discharge static pressure (p_{s8}).

5.14.4.7 Record surfaces exhibiting condensation.

5.14.5 Calculations

5.14.5.1 Air Density. The air density (ρ_{act}) in the test area shall be calculated using Normative Appendix J.

5.14.5.2 Airflow. Volumetric airflow rates (Q) shall be calculated using Equations B-1 or B-2, whichever is applicable, and then Equation B-3.

5.15 Sound

5.15.1 Test Purpose. This test measures the sound discharged or radiated from all terminal unit types within scope of this standard, including single-duct, induction, bypass, dual-duct, integral diffuser, fan-powered, modulating diffuser, mechanically regulated, and exhaust terminal units.

5.15.2 Test Chamber. The acoustic test chamber (reverberant room) shall be qualified for broad-band and discrete frequency sources in the 100 through 10,000 Hz one-third octave bands in accordance with AHRI

Standard 220[8]. As part of those qualifications, the portion of the room directly in front of the wall opening(s) used for the discharge test setups and the floor area directly below the location for the casing radiated tests listed in Table 4 shall be qualified.

NOTE: where a laboratory is unable to achieve quiet air conditions at certain one-third octave bands under certain test conditions, the test will not be in full conformance with this standard. It is the prerogative of the user to either continue to try to reduce background sound levels or to issue a conditional report that indicates at which test conditions the data were limited by background noise. The procedures of AHRI 220 provide corrections for background noise level and reporting requirements—any data affected by corrections are identified as being influenced by the background and potentially having a higher uncertainty than described in the standard.

EXCEPTION: where the terminal unit under test does not have either an integral fan or features that produce audible tones during operation, only those sections of AHRI 220 pertaining to broadband room qualification procedures need to be followed.

5.15.3 Test Setups

5.15.3.1 Table 4 identifies the sound test setup (figure) required for each type of terminal unit.

TABLE 4 Sound Test Setup

Terminal Unit	Sound Test	Test Setup
Single-duct	Discharge	Figure 13
	Radiated	Figure 19
Induction	Discharge	Figure 14
	Radiated	Figure 20
Bypass	Discharge	Figure 15
	Radiated	Figure 21
Dual-Duct	Discharge	Figure 13
	Radiated	Figure 19
Integral Diffuser	Discharge	Figure 16 or 17
	Radiated	—
Series-Flow Fan-Powered	Discharge	Figure 13
	Radiated	Figure 19
Parallel-Flow Fan-Powered	Discharge	Figure 14
	Radiated	Figure 20
Modulating Diffuser	Sound	See ASHRAE Standard 70
Mechanically Regulated	Discharge	Figure 13
	Radiated	Figure 19

Exhaust	Exhaust	Figure 18
	Radiated	Figure 22 or 23

5.15.3.2 Acoustically isolated ducts, as noted on the test setup drawings, shall be provided as determined by the testing laboratory to eliminate sound breakout or break-in contribution. Specific construction is left to the laboratory to determine through successive experimental testing. Refer to Informative Appendix H for example details of acoustically isolated ducts.

5.15.3.3 Sound data shall be measured for the unit under test without modification (e.g., additional lined ductwork or silencers unless these items are shown to be an integral part of the terminal being tested.

5.15.3.4 A corresponding test setup matching the appropriate configuration for the terminal unit type under test is required to demonstrate “quiet air” conditions. See Appendix O for additional information.

5.15.4 Test Procedures

5.15.4.1 Sound power shall be determined in accordance with AHRI 220 with modifications to accommodate sound source locations on chamber walls (e.g., discharge openings) and elevated locations above the floor (e.g., casing radiated tests). Locate the RSS on the floor in a qualified area 1.5m away from the discharge opening for discharge tests and 1.5m away from the unit for casing radiated tests.

5.15.4.2 Test conditions (e.g., air flow(s), inlet static pressure(s), damper position) shall be established by the user of this standard.

5.15.4.3 A total of four tests are required by AHRI 220 to determine the sound power of a unit under test: background noise measurement for comparison with the RSS where all systems are turned off, background noise measurement for comparison with the unit sound test with the laboratory system fan running, RSS sound pressure measurement, and terminal unit under test sound measurement.

5.15.4.4 Only one pair of measurements of the RSS sound levels and associated background noise levels is required for any series of measurements using the same test configuration on the same day, provided that the temperature and relative humidity in the room do not change by more than 5ºC or 5% RH.

5.15.4.5 The background noise levels for comparison with the unit shall be measured without the terminal unit in the setup at the same laboratory system airflow rates as will be used for the unit test. Substitution pieces to take the place of the unit shall be determined and incorporated into the test setup by the testing laboratory (see Appendix O). The laboratory air supply or exhaust system shall meet the definition of quiet air for each test condition.
NOTE: where a laboratory is unable to achieve quiet air conditions at certain one-third octave bands under certain test conditions, the test will not be in full conformance with this standard but may still proceed and the procedures of AHRI 220 shall be followed with respect to corrections for background noise level and reporting requirements—all associated data shall be flagged as required by AHRI 220.

5.15.4.6 The terminal unit under test shall be placed in the appropriate test setup and measurements taken at the established test conditions. Terminal performance is a function of supply/exhaust air volume, inlet static pressure, fan air volume, and discharge static pressure. These variables and others that affect the results shall be measured as appropriate and reported with the terminal unit sound power levels.

5.15.5 Test Data. Measure and record the following data after equilibrium (airflow, static pressure) has been established as appropriate for both the background noise level setup and the terminal unit under test setup and as applicable for the RSS and RSS background tests.

5.15.5.1 Ambient air conditions in the reverberation room: dry-bulb temperature (t_o), relative humidity (φ_o), and barometric pressure at the same elevation as the airflow measurement (p_{bo}).

5.15.5.2 Mass flow measurements (t_5, p_{s5}, $\Delta p_{s,5\text{–}6}$).

5.15.5.3 Static pressure downstream (p_{s8}) of the terminal unit for fan-powered terminal units.

5.15.5.4 Static pressure differential (drop) across the terminal unit.

5.15.5.5 Sound power (dB) in accordance with AHRI 220 in each one-third octave band from 100 Hz through 10000 Hz, inclusive.

5.15.5.6 Power (fan-powered terminal units).

a. Amperes
b. Voltage
c. Watts

5.15.6 Calculations

5.15.6.1 Air Density. The air density (ρ_{act}) in the test area shall be calculated using Normative Appendix J.

5.15.6.2 Volumetric airflow rate shall be calculated using Equations B-1 or B-2, whichever is applicable, and then Equation B-3.

5.15.6.3 Sound Power. Calculate one-third octave band sound power levels of the unit under test, as discharged through openings in the reverberation room walls or radiated from its casing while positioned inside the reverberation room, per AHRI 220. Include corrections for background noise and for end reflection correction for ducted discharge tests (see 5.15.6.4). Octave band sound power levels shall be calculated using corrected values per AHRI 220.

5.15.6.4 End Reflection Correction. The sound power from a ducted terminal unit duct terminating flush with a reverberation room wall (inlet and outlet; see Figures 13, 14, 15, and 18) shall be calculated using Equation 23. The duct-end reflection correction ERC(n) shall be calculated using Equation 24. ERC$_{(n)}$ shall not exceed 14 dB in each one-third octave band.

$$L'_{w(n)} = L_{w(n)} + \mathrm{ERC}_{(n)} \tag{23}$$

where

$L'_{w(n)}$ = sound power level in the n^{th} one-third octave band adjusted for the acoustic test duct end correction, dB
$L_{w(n)}$ = measured sound power level in the n^{th} one-third octave band, dB
ERC$_{(n)}$ = end reflection correction for the n^{th} one-third octave band for a duct terminating flush with a wall, dB

$$\mathrm{ERC}_{(n)} = 10\log_{10}\left[1+\left(\frac{0.7c_o}{\pi f D_e}\right)^2\right] \tag{24}$$

where

c_o = speed of sound in air, e.g., 1135 ft/s (343 m/s)
f = one-third octave band center frequency (Section 3.1; Table 1), Hz
D_e = equivalent diameter of discharge duct, ft (m)

5.15.7 Report. Include the following:

a. Detailed description of test setup
b. Instrumentation
c. Test procedure
d. Test results (supply/exhaust air volume, inlet static pressure, fan air volume, discharge static pressure, and octave band sound power levels).

5.16 Fan Curve – No Primary Air

5.16.1 Test Purpose. This test is to evaluate the fan only performance of a fan-powered terminal unit across a specified envelope.

5.16.2 Test Setup

5.16.2.1 The air terminal to be tested shall be setup as shown in Figure 3.

5.16.2.2 Seal all transverse joints and longitudinal seams downstream of the terminal unit.

5.16.3 Test Procedure

5.16.3.1 The terminal unit primary damper/valve shall be fully closed.

5.16.3.2 The terminal unit fan shall be operated and tested at any desired operating points. Airflow and pressure shall be within ±5% of test values.

5.16.3.3 The following is a list of variables commonly used to define fan operating points:

- Speed – Typically high, medium, or low speed wiring on multi-tap motors.
- SCR voltage – For PSC motors with SCR speed controls (V).
- Signal – For EC motors that accept a speed control signal as a voltage (V) or duty cycle (%) setting.
- Discharge static pressure [in. of water (Pa)]

5.16.4 Test Data. Measure and record the following data after target variables have been reached.

5.16.4.1 Ambient air conditions in the test area: dry-bulb temperature (t_o), relative humidity (φ_o), and barometric pressure at the same elevation as the airflow measurement (p_{bo}).

5.16.4.2 Terminal unit downstream static pressure (p_{s8}).

5.16.4.3 Terminal unit outlet airflow [t_5, p_{s5}, $\Delta p_{s,5\text{-}6}$ (downstream airflow measuring means)].

5.16.4.4 Electric Current (A)

5.16.4.5 Voltage (V)

5.16.4.6 Power (W)

5.16.5 Calculations

5.16.5.1 Air Density. The air density (ρ_{act}) in the test area shall be calculated using Normative Appendix J.

5.16.5.2 Airflow. The volumetric airflow rate shall be calculated using Equations B-1 or B-2, whichever is applicable, and then Equation B-3.

5.16.5.3 Fan-Powered Efficiency. Calculate fan power per unit airflow (W/cfm [W/(L/s)]).

5.17 Fan Curve – Fan Plus Primary Air

5.17.1 Test Purpose. This test is to evaluate the fan plus primary air performance of a fan-powered terminal unit across a specified envelope.

5.17.2 Test Setup

5.17.2.1 The air terminal to be tested shall be setup as shown in Figure 3.

5.17.2.2 Seal all transverse joints and longitudinal seams downstream of the terminal unit.

5.17.3 Test Procedure

5.17.3.1 The terminal unit primary damper/valve shall be open and under control.

5.17.3.2 The terminal unit fan shall be operated and tested at any desired operating points. Airflow and pressure shall be within ±5% of test values.

5.17.3.3 The following is a list of variables commonly used to define fan operating points:

- Speed – Typically high, medium, or low speed wiring on multi-tap motors.
- SCR voltage – For PSC motors with SCR speed controls (V).
- Signal – For EC motors that accept a speed control signal as a voltage (V) or duty cycle (%) setting.
- Discharge static pressure [in. of water (Pa)]

5.17.4 Test Data. Measure and record the following data after target variables have been reached.

5.17.4.1 Ambient air conditions in the test area: dry-bulb temperature (t_o), relative humidity (φ_o), and barometric pressure at the same elevation as the airflow measurement (p_{bo}).

5.17.4.2 Terminal unit downstream static pressure (p_{s8}).

5.17.4.3 Terminal unit outlet airflow [t_5, p_{s5}, $\Delta p_{s,5\text{-}6}$ (downstream airflow measuring means)].

5.17.4.4 Terminal unit inlet static pressure (p_{s7}).

5.17.4.5 Terminal unit primary airflow [t_5, p_{s5}, $\Delta p_{s,5\text{-}6}$ (upstream airflow measuring means)].

5.17.4.6 Electric Current (A)

5.17.4.7 Voltage (V)

5.17.4.8 Power (W)

5.17.5 Calculations

5.17.5.1 Air Density. The air density (ρ_{act}) in the test area shall be calculated using Normative Appendix J.

5.17.5.2 Airflow. The volumetric airflow rate shall be calculated using Equations B-1 or B-2, whichever is applicable, and then Equation B-3.

5.17.5.3 Fan-Powered Efficiency. Calculate fan power per unit airflow (W/cfm [W/(L/s)]).

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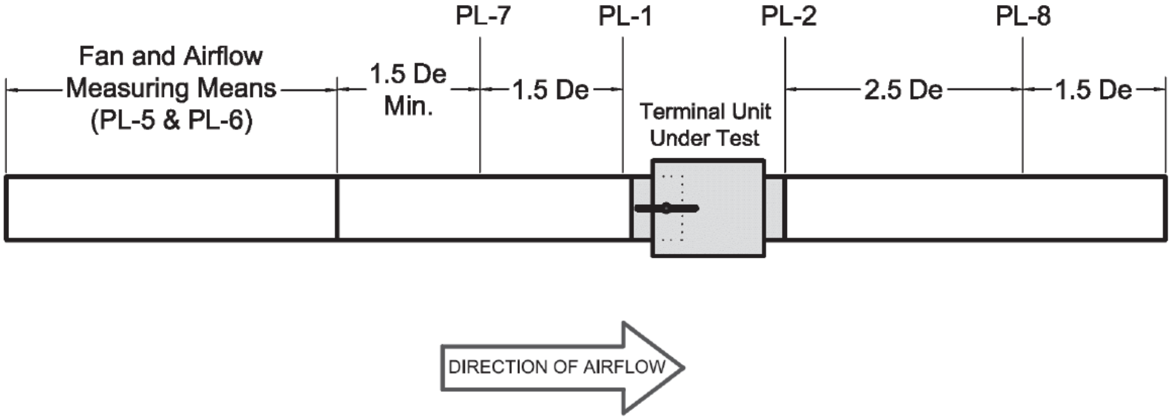

FIGURE 1 Test setup for the tests listed below.
1. Terminal-Unit Minimum Operating Pressure Differential and Loss Coefficient (Section 5.3) (single-duct [supply], dual-duct, induction, bypass, and parallel-flow fan-powered).
2. Mechanically Regulated Terminal-Unit Minimum Operating Pressure Differential (Section 5.4) (supply)
3. Pressure-Compensating Volume Controller Performance (Section 5.5) (single-duct, dual-duct)
4. Terminal -Unit Airflow Sensor Amplification Factor (Section 5.10)
5. Effect of the Control Damper Partially Closed on Airflow Sensor Performance (Appendix E)
6. Airflow Sensor Performance—Inlet Variations from Straight (Section 5.11)
7. Condensation Determination (Section 5.14) (non-fan-powered)

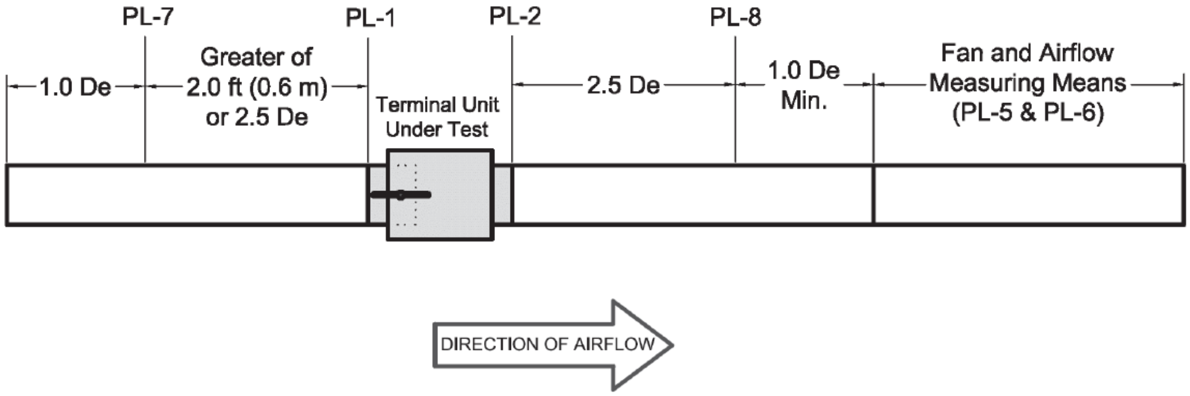

FIGURE 2 Test setup for the tests listed below.
1. Terminal-Unit Minimum Operating Pressure Differential and Loss Coefficient (Section 5.3) (return/exhaust single-duct)
2. Mechanically Regulated Terminal-Unit Minimum Operating Pressure Differential (Section 5.4) (exhaust)

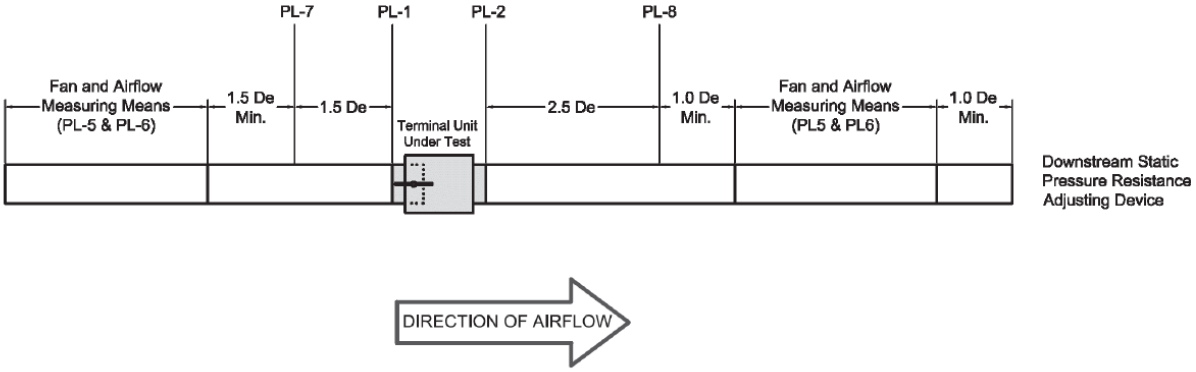

FIGURE 3 Test setup for the tests listed below.

1. Terminal-Unit Minimum Operating Pressure Differential and Loss Coefficient (Section 5.3) (series-flow fan-powered)
2. Pressure-Compensating Volume Controller Performance (Section 5.5) (induction, bypass, fan-powered)
3. Dynamic Leakage for Parallel-Flow Fan-Powered Terminal Units (Section 5.9)
4. Condensation Determination (Section 5.14) (fan-powered, parallel-flow)

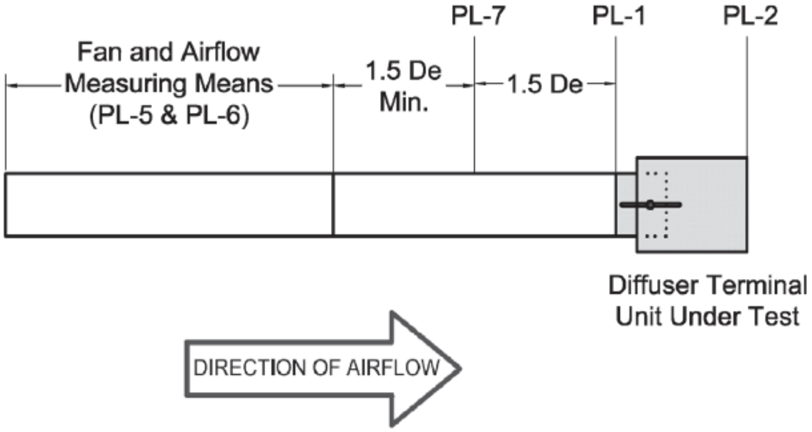

FIGURE 4 Test setup for modulating and integral diffuser terminals.

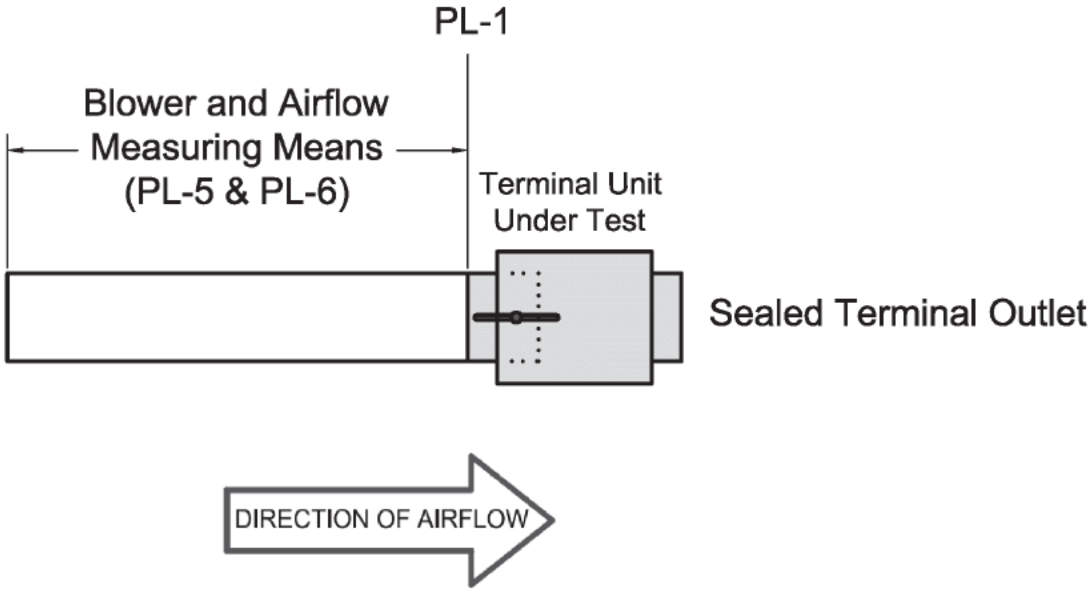

FIGURE 5 Test setup for supply terminal-unit casing leakage.

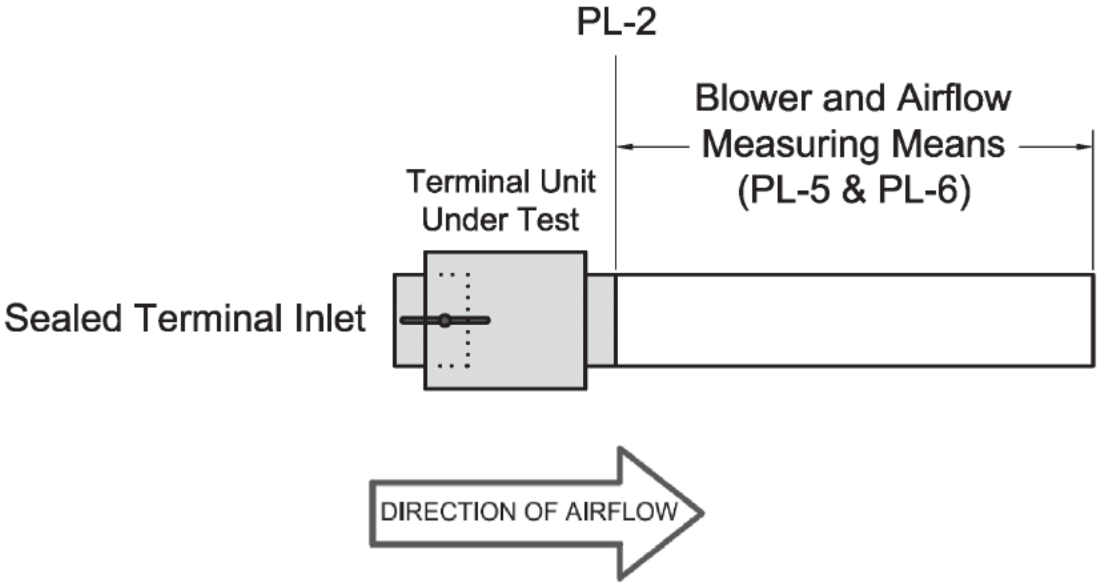

FIGURE 6 Test setup for return/exhaust terminal-unit casing leakage.

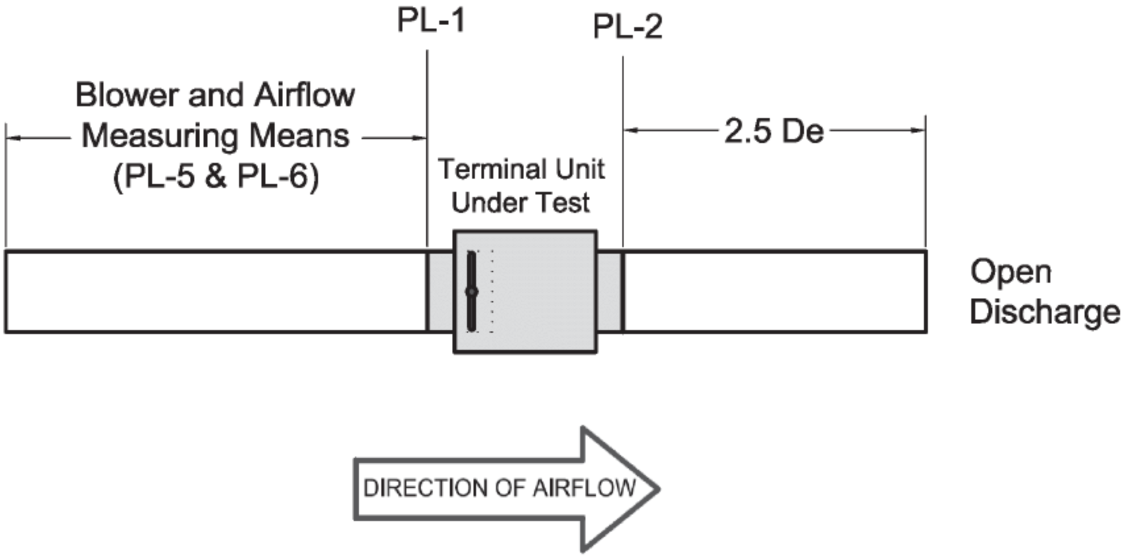

FIGURE 7 Test setup for supply terminal-unit damper/valve leakage.

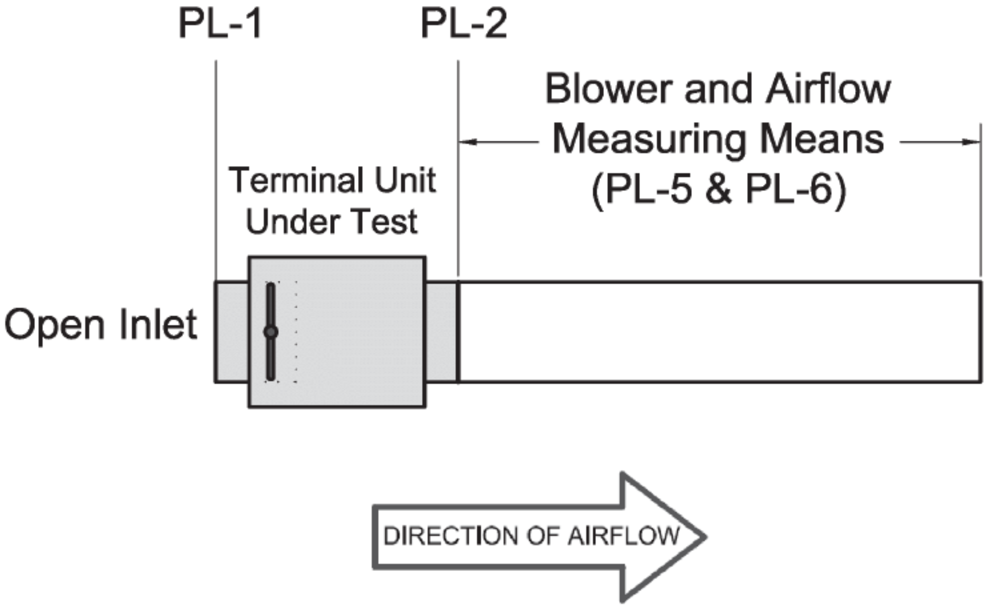

FIGURE 8 Test setup for exhaust terminal-unit total leakage.

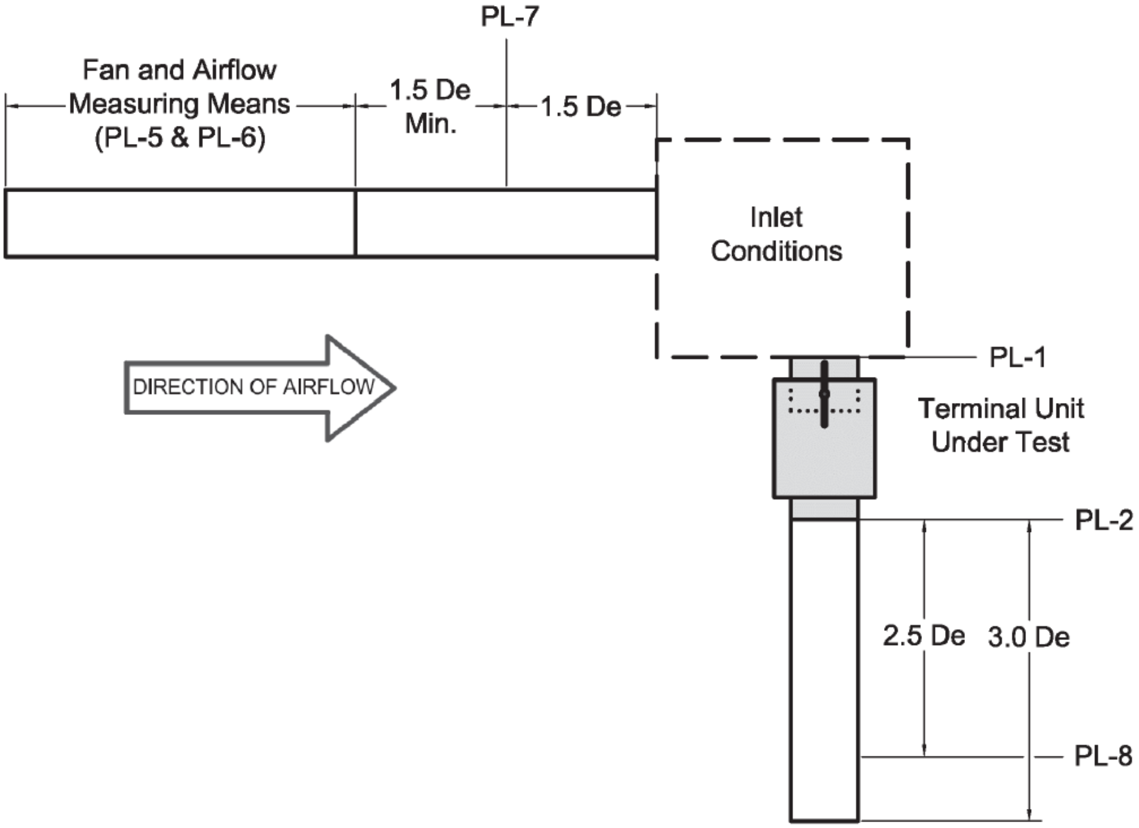

FIGURE 9 Test setup to evaluate non-straight inlet airflow sensor performance.

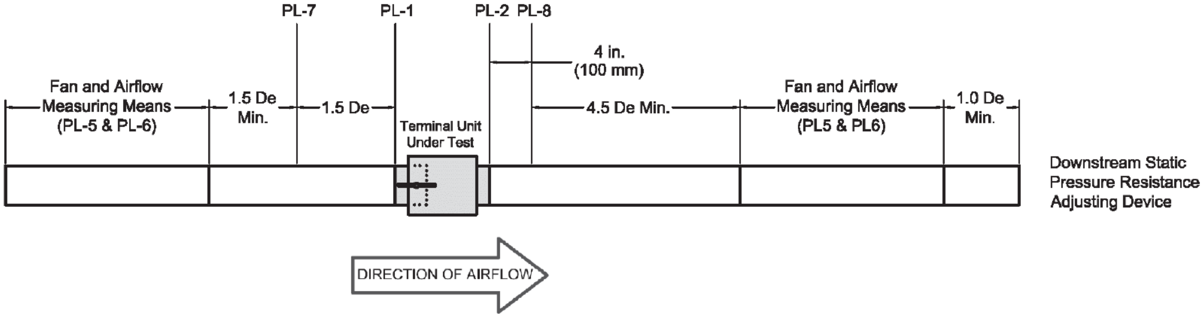

FIGURE 10 Test setup for temperature mixing (induction and fan-powered terminal units) and stratification (fan-powered, induction, and bypass terminal units).

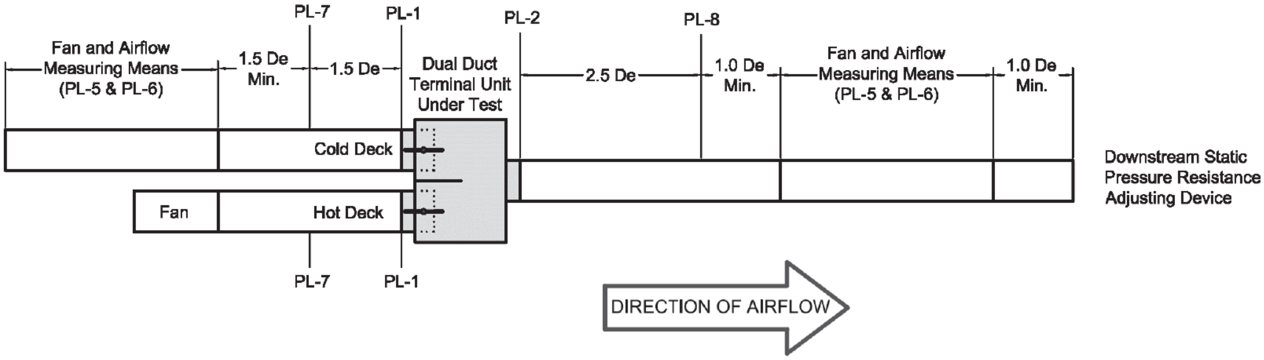

FIGURE 11 Test setup for temperature mixing—dual-duct terminal unit.

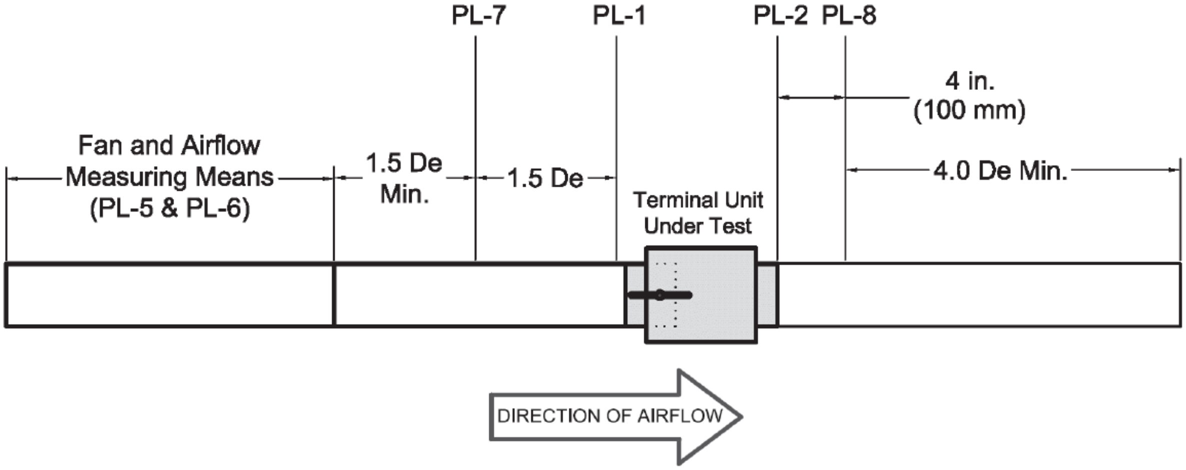

FIGURE 12 Test setup for temperature stratification—single-duct terminal units.

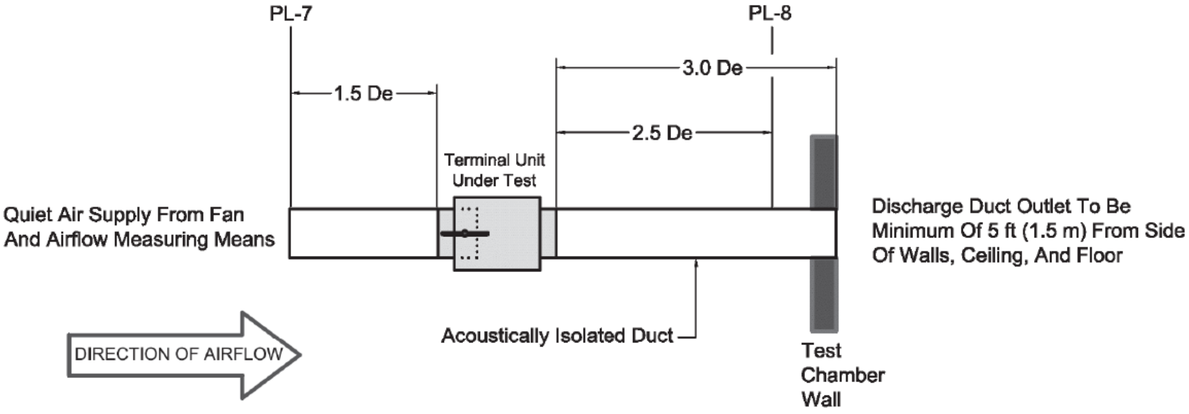

FIGURE 13 Discharge sound test setup for single-duct, dual-duct, series-flow fan-powered, and mechanically regulated terminal units with discharge duct.

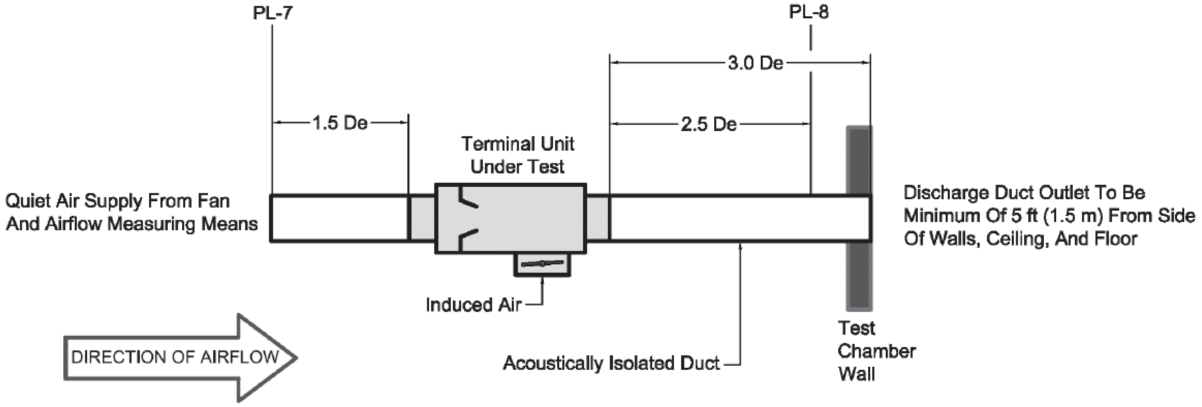

FIGURE 14 Discharge sound test setup for induction and parallel-flow fan-powered terminal units with discharge duct.

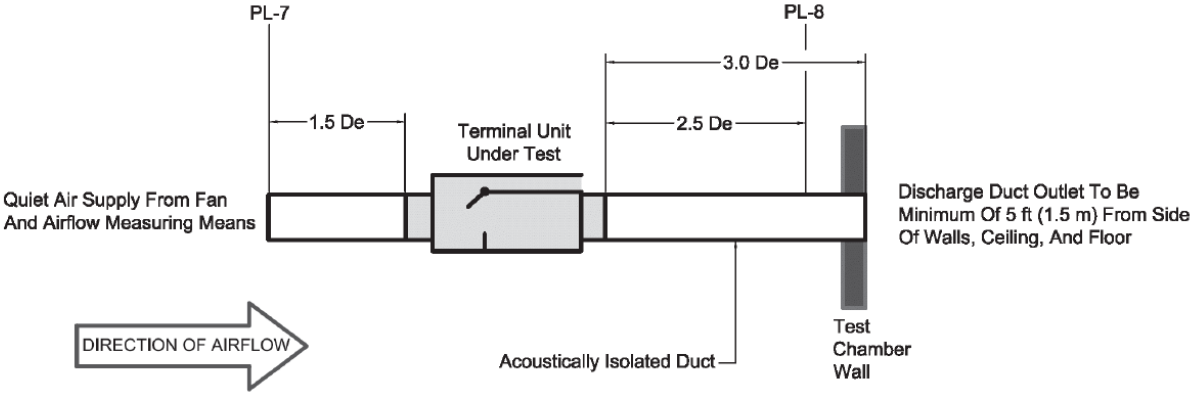

FIGURE 15 Discharge sound test setup for the bypass terminal unit with discharge duct.

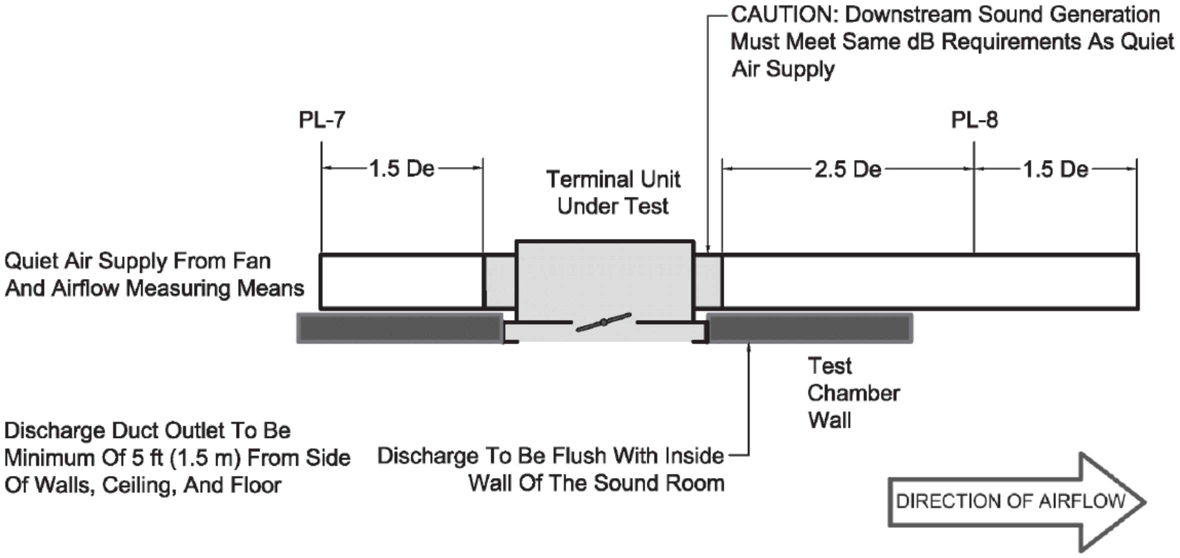

FIGURE 16 Discharge sound test setup for the integral diffuser (side wall) air terminal unit.

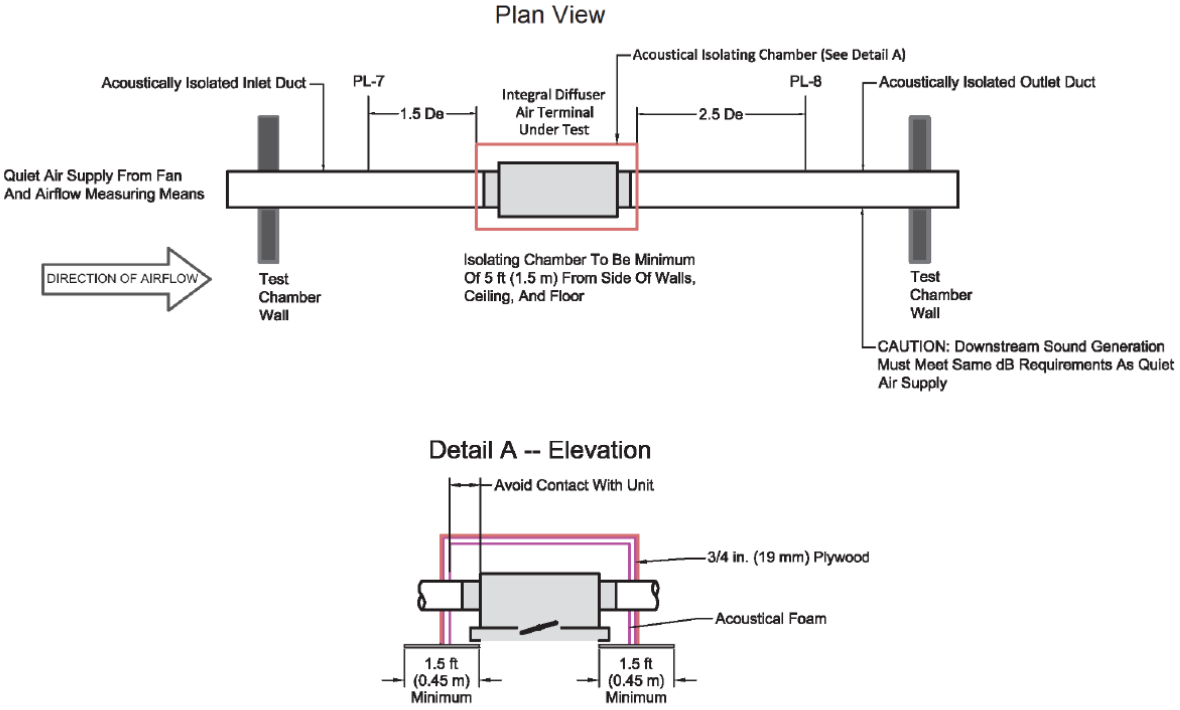

FIGURE 17 Discharge sound test setup for the integral diffuser (ceiling) air terminal unit.

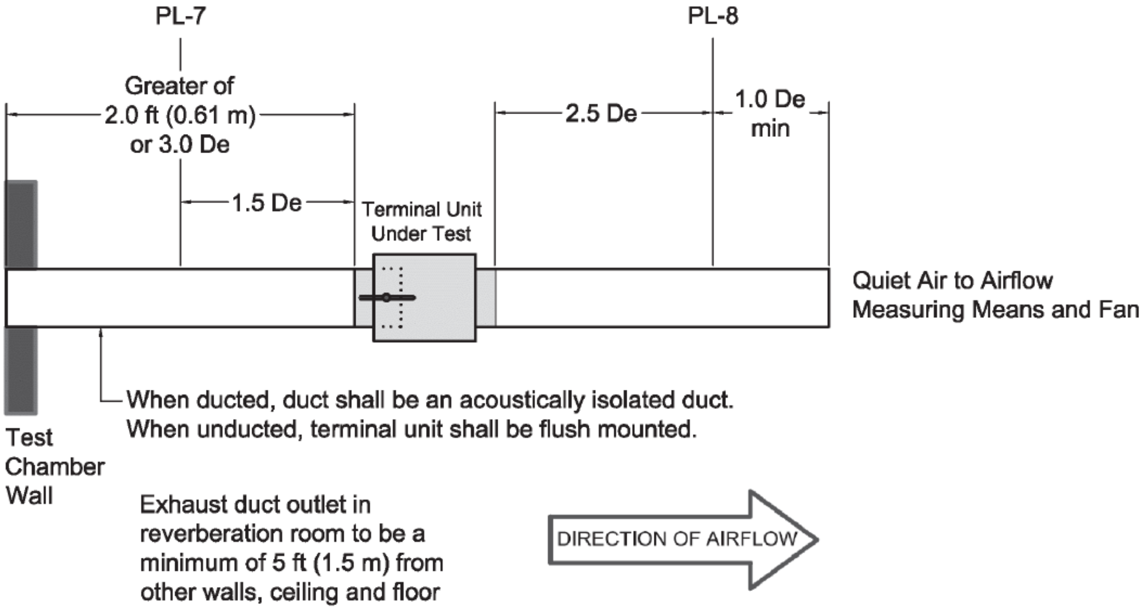

FIGURE 18 Exhaust sound test setup for the exhaust terminal unit.

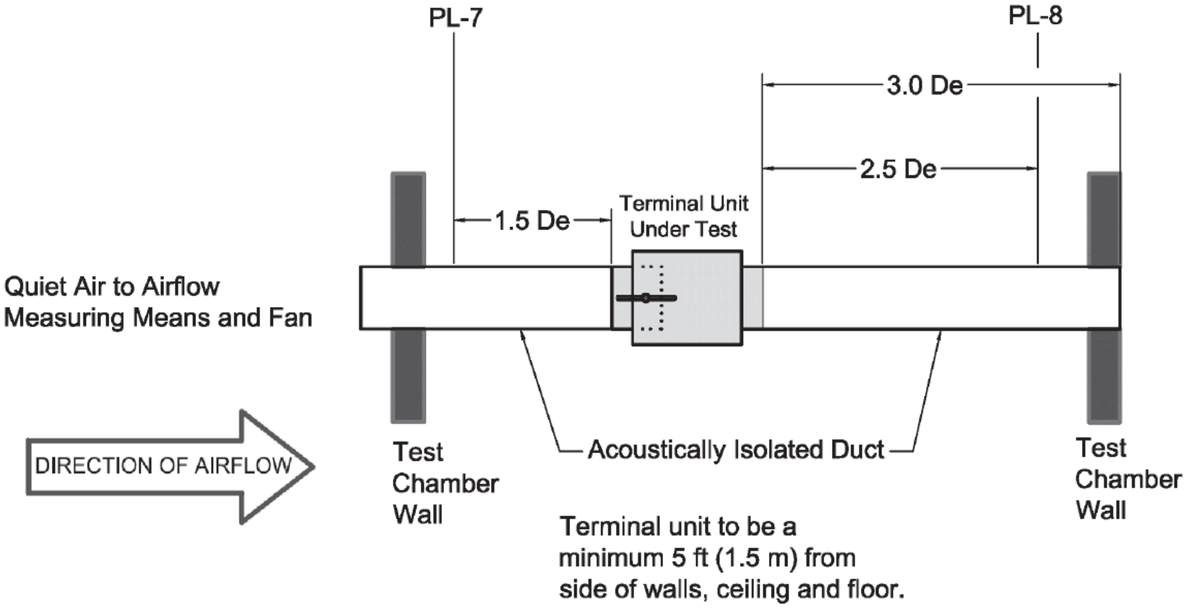

FIGURE 19 Single-duct, dual-duct, and series-flow fan-powered terminal-unit test setup for casing radiated noise.

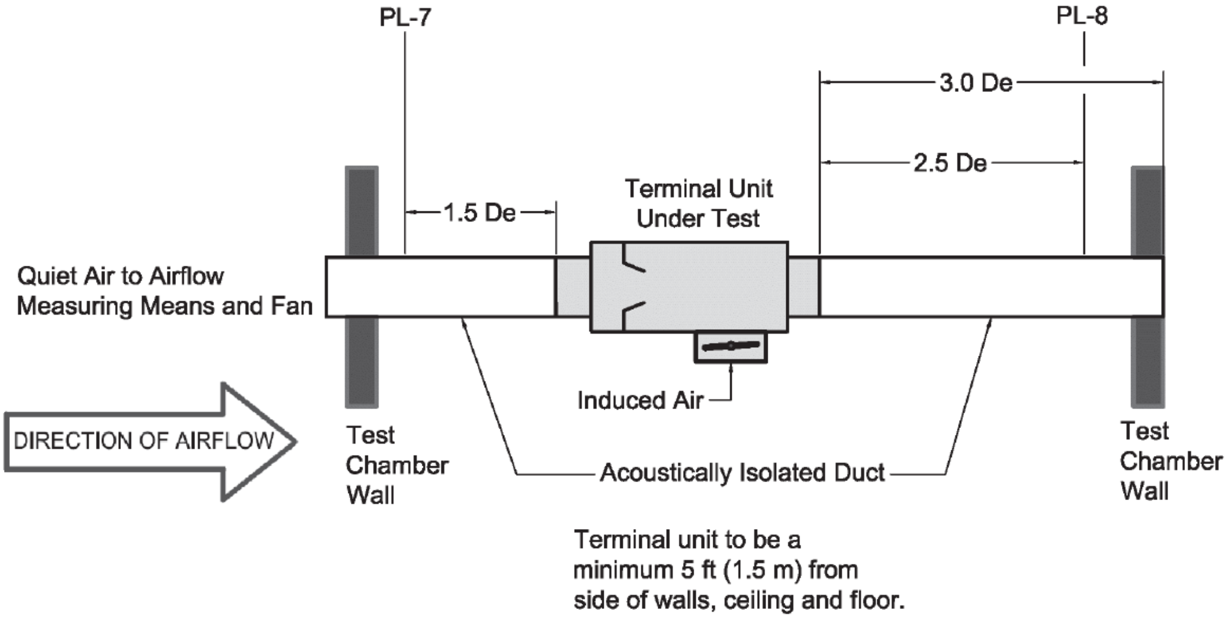

FIGURE 20 Test setup for radiated sound test for induction and parallel-flow fan-powered terminal units.

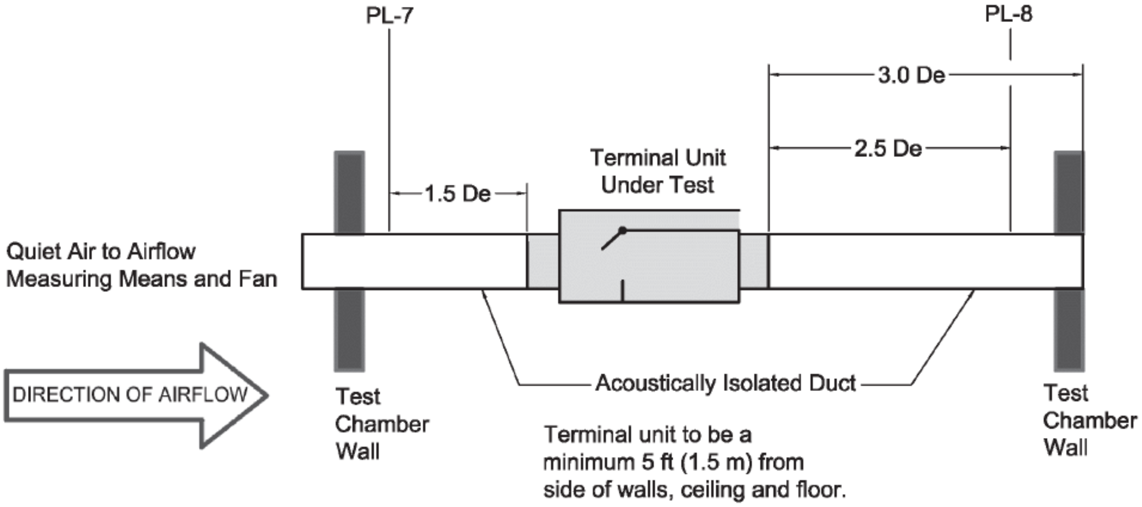

FIGURE 21 Radiated sound test setup for the bypass terminal unit.

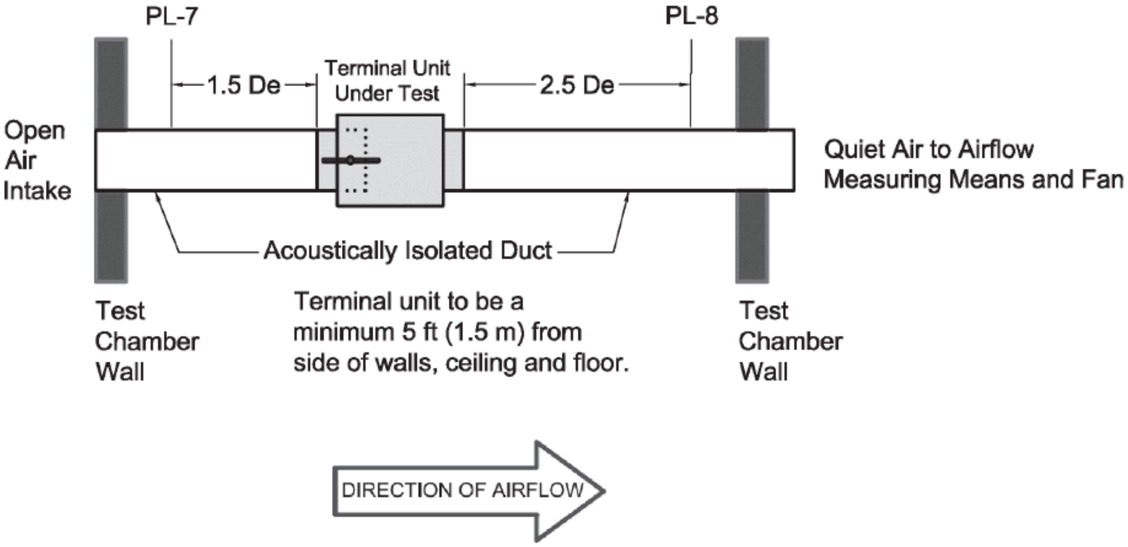

FIGURE 22 Exhaust radiated sound test setup with terminal unit exceeding 5 ft (1.5 m) from wall.

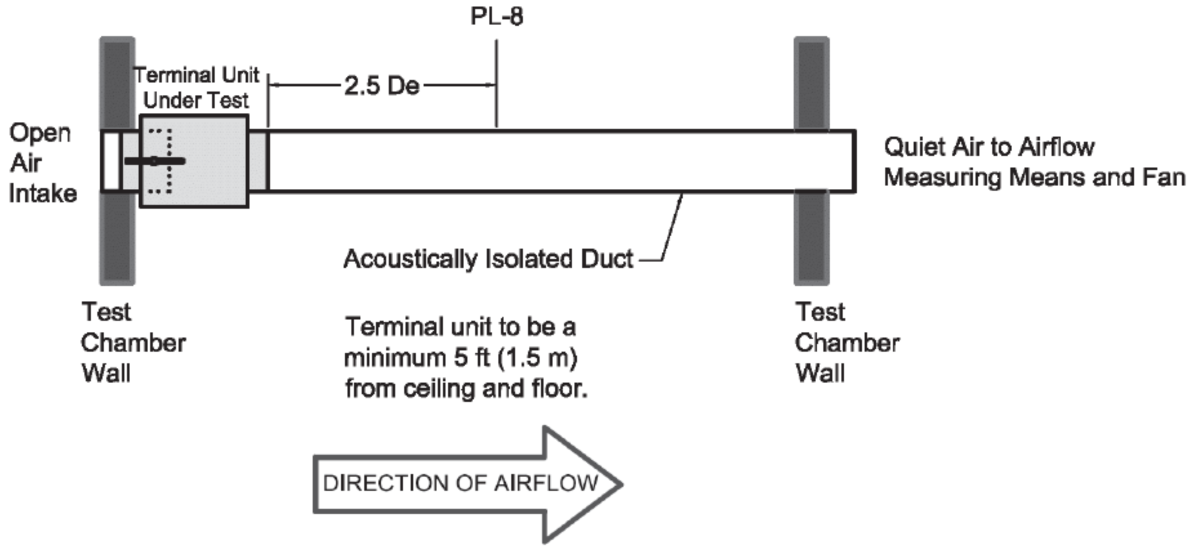

FIGURE 23 Exhaust radiated sound test setup with terminal unit adjacent to wall.

(This is a normative appendix and is part of the standard.)

NORMATIVE APPENDIX A
ROTATING VANE ANEMOMETER FLOW MEASURING SYSTEM

A1. GENERAL

The rotating vane anemometer flow measuring system consists of a straight length of duct with a rotating vane anemometer, humidity measuring instrument, and a temperature probe (see Figure A-1). Optionally, a backpressure regulating device can be installed at the discharge of the flow station. Following is a list of components for a rotating vane anemometer flow measuring system. Not shown is an atmospheric pressure transducer.

a. Item 1: rotating vane anemometer
b. Item 2: flow straightener consisting of at least a grid of 0.5 in. (13 mm) squares deeper than two times the grid size
c. Item 3: static pressure probe
d. Item 4: humidity sensor
e. Item 5: temperature probe

When constructing the rotating vane anemometer flowmeter, locate the rotating vane anemometer within 0.16 equivalent diameters of the center of the duct.

A2. CALIBRATION PROCEDURE

A2.1 The most convenient and accurate method to calibrate a ducted rotating vane anemometer system is using a flow standard such as a NIST-traceable flowmeter. Components of the meter calibration apparatus (see Figure A-2) are:

a. Item 1: NIST traceable flowmeter (venturi shown)
b. Item 2: temperature probe
c. Item 3: transition
d. Item 4: humidity sensor
e. Item 5: temperature probe
f. Item 6: rotating vane anemometer
g. Item 7: static pressure probe
h. Item 8: flow straightener

A2.2 The rotating vane anemometer flow station must be constructed to minimize the potential for leakage. The flowmeter and calibrating airflow meter shall be concentric, straight, and level.

A2.3 The rotating vane anemometer measuring system must be calibrated over its entire range of use.

A2.4 The goal of the calibration is to create an empirical mathematic equation that relates frequency output from the rotating vane anemometer to flow rate. The rotating vane anemometer typically will have a fixed flow range. Several flowmeters may be needed to cover the entire range for flows of interest.

a. Start with the smallest flowmeter and calibrate through its range. Gradually increase and then decrease the flow rate from the lowest practical value for that size flowmeter to the highest practical value in small steps, recording the flow rate and frequency every few seconds.

b. Repeat with the next-size larger flowmeters until the entire flow range of interest is covered. Make sure that the range of each flowmeter overlaps the range of adjacent sizes.
c. Determine the empirical relationship between flow and frequency.

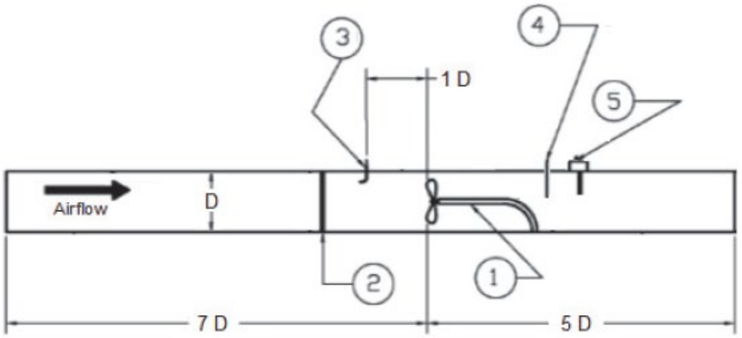

FIGURE A-1 Rotating vane anemometer flow-measuring system.

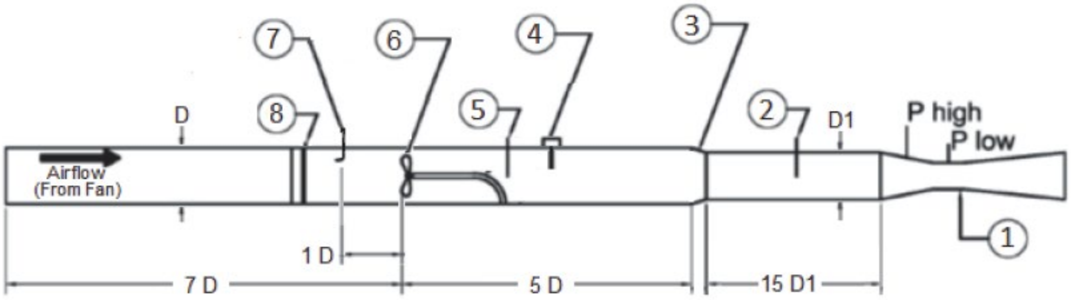

FIGURE A-2 Rotating vane anemometer flowmeter calibration apparatus.

(This is a normative appendix and is part of the standard.)

NORMATIVE APPENDIX B
AIRFLOW AND AIR VELOCITY EQUATIONS

B1. MASS FLOW RATE

B1.1 Ducted Nozzle. For symbols supporting Equation B-1, consult Standard 120[1].

$$\dot{m}_5 = 1.414 C_n A_n \frac{Y_n}{\sqrt{1-\beta^4}} \sqrt{\rho_5 \Delta p_{s,5-6}} \qquad \text{(B-1 SI)}$$

B1.2 Chamber Nozzles. For symbols supporting Equation B-2, consult Standard 120[1].

$$\dot{m}_5 = 1.414 Y_n \sqrt{\rho_5 \Delta p_{s,5-6}} \sum_{n=1}^{N} \left(C_n A_n \right) \qquad \text{(B-2 SI)}$$

where N = number of nozzles.

Informative Note: For a single nozzle, Equation B-2 is the same as Equation B-1, with $\beta = 0$.

B2. VOLUMETRIC AIRFLOW RATE

$$Q_5 = \frac{60 \dot{m}_5}{\rho_5} \qquad \text{(B-3 I-P)}$$

$$Q_5 = \frac{1000 \dot{m}_5}{\rho_5} \qquad \text{(B-3 SI)}$$

B3. VELOCITY

$$V = Q/A \qquad \text{(B-4)}$$

B4. VELOCITY PRESSURE

$$p_v = \rho \left(\frac{V}{1097} \right)^2 \qquad \text{(B-5 I-P)}$$

$$p_v = \rho \left(\frac{V^2}{2} \right) \qquad \text{(B-5 SI)}$$

(This appendix is not part of this standard. It is merely informative and does not contain requirements necessary for conformance to the standard. It has not been processed according to the ANSI requirements for a standard and may contain material that has not been subject to public review or a consensus process. Unresolved objectors on informative material are not offered the right to appeal at ASHRAE or ANSI.)

INFORMATIVE APPENDIX C
EXAMPLE - TERMINAL UNIT LOSS COEFFICIENT CALCULATIONS

This appendix provides two examples regarding terminal unit loss coefficient ($C_{loss,1}$) calculations for a single-duct terminal unit with the following dimensions:

a. Circular inlet: 10 in. (254 mm) diameter; Area = 0.55 ft^2 (0.051 m^2).
b. Rectangular outlet: 12.5 in. (318 mm) high, 14 in. (356 mm) wide; Area = 1.22 ft^2 (0.113 m^2).

The first example describes how to calculate the total pressure loss for a terminal unit, using a known total pressure loss coefficient.

The second example describes how to determine the loss coefficient itself. The test was conducted in compliance with Section 5.2 and Figure 1. The fan and flow measuring means (chamber nozzles) are in compliance with ASHRAE Standard 41.2[2], and also with ASHRAE Standard 120[1], Figure 8.

In this second case, Tables C-1 through C-4 show the measured test data and calculated results used to determine the loss coefficient. The equations used for the calculations are noted in the tables and correspond to those for ducted nozzles (for illustrative purposes), but the results are essentially the same as what would be calculated using chamber nozzle equations, because the nozzle β ratios are nearly zero.

Figures C-1 and C-2 show the fitted loss coefficient, which is referenced to the terminal unit inlet plane (Plane 1), based on linear regression of the $\Delta p_{t,1\text{–}2}$ vs. p_{v1} test results.

Example 1 - Known Total Pressure Loss Coefficient

Determine the total pressure loss for the terminal unit listed above, located in Atlanta and Denver at rated airflow (1400 cfm [661 L/s]). The air density (ρ_{act}) for Atlanta and Denver is 0.071 lb$_m$/ft^3 (1.137 kg/m^3) and 0.061 lb$_m$/ft^3 (0.977 kg/m^3), respectively. The total pressure loss coefficient for the 10 in. (254 mm) terminal unit is 0.38.

Using Equation B-3, the average inlet velocity corresponding to the rated airflow is:

$$V_1 = Q / A = 1400 / 0.55 = 2567 \text{ ft/min (I-P)}$$

$$V_1 = Q / A = (661/1000) / 0.051 = 13.0 \text{ m/s (SI)}$$

The corresponding total pressure loss is:

Atlanta

$$\Delta p_t = C_{loss,1}\rho_{act}\left(\frac{V_1}{1097}\right)^2 = 0.38(0.071)\left(\frac{2567}{1097}\right)^2 = 0.15 \text{ in. of water (I-P)}$$

$$\Delta p_t = C_{loss,1}\rho_{act}\left(\frac{V_1^2}{2}\right) = 0.38(1.137)\left(\frac{13.0^2}{2}\right) = 37 \text{ Pa (SI)}$$

Denver

$$\Delta p_t = C_{loss,1}\rho_{act}\left(\frac{V_1}{1097}\right)^2 = 0.38(0.061)\left(\frac{2567}{1097}\right)^2 = 0.13 \text{ in. of water (I-P)}$$

$$\Delta p_t = C_{loss,1}\rho_{act}\left(\frac{V_1^2}{2}\right) = 0.38(0.977)\left(\frac{13.0^2}{2}\right) = 32 \text{ Pa (SI)}$$

Example 2 - Determining Total Pressure Loss Coefficient

TABLE C-1 Test Conditions (Atlanta)

	Data (I-P)	**Data (SI)**
Barometric pressure (p_{bo})	14.34 psi (29.27 in. Hg)	98.85 kPa
Ambient dry-bulb temperature (t_o)	78.1°F	25.6°C
Ambient relative humidity (φ_o)	59.4%	59.4%
Ambient air density ($\rho_{act,o}$), determined using Appendix J	0.071 lb_m/ft^3	1.144 kg/m^3

TABLE C-2 Test Data (at test conditions listed in Table C-1)

Test Point	**Data**			**Equation 5, ASHRAE Standard 120**[1]	**Appendix J**	
	t_7 °F (°C)	**p_{s7} in. of water (Pa)**	**$\Delta p_{s,7\text{-}8}$ in. of water (Pa)**	**μ_7 Pa s**	**$p_{ws,7}$ psi (Pa)**	**ρ_7 lbm/ft^3 (kg/m^3)**
1	79.0 (26.1)	-0.05 (-12)	-0.049 (-12.2)	1.848E-05	0.4910 (3,385)	0.071 (1.142)
2	80.2 (26.8)	-0.08 (-20)	-0.078 (-19.4)	1.852E-05	0.5107 (3,521)	0.071 (1.139)
3	80.6 (27.0)	-0.11 (-27)	-0.109 (-27.1)	1.853E-05	0.5174 (3,567)	0.071 (1.138)
4	80.4 (26.9)	-0.15 (-37)	-0.149 (-37.1)	1.852E-05	0.5140 (3,544)	0.071 (1.138)
5	80.6 (27.0)	-0.20 (-50)	-0.197 (-49.0)	1.853E-05	0.5174 (3,567)	0.071 (1.137)
6	80.8 (27.1)	-0.26 (-65)	-0.255 (-63.5)	1.853E-05	0.5208 (3,591)	0.071 (1.137)

t = temperature
p_s = static pressure
μ = air viscosity
p_{ws} = air saturation pressure
ρ = air density

TABLE C-3 Test Data and Resulting Mass Flow with Chamber Nozzle

					Refer to ASHRAE Standard 120[1] for the following equations.					
					Equation					
	Nozzle Throat Diameter	Nozzle Throat Area	Nozzle Pressure Data		6	7	8	12^+	13	Equation B-1
Test Point	d_5 in. (mm)	A_n ft^2 (m^2)	p_{s5} Pa	$\Delta p_{s,5\text{–}6}$ Pa	α	β	Y_n	Re_d	C_n	$\dot{m}_5$ lb_m/s (kg/s)
1	6 (152)	0.1963 (0.0182)	274	237	0.9976	0.0556	0.9987	178,001	0.9810	0.9178 (0.4163)
2	6 (152)	0.1963 (0.0182)	429	372	0.9963	0.0556	0.9980	222,901	0.9827	1.1504 (0.5218)
3	6 (152)	0.1963 (0.0182)	619	533	0.9946	0.0556	0.9971	266,956	0.9839	1.3783 (0.6252)
4	8 (203)	0.3491 (0.0324)	332	230	0.9977	0.0741	0.9988	233,527	0.9830	1.6088 (0.7297)
5	8 (203)	0.3491 (0.0324)	431	298	0.9970	0.0741	0.9984	265,894	0.9838	1.8327 (0.8313)
6	8 (203)	0.3491 (0.0324)	547	379	0.9962	0.0741	0.9980	299,974	0.9846	2.0682 (0.9381)

α = ratio of absolute nozzle exit (throat) pressure to absolute approach pressure, dimensionless.
β = ratio of nozzle exit diameter d_5 to approach diameter D_5 (108 in., 2.74 m), dimensionless.
Y_n = nozzle expansion factor, dimensionless.
Re_d = Reynolds number, dimensionless.
C_n = nozzle discharge coefficient, dimensionless.

+: Equation 12 from Standard 120[1] is an approximation for purposes of illustration here. Using the more complicated iterative procedure in Standard 120[1] to solve for the Re_d number that corresponds to C_n makes no significant difference for this example.

TABLE C-4 Results

	Appendix J			Equation B-3	Equation B-4		Equation B-5		Equation 7	Equation 4
Test Point	ρ_5 lb_m/ft^3 (kg/m^3)	ρ_1^* lb_m/ft^3 (kg/m^3)	ρ_2^{**} lb_m/ft^3 (kg/m^3)	Q_1 cfm (L/s)	V_1 fpm (m/s)	V_2^{***} fpm (m/s)	p_{v1} in. of water (Pa)	p_{v2} in. of water (Pa)	$\Delta p_{t,1\text{-}2}$ in. of water (Pa)	Loss Coefficient $C_{loss,1}$
1	0.071 (1.145)	0.071 (1.142)	0.071 (1.142)	770 (364)	1412 (7.2)	634 (3.2)	0.118 (29.4)	0.024 (5.9)	0.045 (11.3)	0.38 (0.38)
2	0.071 (1.144)	0.071 (1.139)	0.071 (1.139)	967 (456)	1772 (9.0)	795 (4.0)	0.186 (46.1)	0.037 (9.3)	0.070 (17.4)	0.38 (0.38)
3	0.071 (1.145)	0.071 (1.138)	0.071 (1.137)	1157 (546)	2121 (10.8)	952 (4.8)	0.265 (66.0)	0.053 (13.3)	0.103 (25.6)	0.39 (0.39)
4	0.071 (1.142)	0.071 (1.138)	0.071 (1.138)	1354 (639)	2482 (12.6)	1114 (5.7)	0.364 (90.4)	0.073 (18.2)	0.141 (35.2)	0.39 (0.39)
5	0.071 (1.143)	0.071 (1.137)	0.071 (1.137)	1541 (727)	2825 (14.4)	1268 (6.4)	0.471 (117.2)	0.095 (23.6)	0.179 (44.6)	0.38 (0.38)
6	0.071 (1.144)	0.071 (1.137)	0.071 (1.136)	1738 (820)	3186 (16.2)	1430 (7.3)	0.599 (148.9)	0.121 (30.0)	0.223 (55.5)	0.37 (0.37)

* Assumes $p_{s1} = p_{s7}$.
** Assumes $p_{s2} = p_{s8}$, such that $p_{s2} = p_{s7} + \Delta p_{s,7\text{-}8}$.
*** Assumes $Q_2 = Q_1$.

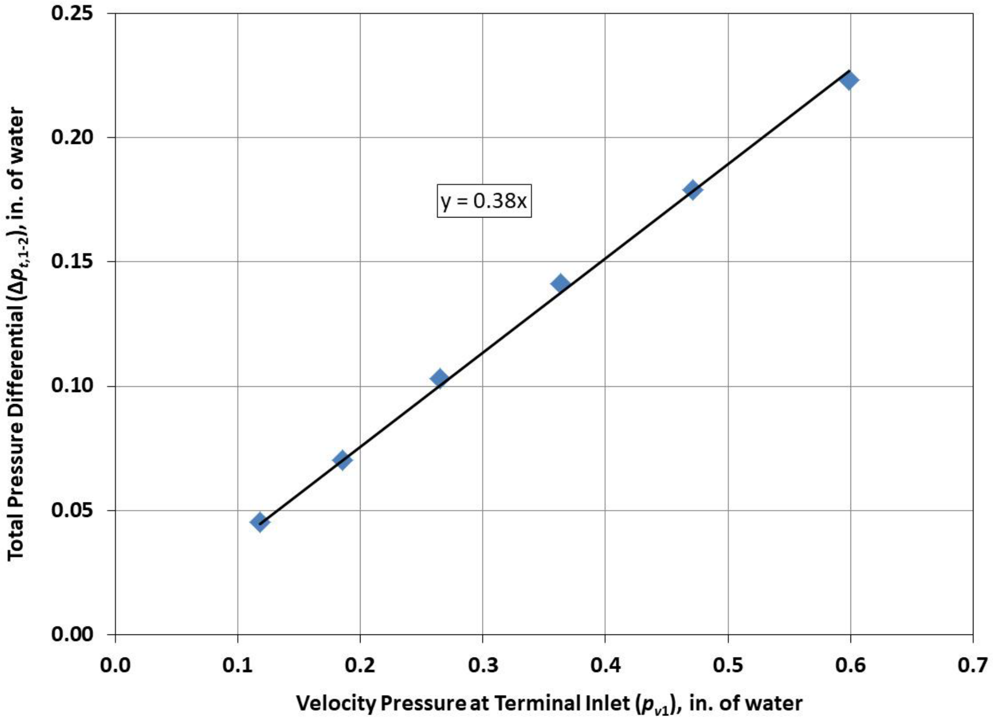

FIGURE C-1 10 in. single-duct terminal unit.

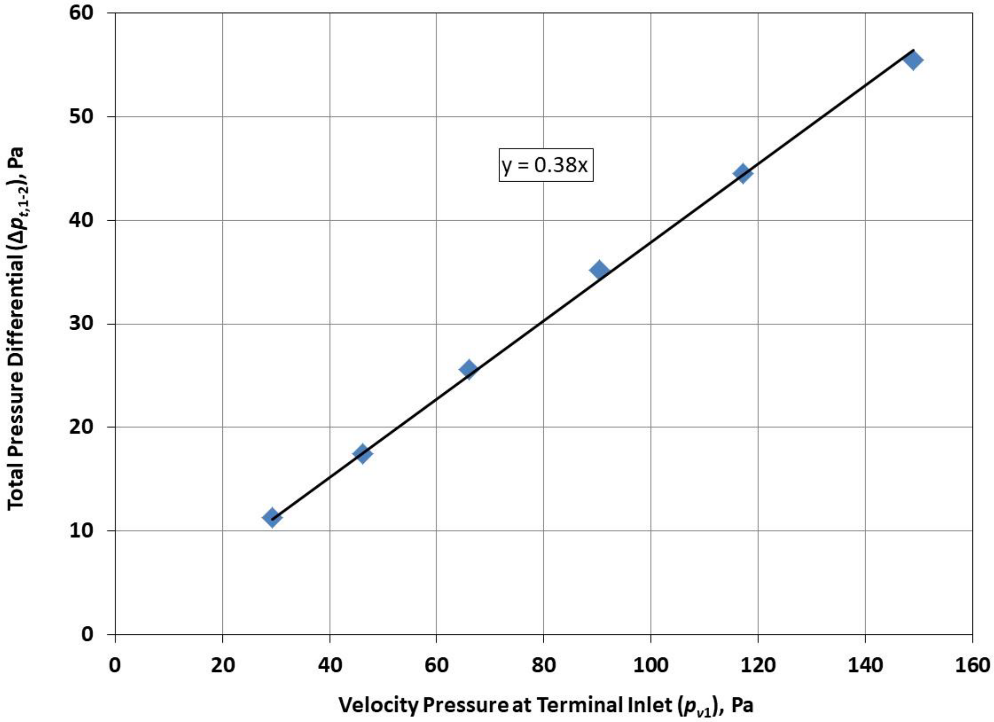

FIGURE C-2 254 mm single-duct terminal unit.

(This appendix is not part of this standard. It is merely informative and does not contain requirements necessary for conformance to the standard. It has not been processed according to the ANSI requirements for a standard and may contain material that has not been subject to public review or a consensus process. Unresolved objectors on informative material are not offered the right to appeal at ASHRAE or ANSI.)

INFORMATIVE APPENDIX D
EXAMPLE – SUPPLY TERMINAL UNIT LEAKAGE TEST

D.1. Example Actual Airflow Calculation. As a specific example, consider the case where the airflow entering a supply terminal unit that was determined using an orifice plate type of device ($Q_{meas,i}$) is 8.6 L/s (18.2 cfm). The measurement device calibration air density (ρ_{calib}) is 1.204 kg/m^3 (0.075 lb$_m$/ft^3), which is the same as standard air density (ρ_{std}).

At the same elevation as the device under test, the barometric pressure is 98,100 Pa (14.228 psi). At the airflow measurement device inlet plane, the static pressure is the same as the barometric, the measured air dry-bulb temperature is 25.0ºC (77.0ºF), and the relative humidity is 50%. At the airflow measurement device outlet plane and inside the device under test, with the measured flow at $Q_{meas,i}$, the static pressure above the barometric pressure is 42.4 Pa (0.170 in. of water).

It is assumed in this example that all instruments have been calibrated or adjusted such that the readings represent the true values (i.e., there are no further bias errors that need to be accounted for in subsequent calculations).

Converting the measured air temperature to absolute temperature:

$$T_x = 25.0 + 273.15 = 298.15\text{ K} \qquad \text{(D-1 SI)}$$

$$T_x = 77.0 + 459.67 = 536.67^{\circ}\text{R} \qquad \text{(D-1 IP)}$$

The actual air density $\rho_{act,i}$ depends in part on the saturation pressure ($p_{ws,in} = p_{ws,out,i}$), which is calculated using Equation J-3:

$$p_{ws,x} = e^{(C_1/T_x + C_2 + C_3 T_x + C_4 T_x^2 + C_5 T_x^3 + C_6 \ln T_x)}$$

$$p_{ws,x} = e^{[(-5.8002206E+03)/(298.15) + (1.3914993) - (4.8640239E-02)(298.15) + (4.1764768E-05)(298.15^2) - (1.4452093E-08)(298.15^3) + (6.5459673)(\ln(298.15))]} = 3{,}169\text{ Pa} \qquad \text{(D-2 SI)}$$

$$p_{ws,x} = e^{[(-1.0440397E+04)/(536.67) - (11.29465) - (2.7022355E-02)(536.67) + (1.289036E-05)(536.67^2) - (2.4780681E-09)(536.67^3) + (6.5459673)(\ln(536.67))]} = 0.4597\text{ psi} \qquad \text{(D-2 IP)}$$

Using Equation J-2 from Normative Appendix J, the saturation pressure from Equation D-2, and setting $\Delta p_{s,x}$ to zero, the actual air density $\rho_{act,i}$ at the airflow measurement device inlet plane is:

$$\rho_{act,i} = \frac{p_b + \Delta p_{s,x} - 0.378\,(\varphi_x/100)\,p_{ws,x}}{R_{da}\,T_x} \qquad \text{(J-2 SI)}$$

$$\rho_{act,i} = \frac{98{,}100 + 0 - 0.378\ (50/100)(3{,}169)}{(287.042)(298.15)} = 1.139\ \text{kg/m}^3 \qquad \text{(D-3 SI)}$$

$$\rho_{act,i} = \frac{144\left[p_b + 0.036\ \Delta p_{s,x} - 0.378\ (\varphi_x/100)\ p_{ws,x}\right]}{R_{da}\ T_x} \qquad \text{(J-2 IP)}$$

$$\rho_{act,i} = \frac{144\left[14.228 + (0.036)(0) - 0.378\ (50/100)(0.4597)\right]}{(53.350)(536.67)} = 0.0711\ \text{lb}_\text{m}/\text{ft}^3 \qquad \text{(D-3 IP)}$$

The “measured” airflow $Q_{meas,i}$ can now be converted to actual leakage airflow at test conditions $Q_{act,i}$. Using Equation 11 in Section 5.5.5.2:

$$Q_{act,i} = Q_{meas,i}\sqrt{\frac{\rho_{calib}}{\rho_{act,i}}} \qquad (11)$$

$$Q_{act,i} = 8.6\sqrt{\frac{1.204}{1.139}} = 8.8\ \text{L/s} \qquad \text{(D-4 SI)}$$

$$Q_{act,i} = 18.2\sqrt{\frac{0.075}{0.0711}} = 18.7\ \text{cfm} \qquad \text{(D-4 IP)}$$

D.2 Example Leakage Parameters Calculation

Consider the example dataset in Table D-1 from pressurization testing a parallel-flow fan-powered supply terminal unit with the unit’s outlet sealed and the backdraft damper “closed” but *unsealed*. In this example, the five “measured” airflows have already been corrected to actual conditions.

Table D-1 (all flows at actual conditions)

	$\Delta p_{s,i}$		$Q_{act,i}$	
i	**(in. of water)**	**(Pa)**	**(cfm)**	**(L/s)**
1	0.049	12.2	8.3	3.9
2	0.070	17.5	10.4	4.9
3	0.099	24.7	13.1	6.2
4	0.120	29.9	14.8	7.0
5	0.170	42.4	18.7	8.8

Using the data from Table D-1, the terms in Equations M-1 through M-3 in Normative Appendix M, using IP units only (with $Q_i = Q_{act,i}$) for simplicity of expression, are:

Table D-2

i	Q_i^2	$Q_i^2\left(\ln\lvert\Delta p_i\rvert\right)$	$Q_i^2\left(\ln\lvert\Delta p_i\rvert\right)^2$	$Q_i^2\left(\ln Q_i\right)$	$Q_i^2\left(\ln Q_i\right)^2$	$Q_i^2\left(\ln\lvert\Delta p_i\rvert\right)\left(\ln Q_i\right)$
1	68.36	-206.15	621.61	144.42	305.07	-435.47
2	109.08	-289.57	768.69	255.91	600.37	-679.34
3	170.44	-393.71	909.48	437.89	1125.02	-1011.53
4	218.92	-463.88	982.94	589.84	1589.25	-1249.85
5	350.16	-619.66	1096.59	1025.68	3004.40	-1815.10
SUM	916.96	-1972.97	4379.30	2453.73	6624.11	-5191.28

Thus, using Equations M-1 through M-5 from Normative Appendix M:

$$S_{xx} = \left(\sum_{i=1}^{N} Q_i^2\right)\left(\sum_{i=1}^{N} Q_i^2 \left(\ln\left|\Delta p_{s,i}\right|\right)^2\right) - \left(\sum_{i=1}^{N} Q_i^2 \ln\left|\Delta p_{s,i}\right|\right)^2 \tag{M-1}$$

$$S_{xx} = (916.96)\ (4379.30) - (-1972.97)^2 = 123{,}053$$

$$S_{yy} = \left(\sum_{i=1}^{N} Q_i^2\right)\left(\sum_{i=1}^{N} Q_i^2 \left(\ln Q_i\right)^2\right) - \left(\sum_{i=1}^{N} Q_i^2 \ln Q_i\right)^2 \tag{M-2}$$

$$S_{yy} = (916.96)\ (6624.11) - (2453.73)^2 = 53{,}234$$

$$S_{xy} = \left(\sum_{i=1}^{N} Q_i^2\right)\left(\sum_{i=1}^{N} Q_i^2 \left(\ln\left|\Delta p_{s,i}\right|\right)\left(\ln Q_i\right)\right) - \left(\sum_{i=1}^{N} Q_i^2 \ln\left|\Delta p_{s,i}\right|\right)\left(\sum_{i=1}^{N} Q_i^2 \ln Q_i\right) \tag{M-3}$$

$$S_{xy} = (916.96)\ (-5191.28) - (-1972.97)\ (2453.73) = 80{,}931$$

The pressure exponent n is determined by:

$$n = \frac{S_{xy}}{S_{xx}} \tag{M-4}$$

so

$$n = \frac{80{,}931}{123{,}053} = \mathbf{0.6577}$$

The flow coefficient C is determined by:

$$C = e^{\left[\left(\frac{\sum_{i=1}^{N} Q_i^2 \ln Q_i}{\sum_{i=1}^{N} Q_i^2}\right) - n\left(\frac{\sum_{i=1}^{N} Q_i^2 \ln\left|\Delta p_{s,i}\right|}{\sum_{i=1}^{N} Q_i^2}\right)\right]} \tag{M-5}$$

so

$$C = e^{\left[\left(\frac{2453.73}{916.96}\right) - 0.6577\left(\frac{-1972.97}{916.96}\right)\right]} = \mathbf{59.8} \text{ cfm per (in. of water)}^{n}$$

One can also calculate the correlation coefficient (r) for the regression using Equation M-6 from Normative Appendix M:

$$r = \sqrt{\frac{\left(S_{xy}\right)^2}{S_{xx} S_{yy}}} \tag{M-6}$$

so

$$r = \sqrt{\frac{80{,}931^2}{\left(123{,}053\right)\left(53{,}234\right)}} = \mathbf{0.9999}$$

Table D-3 shows the airflows fitted to the measured pressures using the calculated parameters C and n, along with the relative error associated with each point.

Table D-3 (all flows at actual conditions)

	$\Delta p_{s,i}$		$Q_{act,i}$		$Q_{fit\_act,i}$		***Relative Error***
i	**(in. of water)**	**(Pa)**	**(cfm)**	**(L/s)**	**(cfm)**	**(L/s)**	**%**
1	0.049	12.2	8.3	3.9	8.2	3.9	0.5
2	0.070	17.5	10.4	4.9	10.4	4.9	0.1
3	0.099	24.7	13.1	6.2	13.1	6.2	0.3
4	0.120	29.9	14.8	7.0	14.8	7.0	0.3
5	0.170	42.4	18.7	8.8	18.7	8.8	0.2

In summary, C = 59.8 cfm per (in. of water)^n and n = 0.6577, with ρ_{act} = 0.0711 lb_m/ft^3 and r = 0.9999. The maximum relative error between fitted and actual data is 0.5% (at $\Delta p_{s,i}$ = 0.049 in. of water).

Figure D-1 shows the resulting correlation between leakage flow and pressure differential.

Using the test parameters C and n with a reference pressure differential of 0.500 in. of water, the leakage flow *with* backdraft damper leakage at actual air density (0.0711 lb_m/ft^3) is:

$$Q_{act,ref} = C\left|\Delta p_{s,ref}\right|^n = 59.8\left|0.500\right|^{0.6577} = 37.9 \text{ cfm}$$

The leakage flow at actual air density with the reference pressure differential of 0.500 in. of water converted to standard air density is:

$$Q_{std,ref} = Q_{act,ref}\left(\frac{\rho_{act}}{\rho_{std}}\right)^{(1-n)} = 37.9\left(\frac{0.0711}{0.075}\right)^{(1-0.6577)} = 37.9(0.982) = 37.2 \text{ cfm}$$

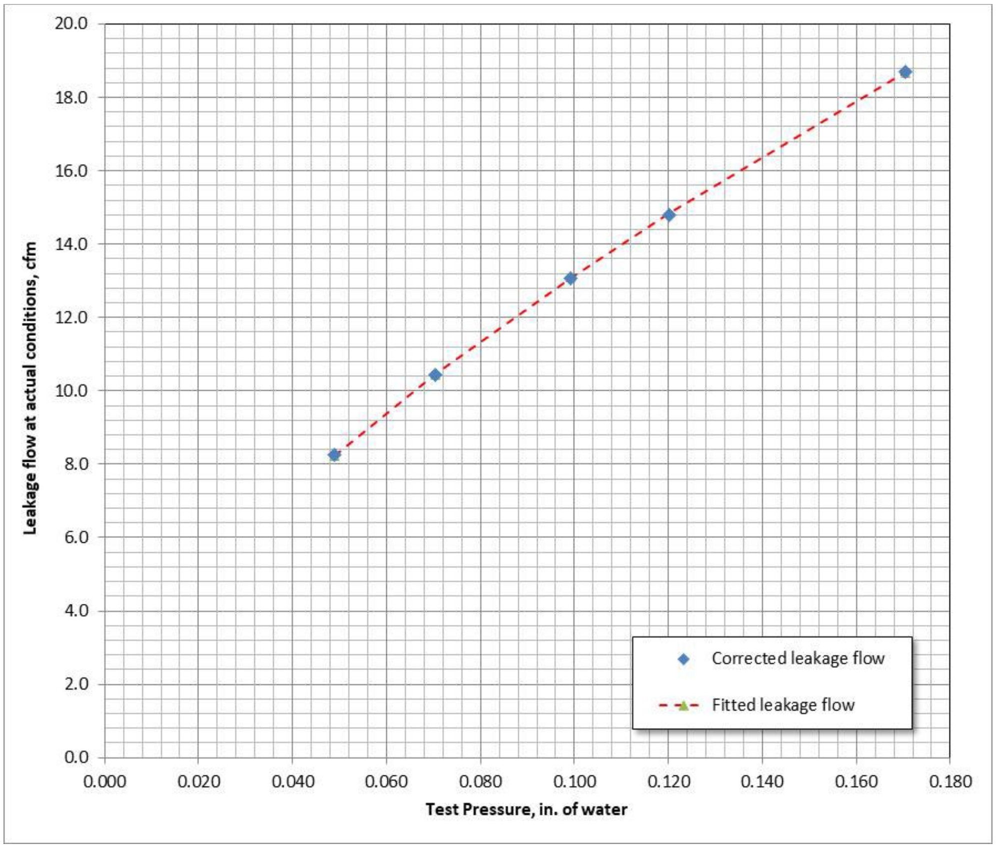
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
Leakage flow at actual conditions, cfm
0.000
0.020
0.040
0.060
0.080
0.100
0.120
0.140
0.160
0.180
Test Pressure, in. of water
Corrected leakage flow
Fitted leakage flow

Figure D-1

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INFORMATIVE APPENDIX E
EFFECT OF PARTIALLY CLOSED CONTROL DAMPER ON AIRFLOW SENSOR PERFORMANCE

E1. TEST PURPOSE

This test determines the effect of throttling devices on airflow sensor performance. This test is applicable for single-duct, induction, bypass, dual-duct, and fan-powered terminal units.

E2. TEST SETUP

The terminal unit to be tested shall be set up as shown in Figure 1.

E3. TEST PROCEDURE

E3.1 Vary airflow from minimum to maximum values in increments not exceeding 10% of maximum value with the damper fully open**.**

E3.2 Set the airflow rate and inlet static pressure to values obtained in Section E3.1 with the damper partially closed.

E4. TEST DATA

Measure and record the following data after equilibrium has been established.

E4.1 Ambient air conditions in the test area: dry-bulb temperature (t_o), relative humidity (φ_o), and barometric pressure at the same elevation as the airflow measurement (p_{bo}).

E4.2 Straight Inlet Conditions

E4.2.1 Mass flow measurements (t_5, p_{s5},$\Delta p_{s,5\text{-}6}$).

E4.2.2 Terminal-unit inlet static pressure (p_{s7}).

E4.2.3 Airflow sensor output (p_{sensor}), in. of water (Pa).

E4.3 Damper Partially Closed

E4.3.1 Mass flow measurements (t_5, p_{s5},$\Delta p_{s,5\text{-}6}$).

E4.3.2 Terminal-unit inlet static pressure (p_{s7}).

E4.3.3 Airflow sensor output (p_{sensor}), in. of water (Pa).

E5. CALCULATIONS

E5.1 Air Density. The air density (ρ_{act}) in the test area shall be calculated using Normative Appendix J.

E5.2 Damper Open

E5.2.1 Airflow. Volumetric airflow rate (Q_o) shall be calculated using Equations B-1 or B-2, whichever is applicable, and then Equation B-3.

E5.2.2 Velocity Pressure. The terminal-unit inlet velocity pressure shall be calculated using Equation B-5, where the inlet velocity is calculated using Equation B-4.

E5.2.3 Amplification Factor. The amplification factor (F) shall be calculated using Equation 1.

E5.2.4 Flow Coefficient. The flow coefficient (K) shall be calculated using Equation 4.

E5.3 Damper Partially Closed

E5.3.1 Airflow. Calculate the airflow rate (Q_c) using Equations B-1 or B-2, whichever is applicable, and then Equation B-3.

E5.4 The change in airflow volume shall be reported as the percent difference between the straight inlet condition and the inlet condition with the control damper partially closed, as shown by Equation E-1.

$$\%\text{Change} = 100\left(\frac{Q_o - Q_c}{Q_o}\right) \tag{E-1}$$

where
Q_o = test conditions with damper open, cfm (L/s)
Q_c = test conditions with damper partially closed, cfm (L/s)

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INFORMATIVE APPENDIX F
EXAMPLE—MIXING TEST

F1. GENERAL

Airflow rate calculations are not shown for this example problem. The airflow rates are calculated using Equations B-1 or B-2, whichever is applicable, and then Equation B-3. For an example of how to calculate airflow rates, see Appendix C.

F2. FAN-POWERED TERMINAL-UNIT TEST

F2.1 Data Acquisition

F2.1.1 Upstream Conditions

a. p_{s7} = 1.0 in. of water (250 Pa)
b. t_1 = 55°F (13°C)

F2.1.2 Induced Air

a. t_o = 85°F (29°C)

F2.1.3 Downstream Conditions

a. Fan discharge opening: 14 × 11 in. (350 × 275 mm)
b. Fan outlet area**:** 1.07 ft^2 (0.096 m^2)
c. p_{s8} = 0.32 in. of water (80 Pa)
d. t_8 (9 readings required per Table 3, Section 5.12.3.3):

Temperature, °F(°C)		
70.3 (21.3)	72.8 (22.7)	73.1 (22.8)
70.1 (21.2)	71.3 (21.8)	72.4 (22.4)
69.5 (20.8)	70.5 (21.4)	72.1 (22.3)

e. $t_{8,min}$ = 69.5°F (20.8°C)
f. $t_{8,max}$ = 73.1°F (22.8°C)

F2.2 Calculations

F2.2.1 Q_{5u} = 200 cfm (94 L/s)

F2.2.2 Q_{5d} = 400 cfm (188 L/s)

F2.2.3 The induced airflow is as follows:

F2.2.4 $\Delta t_x = t_{8,max} - t_{8,min}$ = 73.1 (22.8) – 69.5 (20.8) = 3.6°F (2.0°C)
(2.0).

F2.2.5 $\Delta t_y = t_o - t_1$ = 85 (29) – 55 (13) = 30°F (16°C).

F2.3 Temperature Mixing Efficiency. Mixing efficiency is 3.6°F (2.0°C), with the primary and induced air temperatures at 55°F (13°C) and 85°F (29°C), respectively (30°F [16°C] differential), with test conditions as follows:

a. Upstream: 200 cfm (94 L/s) at 1.0 in. of water (250 Pa)
b. Downstream: 400 cfm (188 L/s) at 0.32 in. of water (80 Pa)

F3. DUAL-DUCT TERMINAL-UNIT TEST

F3.1 Data Acquisition

F3.1.1 Cold-Deck Inlet

a. $p_{s,c7}$ = 1.0 in. of water (250 Pa) inlet static pressure
b. t_{1c} = 55°F (13°C)

F3.1.2 Hot-Deck Inlet

a. $p_{s,h7}$ = 1.0 in. of water (250 Pa) inlet static pressure
b. t_{1h} = 105°F (41°C)

F3.1.3 Downstream Conditions

a. Discharge opening: 6 × 6 in. (150 ×150 mm)
b. Discharge opening area: 0.25 ft^2 (0.022 m^2)
c. $p_{s,8}$ = 0.30 in. of water (75 Pa)
d. t_8 (4 readings per Table 3, Section 5.12.3.3):

Temperature, °F(°C)	
80.5 (26.9)	81.7 (27.6)
79.1 (26.2)	80.1 (26.7)

e. $t_{8,max}$ = 81.7°F (27.6°C)
f. $t_{8,min}$ = 79.1°F (26.2°C)

F3.2 Calculations

F3.2.1 Q_{5c} = 200 cfm (94 L/s)

F3.2.2 Q_{5d} = 400 cfm (188 L/s)

F3.2.3 The hot-deck airflow rate is calculated as follows:

$$Q_{5h} = Q_{5d} - Q_{5c} = 400(188) - 200(94) = \\ 200 \text{ cfm (90 L/s)}$$

F3.2.4 $\Delta t_x = t_{8,max} - t_{8,min}$ = 81.7 (27.6) – 79.1 (26.2) = 2.6°F (1.4°C).

F3.2.5 $\Delta t_y = t_{1h} - t_{1c}$ = 105 (41) – 55 (13) = 50°F (28°C).

F3.3 Temperature Mixing Efficiency. Mixing efficiency is 2.6°F (1.4°C) with the hot- and cold-deck air temperatures at 105°F (41°C) and 55°F (13°C), respectively (50°F [28°C] differential), with test conditions as follows:

a. Upstream, hot-deck: 200 cfm (L/s) at 1.0 in. of water (250 Pa)
b. Upstream, cold-deck: 200 cfm (L/s) at 1.0 in. of water (250 Pa)

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INFORMATIVE APPENDIX G
EXAMPLE STRATIFICATION TEST

G1. GENERAL

Airflow rate calculations are not shown for this example problem. The airflow rates are calculated using Equation B-7. For an example of how to calculate airflow rates, see Appendix C.

G2. FAN-POWERED TERMINAL-UNIT TEST WITH REHEAT COIL

G2.1 Data Acquisition

G2.1.1 Upstream Conditions

a. p_{s7} = 1.0 in. of water (250 Pa)
b. t_1 = 55.0°F (12.8°C)

G2.1.2 Induced Air

a. t_o = 70.0°F (21.1°C)

G2.1.3 Downstream Conditions

a. Fan discharge opening: 14 × 11 in. (350 × 275 mm)
b. Coil size: 25 × 17 in. (625 × 425 mm)
c. Coil face area: 3.0 ft^2 (0.28 m^2)
d. p_{s8} = 0.32 in. of water (80 Pa)
e. t_8 (20 readings required per Table 3, Section 5.12.3.3):

Temperature, °F(°C)				
106.2 (41.2)	107.4 (41.9)	107.6 (42.0)	107.9 (42.2)	108.3 (42.4)
106.1 (41.2)	106.9 (41.6)	107.2 (41.8)	107.5 (41.9)	107.8 (42.1)
105.9 (41.1)	106.1 (41.2)	106.3 (41.3)	106.7 (41.5)	107.5 (41.9)
104.3 (40.2)	105.3 (40.7)	105.7 (40.9)	106.2 (41.2)	107.1 (41.7)

G2.2 Calculations

G2.2.1 $\rho_o = 0.075\ \mathrm{lb_m/ft^3}$ ($1.204\ \mathrm{kg/m^3}$).

G2.2.2 $t_{8,avg} = 106.7$°F (41.5°C).

G2.2.3 $t_{5d} = t_{8,avg} = 106.7$°F (41.5°C).

G2.2.4 $\rho_{5d} = \rho_o\ (t_o + 460/t_{5d} + 460) = 0.075\ (70 + 460/105 + 460) = 0.070\ \mathrm{lb_m/ft^3}$ ($1.120\ \mathrm{kg/m^3}$).

G2.2.5 $Q_{5u} = 200$ cfm (94 L/s).

G2.2.6 $Q_{5d} = 429$ cfm (202 L/s).

G2.2.7 $Q'_{5d} = 400$ cfm (188 L/s).

G2.2.8 The induced airflow calculated is

$$Q_i = Q'_{5d} - Q_{5u} = 400(188) - 200(94) = \\ 200\ \text{cfm}\ (94\ \text{L/s})$$

G2.2.9 $\Delta t_x(horizontal) = t_{8,max} - t_{8,min} = 108.3\ (42.4) - 106.2\ (41.2) = 2.1$°F (1.2°C).

G2.2.10 $\Delta t_y(vertical) = t_{8,max} - t_{8,min} = 107.1\ (41.7) - 104.3\ (40.2) = 2.8$°F (1.5°C).

G2.2.11 $\Delta t_z = t_{8,avg} - t_o = 106.7\ (41.5) - 70.0\ (21.1) = 46.7$°F (20.4°C).

G2.3 Report. The fan-powered terminal unit with reheat stratification is 2.1°F (1.2°C) horizontal and 2.8°F (1.8°C) vertical, with a temperature rise 46.7°F (20.4°C) and test conditions as follows:

a. Upstream: 200 cfm (94 L/s) at 1.0 in. of water (250 Pa)
b. Downstream: 429 cfm (202 L/s) at 0.32 in. of water (80 Pa)

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INFORMATIVE APPENDIX H
ACOUSTICALLY ISOLATED DUCT

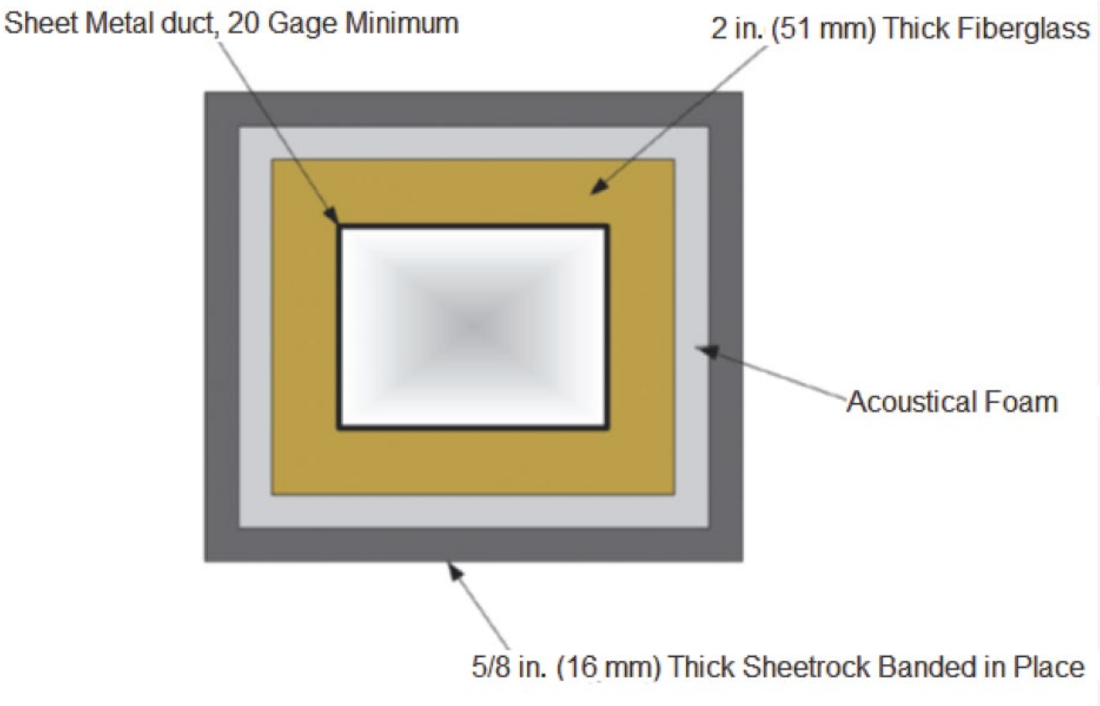

FIGURE H-1 Acoustically isolated rectangular duct.

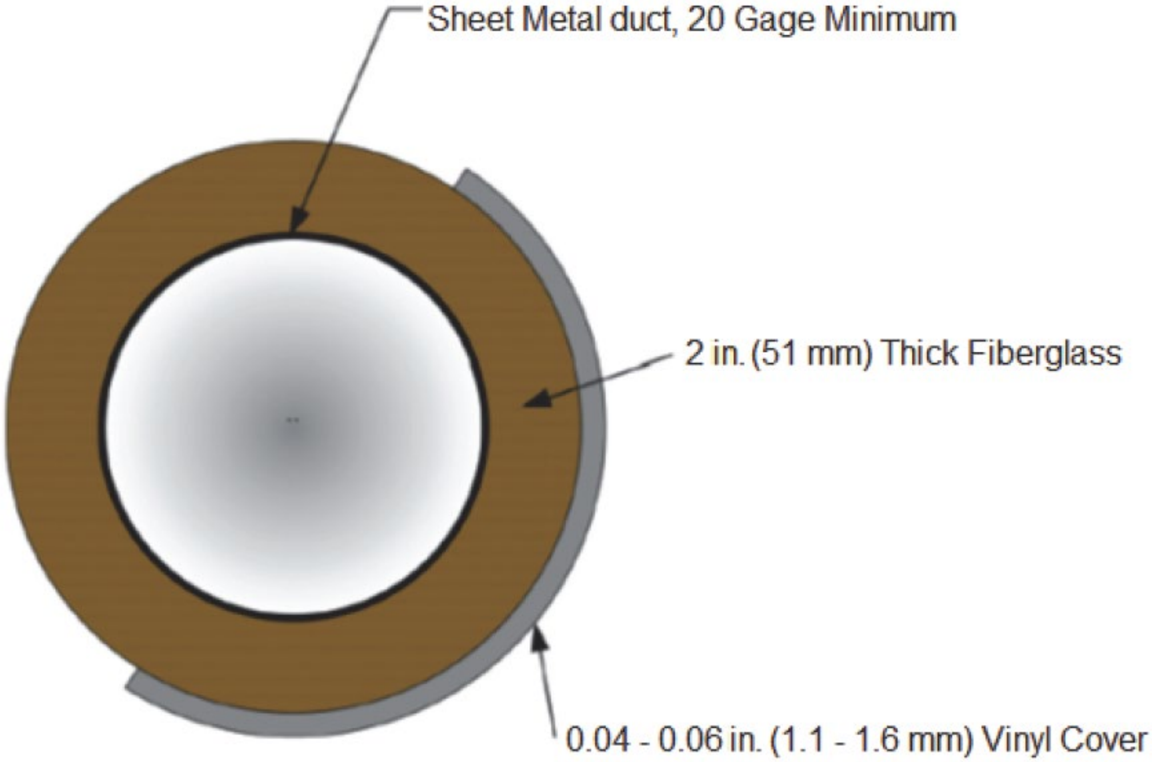

FIGURE H-2 Acoustically isolated round duct.

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INFORMATIVE APPENDIX I
REFLECTION OF AIRBORNE NOISE AT DUCT DETERMINATIONS

Michaud and Cunefare (2007, 2008) confirmed the end reflection loss (ERL) for hard-flush terminations, the type used to conduct sound testing in semi-reverberant test chambers. End reflection occurs when a duct system opens abruptly into a large room, causing some of the low-frequency acoustic energy at the exit of the duct to be reflected back into the duct. The result is that the amount of acoustic energy discharged into the room is reduced. This decrease in discharged energy is larger at lower frequencies. Pertinent information can be found in *ASHRAE Handbook—HVAC Applications* (ASHRAE 2015).

When conducting discharge sound tests to obtain sound power levels for air terminal units, as prescribed in this standard, the sound power measured in the test chamber will be less than the actual sound power in the duct. The ERL is a calculation that is added to the sound data obtained in a test chamber.

I1. INFORMATIVE REFERENCES

ASHRAE. 2015. *ASHRAE Handbook—HVAC Applications*. Chapter 48, “Noise and Vibration Control,” Duct End Reflection Loss, p. 48.26. Atlanta: ASHRAE.

Michaud, A.P, and K.A Cunefare. 2007. Reflection of Airborne Noise at Duct Determinations. ASHRAE Research Project 1314 Final Report. Contractor: The Georgia Institute of Technology. Atlanta: ASHRAE.

Michaud, A.P., and K.A. Cunefare. 2008. Experimental investigation of reflection of airborne noise at duct determinations. *ASHRAE Transactions* 114(2).

(This is a normative appendix and is part of the standard.)

NORMATIVE APPENDIX J
TIME AVERAGING AND AIR DENSITY CALCULATIONS

J.1 Time Averaging

Because airflows and pressures in fan-driven air-handling systems are never strictly steady, the airflow, pressure, temperature, or relative humidity indicated on an instrument fluctuates with time. Time averaging of measured parameters is used in this standard to account for such fluctuations. Instrument readings shall be based on averaged measurement samples recorded using multi-sample averaging instruments and analyzers designed for this purpose.

Averaging periods and the sample frequency in each period shall be selected to result in at least 20 samples for each measurement parameter (e.g., samples once every second over a 20 second period). The same averaging period shall be used for all measurements at a particular measurement plane.

The time-averaged value of the samples for a particular measurement parameter shall be calculated as:

$$\bar{X} = \frac{1}{M}\sum_{i=1}^{M} X_i \qquad \text{(J-1)}$$

where

$\bar{X}$ = average value of measured parameter
X_i = i^{th} sample of measured parameter
M = number of samples for measured parameter

The averaging period and the sample frequency for each measurement parameter at each measurement plane shall be documented in the test report.

The time-averaged readings for all measurements at the specified measurement plane shall be determined at the start and end of the test, and the two time-averaged readings for each measurement parameter shall be averaged for use in Section J.2.

J.2 Calculations

J.2.1 Air Density. The air density ρ_x at a plane of interest shall be calculated as follows:

$$\rho_x = \frac{p_b + \Delta p_{s,x} - 0.378\,(\varphi_x/100)\,p_{ws,x}}{R_{da}\,T_x} \qquad \text{(J-2 SI)}$$

$$\rho_x = \frac{144\left[p_b + 0.036\,\Delta p_{s,x} - 0.378\,(\varphi_x/100)\,p_{ws,x}\right]}{R_{da}\,T_x} \qquad \text{(J-2 I-P)}$$

where

ρ_x = air density at plane x, kg/m^3 (lb$_m$/ft^3)
p_b = time-averaged barometric pressure at same elevation as the airflow point of interest, Pa (psi)
$\Delta p_{s,x}$ = time-averaged static pressure difference at plane x, Pa (in. of water)
$p_{ws,x}$ = time-averaged saturation pressure at plane x, Pa (psi)
φ_x = time-averaged relative humidity at plane x, %
R_{da}. = gas constant of dry air, 287.042 J/(kg·K); [53.350 ft·lb$_f$/(lb$_m$·°R)]

T_x = absolute temperature at plane x, K= $t_{db,x}$ + 273.15; [ºR = $t_{db,x}$ + 459.67]
$t_{db,x}$ = time-averaged dry-bulb air temperature, °C (°F)

Refer to **Informative Appendix K** for a derivation of Equation J-2.

The saturation pressure $p_{ws,x}$ over *liquid water* for the temperature range 0 to 200ºC (32 to 392ºF) shall be calculated as follows:

$$p_{ws,x} = e^{(C_1/T_x + C_2 + C_3 T_x + C_4 T_x^2 + C_5 T_x^3 + C_6 \ln T_x)} \tag{J-3}$$

where

In SI units: C_1 = -5.8002206E+03, C_2 = 1.3914993E+00, C_3 = -4.8640239E-02,
C_4 = 4.1764768E-05, C_5 = -1.4452093E-08, C_6 = 6.5459673E+00.

In IP units: C_1 = -1.0440397E+04, C_2 = -1.1294650E+01, C_3 = -2.7022355E-02,
C_4 = 1.2890360E-05, C_5 = -2.4780681E-09, C_6 = 6.5459673E+00.

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INFORMATIVE APPENDIX K
DERIVATION OF MOIST AIR DENSITY EQUATION

Based on the definition of moist air density, for a mixture of dry air and water vapor:

$$\rho = \frac{m_{da} + m_w}{V} = \frac{m_{da}}{V}\left(1 + \frac{m_w}{m_{da}}\right) \tag{K-1}$$

where

ρ = moist air density, kg/m^3 (lb$_m$/ft^3)
m_{da} = mass of dry air, kg (lb$_m$)
m_w = mass of water vapor, kg (lb$_m$)
V = volume, m^3 (ft^3)

The humidity ratio is the ratio of the mass of water vapor to the mass of dry air:

$$\omega = \frac{m_w}{m_{da}} \tag{K-2}$$

where

ω = humidity ratio, dimensionless [kg$_w$/kg$_{da}$; (lb$_w$/lb$_{da}$)]

Thus, combining Equations K-1 and K-2, the moist air density is:

$$\rho = \frac{m_{da}}{V}\left(1 + \omega\right) \tag{K-3}$$

The density of a mixture of dry air and water vapor is determined using the ideal gas law. Dalton's law of partial pressures states that the total pressure is equal to the sum of the partial pressures of the dry air and water vapor, at the absolute temperature *T* and volume *V* of the mixture. Hence:

$$\frac{m_{da}}{V} = \frac{p_{da}}{R_{da}T} = \frac{p - p_w}{R_{da}T} \tag{K-4 SI}$$

$$\frac{m_{da}}{V} = \frac{144 p_{da}}{R_{da}T} = \frac{p - p_w}{R_{da}T} \tag{K-4 IP}$$

where

p = thermodynamic pressure, Pa (psi)
p_{da} = partial pressure of dry air, Pa (psi)
p_w = partial pressure of water vapor at t_{db}, Pa (psi)
R_{da} = gas constant of dry air, 287.042 J/(kg·K); [53.350 ft·lb$_f$/(lb$_m$·°R)]
T = absolute temperature, K=t_{db}+273.15; [°R=t_{db}+459.67]
t_{db} = measured air temperature, °C (°F)

Therefore, combining Equations K-3 and K-4:

$$\rho = \frac{p - p_w}{R_{da}T}\left(1+\omega\right) \tag{K-5 SI}$$

$$\rho = 144\left(\frac{p - p_w}{R_{da}T}\right)\left(1+\omega\right) \tag{K-5 IP}$$

For a mixture of dry and water vapor, the humidity ratio is expressed as:

$$\omega = 0.622\frac{p_w}{p - p_w} \tag{K-6}$$

Substituting Equation K-6 into Equation K-5 and simplifying:

$$\rho = \frac{p - p_w}{R_{da}T}\left(1+0.622\frac{p_w}{p-p_w}\right) = \frac{1}{R_{da}T}\left(p - p_w + 0.622p_w\right) \tag{K-7 SI}$$

$$\rho = \frac{144\left(p - p_w\right)}{R_{da}T}\left(1+0.622\frac{p_w}{p-p_w}\right) = \frac{144}{R_{da}T}\left(p - p_w + 0.622p_w\right) \tag{K-7 IP}$$

The water vapor partial pressure is expressed in terms of the relative humidity and saturation pressure as follows:

$$p_w = \left(\varphi/100\right)p_{ws} \tag{K-8 SI}$$

$$p_w = \left(\varphi/100\right)p_{ws} \tag{K-8 IP}$$

where

p_{ws} = saturation pressure, Pa (psi)

Therefore, combining Equations K-7 and K-8, the moist air density is given by:

$$\rho = \frac{1}{R_{da}T}\left[p - 0.378\left(\varphi/100\right)p_{ws}\right] \tag{K-9 SI}$$

$$\rho = \frac{144}{R_{da}T}\left[p - 0.378\left(\varphi/100\right)p_{ws}\right] \tag{K-9 IP}$$

In terms of the static pressure difference across the duct or terminal unit walls at any measurement plane and the barometric pressure at the same elevation as the test section, Equation K-9 can be expressed as:

$$\rho_x = \frac{p_b + \Delta p_{s,x} - 0.378\left(\varphi_x/100\right)p_{ws,x}}{R_{da}T_x} \tag{K-10 SI}$$

$$\rho_x = \frac{144\left[p_b + 0.036\Delta p_{s,x} - 0.378\left(\varphi_x/100\right)p_{ws,x}\right]}{R_{da}T_x} \tag{K-10 IP}$$

where

ρ_x = air density at plane x, kg/m^3 (lb$_m$/ft^3)
p_b = measured barometric pressure at same elevation as the airflow measurement, Pa (psi)
$\Delta p_{s,x}$ = measured static pressure difference across duct or terminal unit walls at plane x, Pa (in. of water)
$p_{ws,x}$ = saturation pressure at plane x, Pa (psi)
φ_x = measured relative humidity at plane x, %
R_{da} = gas constant of dry air, 287.042 J/(kg·K); [53.350 ft·lb$_f$/(lb$_m$·°R)]
T_x = absolute temperature at plane x, K= $t_{db,x}$ + 273.15; [°R = $t_{db,x}$ + 459.67]
$t_{db,x}$ = measured dry-bulb air temperature, °C (°F)

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INFORMATIVE APPENDIX L
DERIVATION OF AIR DENSITY CORRECTIONS FOR AIRFLOWS DETERMINED USING AN ORIFICE PLATE

The "measured" airflows through the orifice plate and thus through casing leaks need to be corrected for air densities during the test that differ from calibration conditions. That is, the flow through the airflow meter needs to be corrected to actual conditions. The following describes the derivation of this correction for use in terminal-unit casing leakage tests.

SI units are used here for simplicity of explanation, but the dimensionless correction factors derived are the same regardless of which system of units is used.

An orifice plate located inside a duct causes a static pressure difference between the upstream and downstream pressure taps, which in turn can be used to determine the mass flow through the orifice (ASME MFC-3M-2004 (R2017))[3]:

$$\dot{m} = \frac{\varepsilon C_d}{\sqrt{1-\beta^4}}\left(\frac{\pi}{4}d^2\right)\sqrt{2\Delta p_o \rho} \tag{L-1}$$

where

$\dot{m}$ = mass flow of air through the orifice, kg/s
ε = air expansibility factor, dimensionless
C_d = orifice discharge coefficient, dimensionless
β = diameter ratio ($\beta = d/D$), dimensionless
d = orifice hole diameter, m
D = duct diameter, m
Δp_o = static pressure difference between the pressure taps upstream and downstream of the orifice, Pa
ρ = air density at orifice upstream pressure tap, kg/m^3

Equation L-1 can be simplified to:

$$\dot{m} = \left(K'\sqrt{\rho}\right)\sqrt{\Delta p_o} \tag{L-2}$$

where

$$K' = \frac{\varepsilon C_d}{\sqrt{1-\beta^4}}\left(\frac{\pi}{4}d^2\right)\sqrt{2} \tag{L-3}$$

ASME (2017) shows that C_d itself depends on the diameter ratio β and on the Reynolds number (Re_D) for the duct in which the orifice is located. It also shows that ε depends on β and the pressure ratio between the absolute pressures at the downstream and upstream taps. However, C_d and ε, and therefore K', are approximately constant when the flow through the orifice is turbulent (Re_D greater than about 20,000) and for typical pressures and orifice plates used in ducted airflow for terminal units.

Manufacturers sometimes provide a constant K'_{calib} instead that also includes air density at the upstream tap *at the time of orifice calibration* (ρ_{calib}). In this case, the mass flow of air at calibration conditions ($\dot{m}_{calib}$) is:

$$\dot{m}_{calib} = K'_{calib}\sqrt{\Delta p_o} \qquad \text{(L-4)}$$

where

$$K'_{calib} = \frac{\varepsilon C_d}{\sqrt{1-\beta^4}}\left(\frac{\pi}{4}d^2\right)\sqrt{2\rho_{calib}} \qquad \text{(L-5)}$$

The mass flow of air through the orifice at calibration conditions is also defined by:

$$\dot{m}_{calib} = \rho_{calib} Q_{calib} \qquad \text{(L-6)}$$

where

Q_{calib} = volumetric airflow through the orifice at calibration conditions, m^3/s

Rearranging Equation L-6 and substituting in Equation L-4:

$$Q_{calib} = \frac{\dot{m}_{calib}}{\rho_{calib}} = \frac{K'_{calib}\sqrt{\Delta p_o}}{\rho_{calib}} \qquad \text{(L-7)}$$

If, however, the air density at the upstream tap is not ρ_{calib} at the time of measurement, then to calculate the *actual* mass flow of air, one must apply a correction factor to Equation L-4 to account for the different air density:

$$\dot{m}_{act} = \left(K'_{calib}\sqrt{\Delta p_o}\right)\sqrt{\frac{\rho_{act}}{\rho_{calib}}} \qquad \text{(L-8)}$$

where

$\dot{m}_{act}$ = mass flow of air through the orifice at actual conditions, kg/s
ρ_{act} = air density at orifice upstream tap at actual conditions, kg/m^3

To translate the actual mass flow of air to actual volumetric airflow, one needs to recognize that the mass flow of air through the orifice is also defined by:

$$\dot{m}_{act} = \rho_{act} Q_{act} \qquad \text{(L-9)}$$

where

Q_{act} = volumetric airflow through orifice at actual conditions, m^3/s

Rearranging Equation L-9:

$$Q_{act} = \frac{\dot{m}_{act}}{\rho_{act}} \qquad \text{(L-10)}$$

Combining Equations L-8 and L-10:

$$Q_{act} = \frac{\left(K'_{calib}\sqrt{\Delta p_o}\right)\sqrt{\frac{\rho_{act}}{\rho_{calib}}}}{\rho_{act}} \qquad \text{(L-11)}$$

Simplifying Equation L-11:

$$Q_{act} = \left(K'_{calib}\sqrt{\Delta p_o}\right)\sqrt{\frac{1}{\rho_{calib}\rho_{act}}} \qquad \text{(L-12)}$$

The dimensionless ratio Q_{act} / Q_{calib} can be determined by combining Equations L-7 and L-12:

$$\frac{Q_{act}}{Q_{calib}} = \frac{\left[\left(K'_{calib}\sqrt{\Delta p_o}\right)\sqrt{\frac{1}{\rho_{calib}\rho_{act}}}\right]}{\left[\frac{K'_{calib}\sqrt{\Delta p_o}}{\rho_{calib}}\right]} = \sqrt{\frac{\rho_{calib}}{\rho_{act}}} \tag{L-13}$$

Rearranging L-13:

$$Q_{act} = Q_{calib}\sqrt{\frac{\rho_{calib}}{\rho_{act}}} \tag{L-14}$$

where

Q_{act} = volumetric airflow through the orifice flow meter at actual conditions, m^3/s
Q_{calib} = volumetric airflow through the orifice flow meter at calibration conditions, m^3/s
ρ_{calib} = calibration air density for orifice flow meter at orifice upstream pressure tap, kg/m^3
ρ_{act} = actual air density at orifice upstream pressure tap, kg/m^3

(This is a normative appendix and is part of the standard.)

NORMATIVE APPENDIX M
DETERMINING TERMINAL-UNIT CASING LEAKAGE PARAMETERS

The following equations from Annex B of CAN/CGSB-149.10-2019 (CGSB 2019) shall be used to determine the leakage test parameters *C* and *n*, as well as the correlation coefficient (*r*). In the equations below, Q_i is the volumetric airflow through the orifice meter corrected to actual conditions. That flow is a surrogate for the actual mass flow through the meter, which is the same as the actual mass flow through the leaks.

Three parameters (S_{xx}, S_{yy}, and S_{xy}) are first calculated using N data points where Q_i is the orifice flow at static pressure difference $\Delta P_{s,i}$:

$$S_{xx} = \left(\sum_{i=1}^{N} Q_i^2\right)\left(\sum_{i=1}^{N} Q_i^2 \left(\ln\left|\Delta p_{s,i}\right|\right)^2\right) - \left(\sum_{i=1}^{N} Q_i^2 \ln\left|\Delta p_{s,i}\right|\right)^2 \tag{M-1}$$

$$S_{yy} = \left(\sum_{i=1}^{N} Q_i^2\right)\left(\sum_{i=1}^{N} Q_i^2 \left(\ln Q_i\right)^2\right) - \left(\sum_{i=1}^{N} Q_i^2 \ln Q_i\right)^2 \tag{M-2}$$

$$S_{xy} = \left(\sum_{i=1}^{N} Q_i^2\right)\left(\sum_{i=1}^{N} Q_i^2 \left(\ln\left|\Delta p_{s,i}\right|\right)\left(\ln Q_i\right)\right) - \left(\sum_{i=1}^{N} Q_i^2 \left|\ln \Delta p_{s,i}\right|\right)\left(\sum_{i=1}^{N} Q_i^2 \ln Q_i\right) \tag{M-3}$$

Equations M-1 through M-3 each apply a weighting factor (Q_i^2) so that more weight is given to data points with greater airflow.

The pressure exponent *n* is determined by:

$$n = \frac{S_{xy}}{S_{xx}} \tag{M-4}$$

The flow coefficient *C* is determined by:

$$C = e^{\left[\left(\frac{\sum_{i=1}^{N} Q_i^2 \ln Q_i}{\sum_{i=1}^{N} Q_i^2}\right) - n\left(\frac{\sum_{i=1}^{N} Q_i^2 \ln\left|\Delta p_{s,i}\right|}{\sum_{i=1}^{N} Q_i^2}\right)\right]} \tag{M-5}$$

The correlation coefficient (*r*) shall be calculated by:

$$r = \sqrt{\frac{\left(S_{xy}\right)^2}{S_{xx} S_{yy}}} \tag{M-6}$$

References

CGSB. 2019. “CAN/CGSB-149.10-2019, Determination of the Airtightness of Building Envelopes by the Fan Depressurization Method”. Ottawa: Canadian General Standards Board. November.

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INFORMATIVE APPENDIX N
EXAMPLE – PRESSURE-COMPENSATING VOLUME CONTROLLER PERFORMANCE TEST

Table N-1 summarizes data resulting from a test based on the procedures in Section 5.5. Figure N-1 is a plot of these data.

TABLE N-1 Test Data Summarized

	Airflow (Q),		
Data Point	**cfm (L/s)**	**Q_n/Q_1**	**$P_{s7\text{–}8}$, in. of water (Pa)**
1	1000 (472)	1.0	0.25 (63)
2	1006 (475)	1.0	1.00 (250)
3	1112 (525)	1.1	1.75 (438)
4	950 (448)	0.95	0.25 (63)

The changes in airflow (ΔQ_{up} and ΔQ_{down}) caused by increasing and decreasing variations in the inlet static pressure of the terminal-unit/controller combination, respectively, are calculated using Equations 9 and 10.

$$\Delta Q_{up} = 100\left(\frac{Q_3 - Q_1}{Q_1}\right) = 100\left(\frac{1112-1000}{1000}\right) = +11.2\% \tag{9 I-P}$$

$$\Delta Q_{up} = 100\left(\frac{Q_3 - Q_1}{Q_1}\right) = 100\left(\frac{525-472}{472}\right) = +11.2\% \tag{9 SI}$$

$$\Delta Q_{down} = 100\left(\frac{Q_4 - Q_3}{Q_1}\right) = 100\left(\frac{950-1112}{1000}\right) = -16.2\% \tag{10 I-P}$$

$$\Delta Q_{down} = 100\left(\frac{Q_4 - Q_3}{Q_1}\right) = 100\left(\frac{448-525}{472}\right) = -16.3\% \tag{10 SI}$$

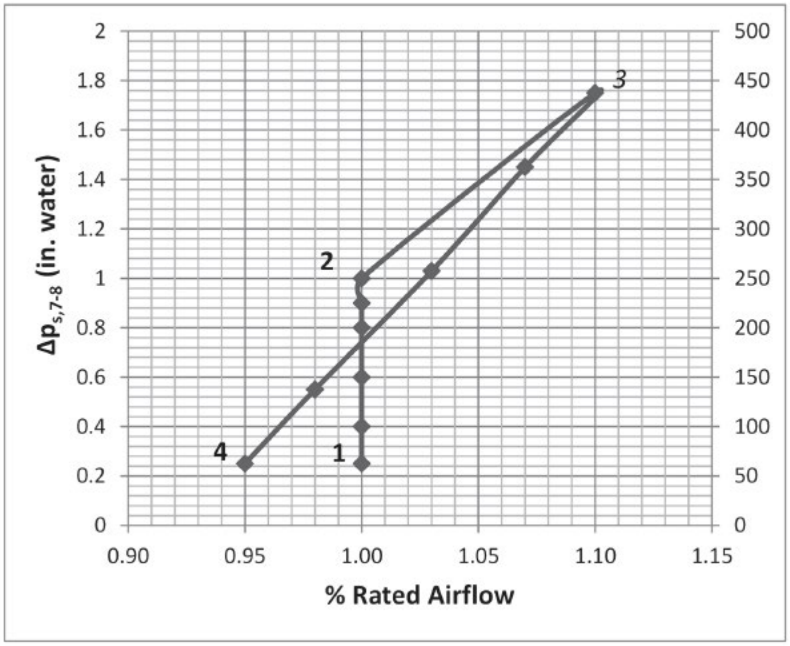

FIGURE N-1 Graphic depiction of terminal-unit pressure-compensating volume control performance.

(This is a normative appendix and is part of the standard.)

NORMATIVE APPENDIX O
TEST SETUP DIAGRAMS FOR DETERMINING BACKGROUND NOISE FOR COMPARISON WITH UNIT SOUND TEST

O.1 GENERAL

This appendix provides supplementary information to assist the user in performing the sound testing described in Section 5.15.4.

It is important to determine any contribution by exterior sources to unit sound measurements to ensure quiet air conditions are met per AHRI 220 and to provide information needed to correct the measured sound levels as required. The following figures are provided to assist the user in determining appropriate setups that correlate with the various terminal unit types shown in Figures 13 through 23.

O.2 PROCEDURES

Tests to determine background noise levels at corresponding airflow rates are required as part of any test series for a particular terminal unit type. It is permissible to use the same series of background noise tests for multiple terminal units provided that all of the units use the same figure shown below, the relative humidity does not change by more than 5%, and the temperature does not change by more than 3 degrees Celsius (5 degrees Fahrenheit) over the period of testing.

The only change in physical setup from the terminal unit sound test and the background noise test is the replacing of the unit under test with a substitution piece. The design and construction of the substitution pieces shown in the figures below are to be determined by the test lab to match the configurations shown as closely as possible. Where transitions are used, they shall be in accordance with SMACNA Duct Construction Standards.

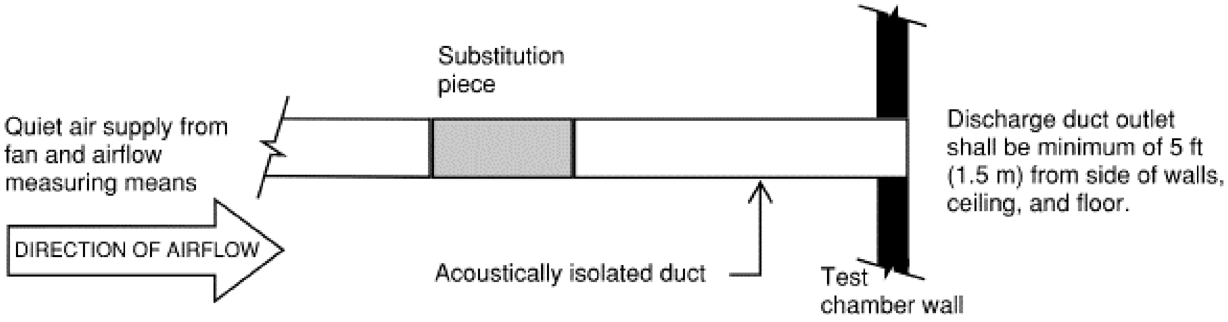

FIGURE O-1 Background noise test setup for single-duct, dual-duct, series-flow fan-powered, mechanically regulated, induction, parallel-flow fan-powered, and bypass terminal units with discharge duct.

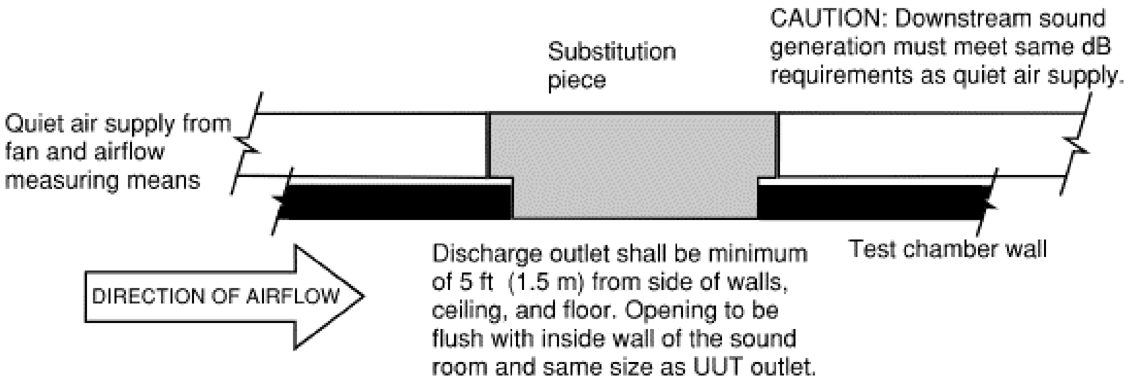

FIGURE O-2 Background noise test setup for integral diffuser (side wall) air terminal units.

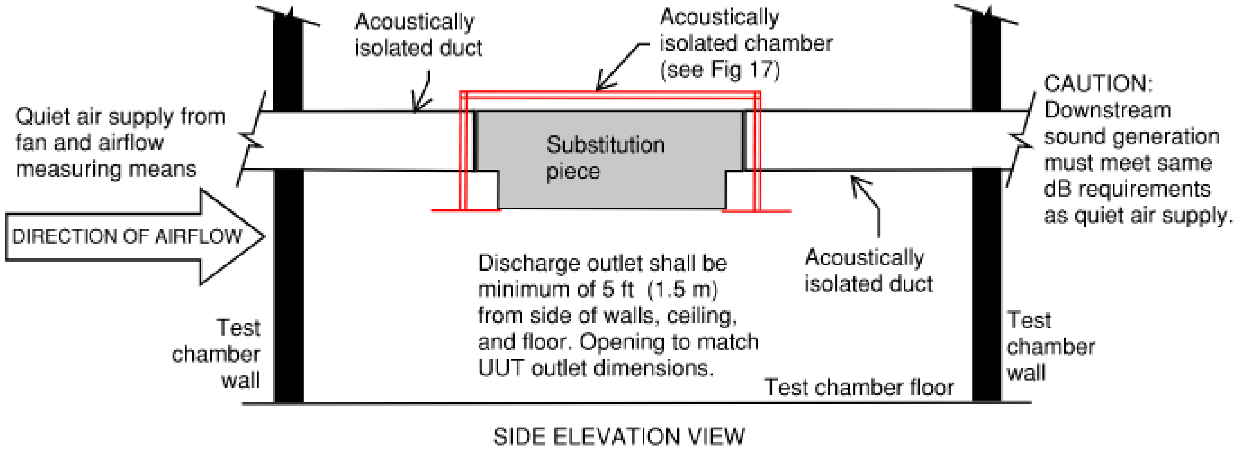

FIGURE O-3 Background noise test setup for integral diffuser (ceiling) air terminal units.

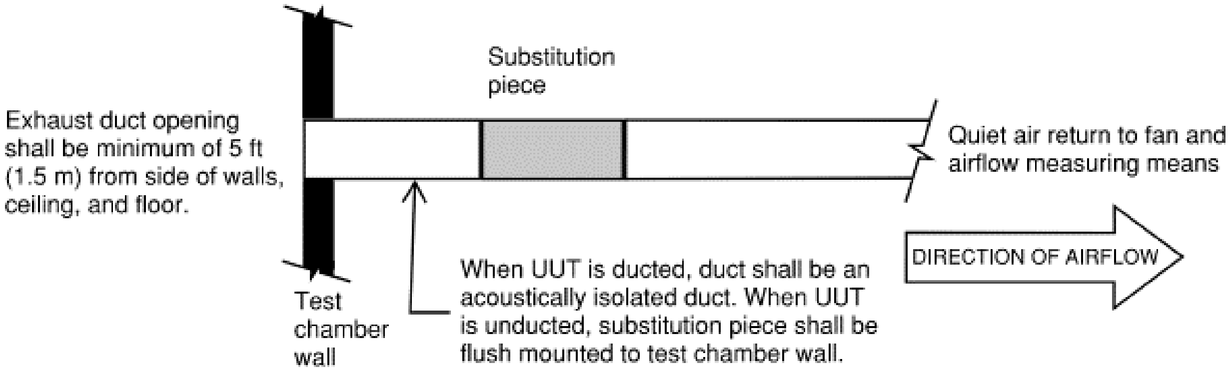

FIGURE O-4 Background noise test setup for exhaust terminal units.

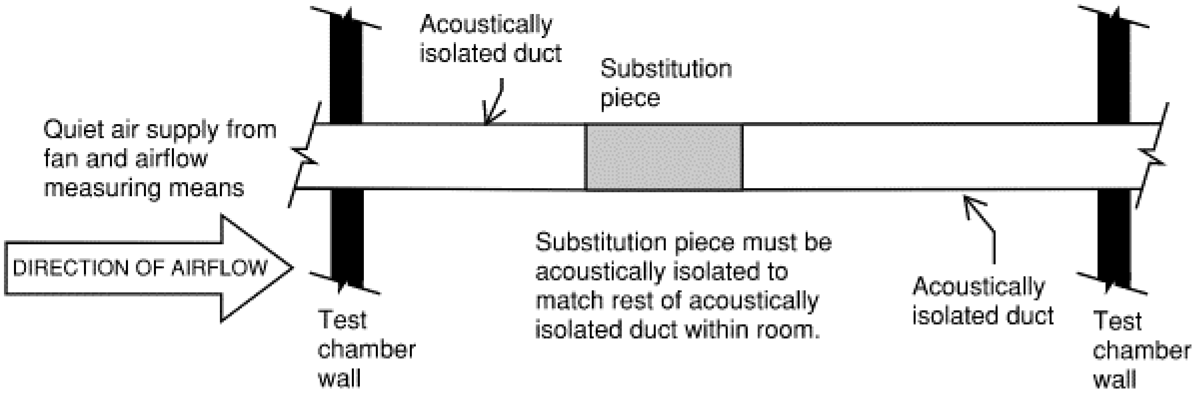

FIGURE O-5 Background noise test setup for comparison with casing radiated sound levels for all ducted terminal units.