BSR/ASHRAE Standard 195-2013R

Public Review Draft

Method of Test for Rating Air Terminal Unit Controls

First Public Review (March 2019)
(Complete Draft for Full Review)

This draft has been recommended for public review by the responsible project committee. To submit a comment on this proposed standard, go to the ASHRAE website at www.ashrae.org/standards-research--technology/public-review-drafts and access the online comment database. The draft is subject to modification until it is approved for publication by the Board of Directors and ANSI. Until this time, the current edition of the standard (as modified by any published addenda on the ASHRAE website) remains in effect. The current edition of any standard may be purchased from the ASHRAE Online Store at www.ashrae.org/bookstore or by calling 404-636-8400 or 1-800-727-4723 (for orders in the U.S. or Canada).

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(This foreword 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.)

FOREWORD

Standard 195 specifies instrumentation and facilities, test installation methods, and procedures for determining the accuracy and stability of airflow control systems for terminal units at various airflow setpoints.

It is intended for application in the following scenarios:

- *An HVAC system specifier indicates performance requirements for airflow control for a given project. The requirements are specified in terms of nominal flow rates, accuracy, stability, operating pressures, and other relevant conditions. Contractors or suppliers document performance of proposed equipment based on tests run and reported in accordance with this standard.*

- *A supplier of airflow controls wishing to publish the capabilities of a product executes tests and reports results in accordance with this standard. The supplier chooses the operating conditions to test and report.*

The Standard Project Committee does not envision application of this standard to field tests or acceptance tests in construction projects.

This edition of Standard 195 expands the testing options for the scope of the test. All tests in the 2013 edition apply to the combination of a controller and air terminal. This edition of the standard includes the option to test only the performance of the controller, paired with a standard air terminal. The air terminal used for this testing must meet the requirements in the new Normative Appendix C. The full-system test is intended to determine the lowest airflow setpoint at which a full system passes the system performance tests. The controller-only test is intended to determine the lowest flow probe signal (Pvm) at which a controller passes the system performance tests. It does not necessarily indicate how stably or accurately a controller can maintain an airflow setpoint when paired with a terminal unit that is different than the standard terminal unit. For example, if the controller is paired with a terminal unit whose flow probe has lower amplification than the standard terminal unit, then the controller may not be able to control as accurately at low flow. Similarly, if the terminal unit flow probe signal or amplification degrades at low flow, then the controller may not perform as well as the controller-only test might imply.

However, it should be noted that ASHRAE RP-1353 tested terminal units from 3 manufacturers along with controllers from 4 manufacturers and consistently found the flow probe signal and amplification to be stable at flows well below what the controllers could stably and accurately control—the controller was always the limiting factor in full system performance. Similar research by Pacific Gas & Electric came to the same conclusion. Furthermore, the required amplification of the standard terminal unit is typical of the amplification factors published by many of the major VAV box manufacturers. The advantage of the controller-only tests is that it allows for an apples-to-apples comparison between controllers, regardless of which terminal unit they are paired with. It also allows controller manufacturers to provide standardized performance data for their *controllers without fear of being unfairly compared to a competitor's controller paired with a terminal unit with unusually high amplification. The controller only test only evaluates systems using velocity pressure sensing. To compare systems using other sensing technology, the full system test is appropriate.*

This standard method of test (MOT) reports performance as a pass/fail rating with respect to a control accuracy tolerance, rather than reporting a measured, numerical accuracy. It is envisioned that the standard may be extended in the future to report measured accuracy.

This standard MOT pertains to some of the same equipment as Standard 130[1] and measures some of the same quantities. In particular, Standard 130 includes tests that measure accuracy of an airflow sensor installed in a terminal. This MOT measures the accuracy of the airflow control system, which encompasses the terminal and sensor, but also includes sensing functions and control actions integral to an airflow controller.

This standard MOT describes procedures that apply to single-duct air terminals without fans. Future versions may include procedures that apply to other air terminals.

1 PURPOSE

This standard specifies instrumentation and facilities, test installation methods, and procedures for determining the accuracy and stability of airflow control systems for terminal units at various airflow setpoints.

2 SCOPE

This standard applies to electronic and/or pneumatic control systems used for pressure independent airflow control in terminal units for VAV and CV air moving systems.

3 DEFINITIONS

3.1 This section provides definitions of key terms used in this standard. For terms not defined, refer to the definitions listed in *ASHRAE Terminology of Heating, Ventilation, Air Conditioning, and Refrigeration.*[2]

air terminal: a single-duct air valve that selectively restricts or conducts passage of air between a fan system and a defined space in response to an external demand.

airflow: for the purpose of this test method, airflow is the unit volume displacement of standard air per unit time. It is normally measured in standard cubic feet per minute (scfm) or liters per second (L/s).

ammeter: a device used to measure the electrical current in a circuit.

amplification factor (F): the ratio of flow probe pressure sensor output to true velocity pressure. For example, a flow probe pressure sensor output of 1.0” of pressure at a velocity pressure of 0.43” would have an amplification factor of 1.0/0.43 = 2.3.

$$F = \frac{Pvm}{Pv}$$

Where both pressures are expressed in the same units.

F may be calculated from K with the following formula, where A is the nominal duct area in ft^2. The nominal duct area is calculated based on the geometry of the duct, not on the actual free area.

$$F = \left(\frac{1096A}{K\sqrt{\rho}} \right)^2$$

auto-zero feature: any automatic means of adjusting the zero calibration point of a pressure or velocity transducer.

controlled air terminal: a single-duct air valve that automatically modulates the volume of air delivered to or removed from a defined space in response to an external demand.

controller-only test: This is used to measure the performance of a controller and actuator independent from the air terminal unit.

differential pressure: difference in pressure between any two locations in a system.

equivalent diameter: the diameter of a circular-duct equivalent that will have a cross-sectional area that is equal to that of a particular rectangular duct. The equivalent diameter is calculated by the following equation:

$D_e = (4 \times A/\pi)^{0.5}$, where A is the cross-sectional area.

flow coefficient (K-Factor): standard airflow (in ft^3/min) corresponding to a flow probe pressure sensor output of 1" w.g. K may be calculated from the amplification factor, F, with the following formula, where A is the nominal duct area in ft^2:

$$K = \left(\frac{1096A}{\sqrt{\rho F}} \right)$$

K is used with some terminal unit controls to calculate standard airflow using the following equation, where Q is airflow in ft^3/min and Pvm is flow sensor output in inches water gauge:

$$Q = K * \sqrt{Pvm}$$

flow probe signal (P_{vm}): output of a velocity pressure flow probe (typically an amplified velocity pressure).

full-system test: This measures the combined performance of a controller, actuator, and *air terminal unit.*

national measurement standard: measurement standard recognized by national authority to serve in a state or economy as the basis for assigning quantity values to other measurement standards.

pressure: force exerted per unit area.

reference airflow measuring system: combination of sensing devices and data acquisition hardware and software that produces the airflow value against which the system under test (SUT) is compared.

shall: where *shall* and *shall not* are used for a specified provision, that provision is mandatory if compliance with this test method is claimed.

standard air: air that meets the following criteria:

I-P units: dry air at 70°F and 14.696 psia. Under these conditions, dry air has a mass density of 0.075 lb/ft^3. Note: this is not the same as SI standard air.

SI units: dry air at 20°C and 101.325 kPa. Under these conditions, dry air has a mass density of 1.204 kg/m^3. Note: this is not the same as IP standard air.

system under test (SUT): the combination of components whose performance is the subject of the test, as distinct from the components that serve as the test facility or test equipment.

test specifier: individual or organization that calls out details for a test conforming to this MOT. The test specifier may designate products to be tested, airflow rates and pressure drops, ambient temperatures, calibration procedure, and pass/fail criteria.

tolerance: the level of accuracy desired in the airflow control system under test; the criterion by which the SUT is judged to pass or fail the steady state accuracy test.

velocity pressure (P_v): in a moving fluid, the pressure due to the velocity and density of the fluid, expressed by the velocity squared times the fluid density, divided by two (ρV2/2). For example, with standard air specific at 0.075 lbm/ft3, Pv in inches water gauge = (V/4005)2.

voltmeter: a device used to measure differences in electrical potential between points in an electrical circuit.

zero drift: change in sensor output at zero flow with the passage of time, change in temperature, or both.

3.2 The following nomenclature is used throughout this test method:

Table 1. Nomenclature

Symbol	Quantity	I-P Units	SI Units
A	Internal cross section of duct	ft^2	m^2
D_e	Equivalent diameter	ft	m
P	Absolute static pressure	in H_2O	Pa
P_a	Atmospheric pressure	in Hg	Pa
P_v	Velocity pressure	in H_2O	Pa
P_{vm}	Flow probe signal	in H_2O	Pa
P_s	Static pressure	in H_2O	Pa
P_t	Total pressure	in H_2O	Pa
ΔP	Differential pressure	in H_2O	Pa
ΔP_t	Total differential pressure	in H_2O	Pa
Q_a	Airflow at actual test conditions	ft^3/min (cfm)	L/s
Q_s	Airflow at standard conditions	ft^3/min (cfm)	L/s
V	Air velocity	ft/min (fpm)	m/s
ρ	Air density	lb_m/ft^3	Kg/m^3

4 INSTRUMENTATION

4.1 Temperature Measurement

Temperature measurements made to support determining the reference airflow are covered in Section 4.3. This section applies to other temperature measurements taken during testing.

Temperature measuring instruments shall meet the requirements of *ASHRAE Standard 41.1-2013 (RA 2006)*[3] and the following:

4.1.1 Accuracy of the temperature measuring instruments shall be within ±0.18°F (0.1°C). The smallest scale division or output resolution of the temperature measuring device shall not exceed the specified accuracy.

4.1.2 Temperature measuring instruments shall be calibrated, on an annual basis, in the range of use by comparison to a national measurement standard, with uncertainties traceable to that national measurement standard, and shall be certified to provide the accuracies listed in 4.1.1.

4.2 Pressure Measurement

Refer to Section 5.3 for pressure measurements made to support determining the reference airflow.

Pressure measuring instruments shall meet the requirements of *ASHRAE Standard 41.3-2014*[4] and the following:

4.2.1 Accuracy of the duct pressure measuring instruments shall be within 5% of the measured pressure. The smallest scale division or output resolution of the pressure measuring device shall not exceed the specified accuracy.

4.2.2 Accuracy of the sensor recording the flow probe signal (if the SUT includes flow probe pressure taps) shall be within 5% of the reading.

4.2.3 Pressure measuring instruments shall be calibrated annually, in the range of use, by comparison with a national measurement standard (e.g., a NIST standard). Instruments shall be calibrated directly against the national standard, or through a traceable chain of not more than two intermediary instruments. Measurement uncertainty, based on that calibration, shall satisfy the accuracies listed.

4.3 Airflow Measurement

The reference airflow measuring system shall be calibrated annually, in the range of use, by comparison with a national measurement standard (e.g., a NIST standard). The reference airflow measuring system shall be calibrated as an assembly. Instruments shall be calibrated directly against the national standard, or through a traceable chain of not more than two intermediary instruments. Based on that calibration, the airflow measuring reference system shall be certified to provide an accuracy at least 4:1 better than the specified tolerance at the measurement point and under all the conditions required for the intended rating. The tolerance shall specify sufficient detail to allow application at the measurement points selected by the specifier. For example, if from 0 to 2,000 fpm (10.1 m/s) the test tolerance is “the greater of ±5% and 20 fpm (0.1 m/s),” then the uncertainty in the reference airflow measuring system can be no greater than ±5 fpm (0.025 m/s) at any point below 400 fpm (2.03 m/s). The reference tolerance must be ±1.25% from 400 to 2,000 fpm (2.03 – 10.1 m/s) in this example.

Separate reference airflow measuring systems may be used for the high flow and low flow accuracy subtests in 6.2.1.

Airflow-measuring instruments shall meet the requirements of *ASHRAE Standard 41.2-2018*[5] and the following:

4.3.1 Type of Instrument

Airflow measurements shall be made with one of the following types of instruments:

Velocity Pressure - Laboratory Pitot-static tube array with high accuracy pressure sensors.

Differential Pressure - orifice plate or nozzles using differential pressure sensors similar to that indicated above for velocity pressure measurement.

Other Measuring Means - volumetric airflow or velocity measuring means.

4.3.2 Measurements to Determine Air Density

The requirements in this section apply if the airflow measuring reference system depends on calculation of air density. Density shall be calculated according to ASHRAE Handbook—Fundamentals Chapter 6[6].

Sensing instruments that support the density calculation shall meet the following specifications.

4.3.2.1 Temperature

Temperature at the airflow reference measurement point shall be accurate to within ±1.0°F (0.5°C).

4.3.2.2 Absolute and Barometric Pressure

Absolute air pressure in the duct, at the airflow reference measurement point, shall be accurate to within ±0.5 in. w.c. (125 Pa) (including accuracy of the duct static pressure sensor and the barometric pressure sensor).

Barometric pressure shall be obtained by means of a barometer located within the test area.

4.3.2.3 Humidity

The moisture content of the air shall be determined by measuring one of the following properties.

1. Wet-bulb Temperature

Wet-bulb temperatures shall be read only under conditions that ensure an air velocity between 700 fpm (3.5 m/s) and 2000 fpm (10 m/s) over the wet-bulb and only after sufficient time has been allowed for evaporative equilibrium to be attained. The wick on the wet-bulb thermometer shall be clean, fit the thermometer tightly, and be moistened by distilled water. Wet-bulb thermometers shall always be downstream from dry-bulb thermometers, or if not, they shall be shielded from each other.

2. Relative humidity or dew point:

A direct reading electronic relative humidity or dew point meter shall provide relative humidity readings to within +/- 5% or dew point readings to within ±1.0°F (0.5°C).

4.4 Electrical Measurement

4.4.1 Electrical measurements shall be made with the following instruments.

Voltmeters shall be true RMS, high-impedance meters with an accuracy within ± 1% of reading. Ammeters shall have a true RMS accuracy of ± 2% of reading.

4.4.2 Electrical measuring instruments shall be calibrated annually, in the range of use, by comparison with a national measurement standard (e.g., a NIST standard). Instruments shall be calibrated directly against the national standard, or through a traceable chain of not more than two intermediary instruments. Measurement uncertainty, based on that calibration, shall satisfy the accuracies listed.

4.5 Automatic Data Acquisition

Test data shall be automatically gathered from the prescribed sensors or instruments and logged for analysis and reporting purposes.

5 TEST SETUP

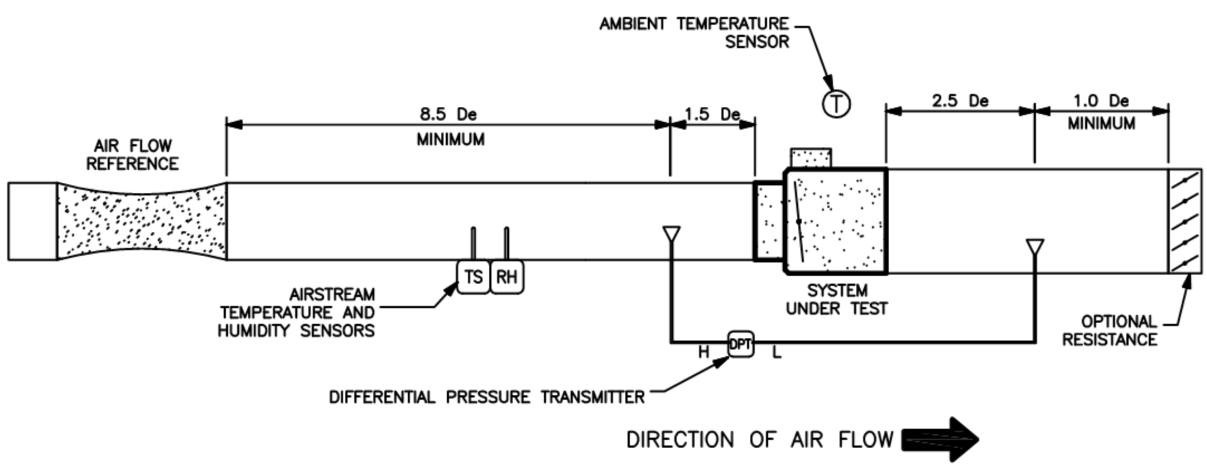

Figure **1** illustrates the required test setup. The following sections describe the components and their relationship.

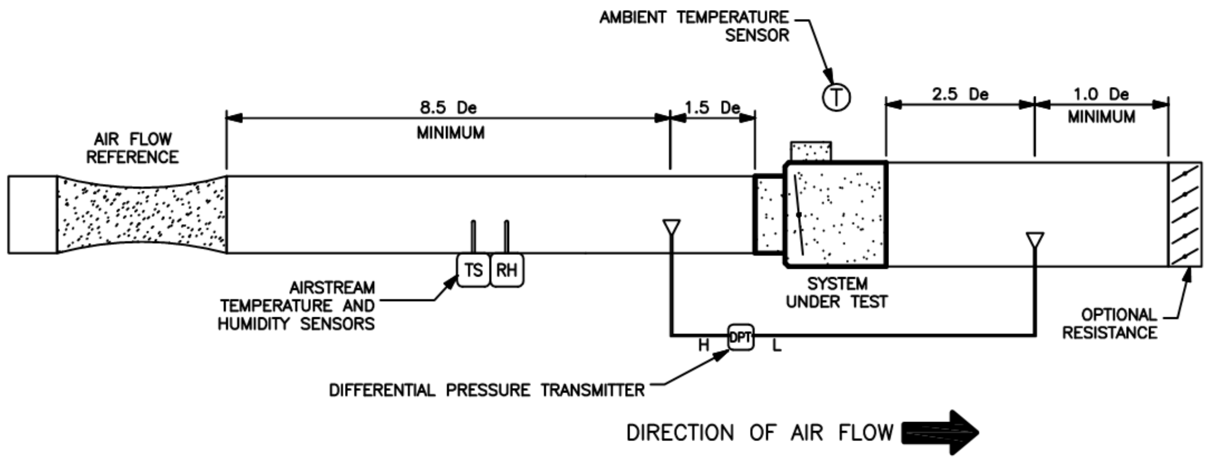

Figure 1 Required Test Setup.

5.1 Inlet to Terminal

The nominal test condition is a straight, hard inlet to the terminal. Minimum of 10 duct diameters. The inlet duct dimensions shall be the same size as terminal inlet, i.e., no transitions. The test specifier may designate other required inlet conditions.

5.2 Outlet from Terminal

Minimum of 3.5 straight duct diameters. Downstream duct size shall match the terminal unit outlet, i.e., no transitions. A flow resistance (e.g., damper) may be installed downstream of this duct.

5.3 Airflow Reference

A reference airflow measuring system, conforming to Section 4.3, shall be installed a minimum of 10 duct diameters upstream of the air terminal.

5.4 Ambient Air Temperature Sensor

Ambient air temperature sensor shall not be in the airstream. It shall be located within 12" (30 cm) of the controller and shall be representative of the temperature of air surrounding the controller.

5.5 Airstream Temperature and Humidity Sensors

The airstream temperature sensor and humidity sensor shall be located in the airstream of the air terminal. They shall be located between 3 and 10 diameters upstream of the air terminal.

5.6 Static Pressure Drop (ΔSP)

The static pressure drop (a.k.a. differential static pressure) across the air terminal shall be measured. The high pressure port shall be located 1.5 equivalent duct diameters upstream of the air terminal. The low pressure port shall be located 2.5 equivalent duct diameters downstream of the air terminal.

5.7 Flow Probe Signal (for systems that include a velocity pressure flow probe)

If tees are available in the tubing between the flow probe and the controller, then they shall be used in order to measure the flow probe signal with a reference pressure sensor. The reference sensor needs to use a pressure sensor that has a dead end so it does not disrupt the pressure seen by the controller under test.

5.8 Controller

The controller shall be mounted and connected per the manufacturer's instructions.

5.9 Ductwork Leakage

Every joint of the ductwork between the reference airflow station and the unit under test must be sealed and tested. A duct pressure test shall be conducted at 6.0 in. w.c (1500 Pa). The measured leakage rate shall be less than 10 scfm (5 L/s).

6 TEST METHODS

To ensure the highest level of comparability between the test results of two different SUTs, regardless of the documented accuracy of the comparison references involved, the test specifier shall require that the tests be performed in the same lab, using the same equipment, reference, and setup.

6.1 Calibration

The SUT is calibrated on the test installation, with the intention that the calibration process used in the lab represents the one that will be used in a field installation. The reference airflow measuring system, used for the System Performance Tests, shall also be used for calibration.

The SUT shall be calibrated in the test installation according to the procedures recommended by the manufacturer.

6.2 System Performance Test Methods

The test specifier may specify that all of the following Test Methods be performed or only one or more of the Test Methods. For each Test Method specified, the method must be followed in its entirety and all other requirements of this standard must be followed (e.g. Instrumentation, Calibration, etc.)

6.2.1 Steady State Accuracy Test Method

This test is intended to measure the accuracy of the system as installed on an airflow terminal unit.

The terminal unit/control assembly to be tested shall be installed per Section 5.

6.2.1.1 Test Steps

1. Calibrate the airflow control at the minimum (Qmin) and maximum (Qmax) airflow setpoints of interest.
    a. Record the ambient temperature at which the controller was calibrated, Tcal.
2. Subtest 1 – Qmax:
    a. With the static pressure difference across the terminal at setpoint (ΔSP), set the controller to Qmax.
    b. Maintain pressure across the flow control device within 15% of setpoint during the test.

c. Begin recording with data acquisition system. Record 30 samples at regular intervals of between 10 and 60 seconds. Data collected shall include:
    i. Reference airflow rate
    ii. Ambient dry-bulb temperature
    iii. Airstream dry-bulb temperature
    iv. Pressure drop across the flow control device
    v. Flow rate indicated by product under test (if available)
    vi. Flow probe signal (inches w.c.) for systems that include velocity pressure sensors (note: Controller-Only Tests include velocity pressure sensors).

3. Without recalibrating the airflow control, proceed to Subtest 2.
4. Subtest 2 – Qmin.
    a. With the static pressure difference across the terminal at setpoint (∆SP), set the control to the desired setpoint (Qstpt).
    b. Maintain pressure across the flow control device within 15% of setpoint during the test.
    c. Begin recording with data acquisition system. Record 30 samples at regular intervals of between 10 and 60 seconds. Data collected shall include:
        i. Reference airflow rate
        ii. Ambient dry-bulb temperature
        iii. Airstream dry-bulb temperature
        iv. Pressure drop across the flow control device
        v. Flow rate indicated by product under test (if available)
        vi. Flow probe signal (inches w.c.) for systems that include velocity pressure sensors.
5. Report
    a. Ambient dry-bulb temperature during calibration.
    b. Ambient wet-bulb, relative humidity, or dew point used for air density.
    c. Barometric pressure used for air density.
    d. Table of all data readings.
    e. Average airflow reading in scfm, fpm, and % of setpoint for each Subtest.
    f. Highest and lowest airflow readings in scfm and % of setpoint for each Subtest.
    g. For systems that include velocity pressure sensors:
        i. Average flow probe signal in inches w.c. for each Subtest

ii. Average amplification factor for each Subtest.

6.2.2 Zero Drift Test Method

1. Perform the System Accuracy Test.
2. Set the ∆SP setpoint and Qstpt to the desired values.
3. If the auto-zero feature requires shutting off the fan or closing the damper, then it shall be disabled during Subtest 1 and Subtest 2.
4. Subtest 1:
    a. Raise the ambient temperature and airstream temperature so that it is at least 7°F (3.5°C) above the calibration temperature during part b.
    b. With ∆SP at setpoint and the unit controlling to Qstpt, record 30 samples of actual airflow and ambient and airstream temperature at regular intervals of between 10 and 60 seconds.
5. Subtest 2:
    a. Lower the ambient temperature and airstream temperature so that it is at least 7°F (3.5°C) below the calibration temperature during part b.
    b. With ∆SP at setpoint and the unit controlling to Qstpt, record 30 samples of actual airflow and ambient and airstream temperature at the same interval used in Subtest 1.
6. Enable auto-zero and wait until the unit goes through at least one auto-zero cycle. The auto-zero function may be manually initiated if wait time exceeds one hour (e.g., override master time clock to trigger auto-zero). Skip this step if the unit does not have an auto-zero feature.
7. Record the auto-zero ambient temperature (Taz) and auto-zero supply air temperature (Tsz) during the auto-zero cycle. If the unit does not have an auto-zero feature, then Taz and Tsz shall be the current ambient and supply air temperatures. Taz and Tsz shall be at least 7°F (3.5°C) below the calibration temperature.
8. If the auto-zero feature requires shutting off the fan or closing the damper, then it shall be disabled during Subtests 3, 4, and 5.
9. Subtest 3:
    a. With ambient and supply air temperatures within 2°F (1°C) of Taz and Tsz, ∆SP at setpoint, and the unit controlling to Qstpt, record 30 samples of actual airflow and ambient and supply air temperatures at the same interval used in Subtest 1.
10. Subtest 4:
    a. Raise the ambient temperature and supply air temperature so that it is at least 7°F (3.5°C) above Taz and Tsz during part b.

b. With ∆SP at setpoint and the unit controlling to Qstpt, record 30 samples of actual airflow and ambient and supply air temperatures at the same interval used in Subtest 1.

11. Subtest 5:
    a. Lower the ambient temperature and supply air temperature so that it is at least 7°F (3.5°C) below Taz and Tsz during part b. (This implies a test at least 14°F (7°C) below calibration temperature.)
    b. With ∆SP at setpoint and the unit controlling to Qstpt, record 30 samples of actual airflow and ambient and supply air temperatures at the same interval used in Subtest 1.
12. Report:
    a. Ambient and supply air temperatures during calibration.
    b. Ambient and supply air temperatures during auto-zero.
    c. Table of all subtest data readings.
    d. Average airflow reading of all subtests in scfm and % of setpoint.
    e. Highest and lowest airflow readings of all subtests in scfm and % of setpoint.

6.2.3 Stability Test Method

1. Perform the System Accuracy Test.
2. Set the ∆SP setpoint and Qstpt to the desired values.
3. Begin recording data.
4. After 10 minutes, the ∆SP shall gradually decrease to 50% of the original setpoint over at least 15 minutes and no more than 20 minutes.
5. Wait 10 minutes with ∆SP stable at new setpoint.
6. The ∆SP shall gradually rise to 200% of the original setpoint over at least 15 minutes and no more than 20 minutes.
7. Wait 10 minutes with ∆SP stable at new setpoint.
8. Stop recording data.
9. Recorded data with data acquisition system:
    a. Average airflow reading in scfm and % of setpoint.
    b. Highest and lowest reference airflow readings in scfm and % of setpoint.
    c. Actual airflow rate, 1 minute intervals.
    d. Pressure drop across the flow control device, 1 minute interval.
    e. Flow rate indicated by product under test (if available), 1 minute interval.

7 CONTROLLER-ONLY TESTS

The *controller-only test* determines the flow probe signal (P_{vm}) at which the flow control system passes the System Performance Tests.

The SUT for the controller-only test is the same as the SUT for the full-system test, except that the air terminal is replaced with a standard air terminal that meets the requirements listed in Normative Appendix C.

8 TEST REPORT

The following figures illustrate an acceptable format for reporting the accuracy test results. The report shall not present average accuracy values that indicate better than 4 times the accuracy of the reference airflow measuring system.

The test report shall include information on the test equipment used, including names, model numbers, serial numbers, and calibration records. The following figures illustrate an acceptable format for the test data.

Table 8.1 Summary of Test Conditions

Qmax				500	SCFM		ambient dry bulb during calibration		
Qstp	(set point)			65	SCFM		Barometric Pressure:		
Pvm (average velocity pressure signal at Qstpt)				**0.0050**	Inches W.G		relative humidity:		
Duct area at location of sensor				0.35	ft2		air density		
published amplification factor (F)				2.3	unit less		Delta SP set point:		
sample interval				15	seconds				
Reference Meter Accuracy at Max flow.				1%	5	SCFM			
Reference Meter Accuracy at Set point.				1%	0.65	SCFM			
Average Flow Tolerance at Max (must be greater then 4X the reference accuracy)				10%	50	SCFM			
Single-Sample Flow Tolerance at Max (must be greater then 4X the reference accuracy)				20%	100	SCFM			
Average Flow Tolerance at Setpoint (must be greater then 4X the reference accuracy)				10%	6.5	SCFM			
Single-Sample Flow Tolerance at Setpoint (must be greater then 4X the reference accuracy)				20%	13	SCFM			
			Min	Max					
Measurement Accuracy		4%	96.00%	104.00%					

Table 8.2 Summary of Test Results

		Reference Sensor Output						Calculated Values					
		Ambient Dry Bulb (deg. F)	Airstream dry bulb (F)	Reference Air Flow (SCFM)	dSP across the unit (in. w.g.)	flow probe output (in. w.g.)	Airflow Output from System Under Test (CFM)	velocity at System Under Test (fpm)	Pct of airflow set point (ref/set point)	Difference between reference and setpoint (SCFM)	flow calculated from probe output and published sensor characteristic (CFM)	observed amplification factor	Test Tolerance Pass/Fail
average at setpoint		73.2	56.3	67	0.62	0.0050	64	192	0.96 to 1.04%	-2.6 to 2.6	65.4	2.19	Pass
min at setpoint		73.2	56.2	55	0.61	0.0050	56	157	85%	-10.0	65.4	3.25	Pass
max at setpoint		73.2	56.4	77	0.64	0.0050	67	220	118%	12.0	65.4	1.66	Pass
average at max		73.2	56.3	505	0.62	0.2800	499	1444	0.96% - 1.04%	-20 to 20	489.1	2.15	Pass
min at max		73.2	56.2	436.0	0.61	0.2800	488	1246	87%	-64.0	489.1	2.89	Pass
max at max		73.2	56.4	551	0.64	0.2800	512	1574	110%	51.0	489.1	1.81	Pass

Table 8.3 Test Report Sheet Showing Data at Q_{setpt}

Qstp		Reference Sensor Output						Calculated Values					
Sample Number	Time (sec)	Ambient Dry Bulb (deg. F)	Airstream dry bulb (F)	Reference Air Flow (SCFM)	dSP across the unit (in. w.g.)	flow probe output (in. w.g.)	Airflow Output from System Under Test (CFM)	velocity at System Under Test (fpm)	Pct of airflow set point (ref/set point)	Difference between reference and setpoint (SCFM)	flow calculated from probe output and published sensor characteristic (CFM)	observed amplification factor	Test Tolerance Pass/Fail
1	0	73.2	56.3	66.0	0.62	0.005	65	189	102%	1.0	65.4	2.26	Pass
2	15	73.2	56.3	67.0	0.62	0.005	65	191	103%	2.0	65.4	2.19	Pass
3	30	73.2	56.2	65.0	0.62	0.005	65	186	100%	0.0	65.4	2.32	Pass
4	45	73.2	56.2	67.3	0.62	0.005	62	192	104%	2.3	65.4	2.17	Pass
5	60	73.2	56.3	68.1	0.62	0.005	62	195	105%	3.1	65.4	2.12	Pass
6	75	73.2	56.3	68.1	0.62	0.005	64	195	105%	3.1	65.4	2.12	Pass
7	90	73.2	56.3	68.1	0.63	0.005	64	195	105%	3.1	65.4	2.12	Pass
8	105	73.2	56.3	68.1	0.63	0.005	65	195	105%	3.1	65.4	2.12	Pass
9	120	73.2	56.3	68.1	0.63	0.005	66	195	105%	3.1	65.4	2.12	Pass
10	135	73.2	56.3	71.0	0.63	0.005	64	203	109%	6.0	65.4	1.95	Pass
11	150	73.2	56.3	74.0	0.63	0.005	65	211	114%	9.0	65.4	1.79	Pass
12	165	73.2	56.4	76.0	0.64	0.005	65	217	117%	11.0	65.4	1.70	Pass
13	180	73.2	56.3	77.0	0.64	0.005	65	220	118%	12.0	65.4	1.66	Pass
14	195	73.2	56.3	68.1	0.64	0.005	64	195	105%	3.1	65.4	2.12	Pass
15	210	73.2	56.3	65.0	0.63	0.005	64	186	100%	0.0	65.4	2.33	Pass
16	225	73.2	56.3	68.1	0.63	0.005	65	195	105%	3.1	65.4	2.12	Pass
17	240	73.2	56.3	68.1	0.63	0.005	65	195	105%	3.1	65.4	2.12	Pass
18	255	73.2	56.3	61.7	0.62	0.005	63	176	95%	-3.3	65.4	2.58	Pass
19	270	73.2	56.4	68.1	0.62	0.005	64	195	105%	3.1	65.4	2.12	Pass
20	285	73.2	56.4	60.0	0.62	0.005	65	171	92%	-5.0	65.4	2.73	Pass
21	300	73.2	56.3	58.0	0.62	0.005	65	166	89%	-7.0	65.4	2.92	Pass
22	315	73.2	56.3	55.0	0.61	0.005	56	157	85%	-10.0	65.4	3.25	Pass
23	330	73.2	56.3	68.1	0.61	0.005	65	195	105%	3.1	65.4	2.12	Pass
24	345	73.2	56.4	60.6	0.61	0.005	65	173	93%	-4.4	65.4	2.68	Pass
25	360	73.2	56.3	69.0	0.61	0.005	65	197	106%	4.0	65.4	2.06	Pass
26	375	73.2	56.3	68.1	0.62	0.005	65	195	105%	3.1	65.4	2.12	Pass
27	390	73.2	56.4	65.0	0.62	0.005	66	186	100%	0.0	65.4	2.33	Pass
28	405	73.2	56.4	68.1	0.62	0.005	66	195	105%	3.1	65.4	2.12	Pass
29	420	73.2	56.4	68.1	0.62	0.005	66	195	105%	3.1	65.4	2.12	Pass
30	435	73.2	56.3	68.1	0.62	0.005	67	195	105%	3.1	65.4	2.12	Pass

Table 8.4 Test Report Sheet Showing Data at Q_{max}

Qmax		Reference Sensor Output						Calculated Values					
Sample Number	Time (sec)	Ambient Dry Bulb (deg. F)	Airstream dry bulb (F)	Reference Air Flow (SCFM)	dSP across the unit (in. w.g.)	flow probe output (in. w.g.)	Airflow Output from System Under Test (CFM)	velocity at System Under Test (fpm)	Pct of airflow set point (ref/set point)	Difference between reference and setpoint (SCFM)	flow calculated from probe output and published sensor characteristic (CFM)	observed amplification factor	Test Tolerance Pass/Fail
1	0	73.2	56.3	511.0	0.62	0.28	505	1,460	102%	446.0	489.1	2.11	Pass
2	15	73.2	56.3	525.0	0.62	0.28	508	1,500	105%	460.0	489.1	2.00	Pass
3	30	73.2	56.2	511.0	0.62	0.28	508	1,460	102%	446.0	489.1	2.11	Pass
4	45	73.2	56.2	537.0	0.62	0.28	508	1,534	107%	472.0	489.1	1.91	Pass
5	60	73.2	56.3	525.0	0.62	0.28	505	1,500	105%	460.0	489.1	2.00	Pass
6	75	73.2	56.3	511.0	0.62	0.28	507	1,460	102%	446.0	489.1	2.11	Pass
7	90	73.2	56.3	511.0	0.63	0.28	505	1,460	102%	446.0	489.1	2.11	Pass
8	105	73.2	56.3	482.0	0.63	0.28	512	1,377	96%	417.0	489.1	2.37	Pass
9	120	73.2	56.3	491.0	0.63	0.28	501	1,403	98%	426.0	489.1	2.28	Pass
10	135	73.2	56.3	511.0	0.63	0.28	505	1,460	102%	446.0	489.1	2.11	Pass
11	150	73.2	56.3	466.0	0.63	0.28	505	1,331	93%	401.0	489.1	2.53	Pass
12	165	73.2	56.4	484.0	0.64	0.28	505	1,383	97%	419.0	489.1	2.35	Pass
13	180	73.2	56.3	511.0	0.64	0.28	505	1,460	102%	446.0	489.1	2.11	Pass
14	195	73.2	56.3	511.0	0.64	0.28	505	1,460	102%	446.0	489.1	2.11	Pass
15	210	73.2	56.3	503.0	0.63	0.28	505	1,437	101%	438.0	489.1	2.17	Pass
16	225	73.2	56.3	505.0	0.63	0.28	498	1,443	101%	440.0	489.1	2.16	Pass
17	240	73.2	56.3	551.0	0.63	0.28	498	1,574	110%	486.0	489.1	1.81	Pass
18	255	73.2	56.3	522.0	0.62	0.28	498	1,491	104%	457.0	489.1	2.02	Pass
19	270	73.2	56.4	508.0	0.62	0.28	490	1,451	102%	443.0	489.1	2.13	Pass
20	285	73.2	56.4	475.0	0.62	0.28	490	1,357	95%	410.0	489.1	2.44	Pass
21	300	73.2	56.3	459.0	0.62	0.28	490	1,311	92%	394.0	489.1	2.61	Pass
22	315	73.2	56.3	488.0	0.61	0.28	490	1,394	98%	423.0	489.1	2.31	Pass
23	330	73.2	56.3	436.0	0.61	0.28	490	1,246	87%	371.0	489.1	2.89	Pass
24	345	73.2	56.4	495.0	0.61	0.28	490	1,414	99%	430.0	489.1	2.25	Pass
25	360	73.2	56.3	511.0	0.61	0.28	488	1,460	102%	446.0	489.1	2.11	Pass
26	375	73.2	56.3	533.0	0.62	0.28	488	1,523	107%	468.0	489.1	1.94	Pass
27	390	73.2	56.4	545.0	0.62	0.28	488	1,557	109%	480.0	489.1	1.85	Pass
28	405	73.2	56.4	524.0	0.62	0.28	494	1,497	105%	459.0	489.1	2.00	Pass
29	420	73.2	56.4	511.0	0.62	0.28	494	1,460	102%	446.0	489.1	2.11	Pass
30	435	73.2	56.3	511.0	0.62	0.28	494	1,460	102%	446.0	489.1	2.11	Pass

9 REFERENCES

1. *ANSI/ASHRAE Standard 130-2008, Methods of Testing Air Terminal Units.* Atlanta: American Society of Heating, Refrigerating and Air Conditioning Engineers Inc.
2. *ASHRAE Terminology of Heating, Ventilation, Air Conditioning, and Refrigeration.* Atlanta: American Society of Heating, Refrigerating and Air Conditioning Engineers Inc.
3. *ANSI/ASHRAE Standard 41.1-2013 (RA 2006), Standard Method for Temperature Measurement*. Atlanta: American Society of Heating, Refrigerating and Air Conditioning Engineers Inc.
4. *ANSI/ASHRAE Standard 41.2-1987 (RA 1992), Standard Methods for Airflow Measurement*. Atlanta: American Society of Heating, Refrigerating and Air Conditioning Engineers Inc.
5. *ANSI/ASHRAE Standard 41.3-2014, Standard Method for Pressure Measurement*. Atlanta: American Society of Heating, Refrigerating and Air Conditioning Engineers Inc.
6. *ASHRAE Handbook—Fundamentals*. Atlanta: American Society of Heating, Refrigerating and Air Conditioning Engineers Inc.

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 a public review or a consensus process. Unresolved objectors on informative material are not offered the right to appeal at ASHRAE or ANSI.

APPENDIX A – RATING CONDITIONS

A.1 System Performance Test

A.1.1 Accuracy

- ΔSP = 0.3 in. w.c. (75 Pa) or pressure required to reach Qmax
- Qmax = flow rate corresponding to an inlet velocity of 1,800 feet/min, or mfg suggested maximum flow, whichever is lower
- Qstpt = any setpoint

The System Accuracy test is passed if the following tolerance conditions are met:

1. No individual airflow reading is more than 20% above or below the setpoint.
2. The average airflow reading is within 10% of the setpoint.

For full system tests: The tester is encouraged to repeat the test at different Qstpt in order to determine the lowest airflow rate at which the test is passed.

For Controller-Only tests: The tester is encouraged to repeat the test at different Qstpt in order to determine the lowest flow probe signal (P_{vm}) at which the test is passed.

A.1.2 Zero Drift

ΔSPstpt and Qstpt shall be values at which the system also passed the Accuracy Test.

The Zero Drift test is passed if the following tolerance conditions are met during all subtests:

1. No individual airflow reading is more than 30% above or below the setpoint.
2. The average airflow reading for each subtest is within 15% of the setpoint.

A.1.3 Stability – Low Flow

ΔSPstpt and Qstpt shall be values at which the system also passes the Accuracy Test.

The Stability test is passed if the following tolerance conditions are met during all subtests:

1. No individual airflow reading is more than 30% above or below the setpoint.
2. The average airflow reading for each subtest is within 15% of the setpoint.

A.1.4 Stability – Max Flow

ΔSPstpt = 0.6 in. w.c. (150 Pa) or twice the pressure required to reach Qmax

Qstpt = Qmax = flow rate corresponding to an inlet velocity of 1,800 feet/min, or mfg suggested maximum flow, whichever is lower

The Max Flow Stability test is passed if the following tolerance conditions are met during all Stability subtests:

1. No individual airflow reading is more than 30% above or below the setpoint.
2. The average airflow reading for each subtest is within 15% of the setpoint.

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APPENDIX B – EXEMPLARY TEST FACILITY AND GUIDANCE FOR MEASURING AIR AT LOW FLOW RATES

This informative appendix describes a test facility that is suited to support tests conforming to this standard. This appendix and the list of instrumentation are more specific than the requirements of the standard. It presents an example of possible conformant testing situations and their associated capabilities or limitations. It does not add requirements or constrain users of the standard.

B.1 Instrumentation

The examples listed below represent variations in cost, type, and performance. Both the mechanical configuration of the lab setup and the instruments selected influence the ability of the lab to provide the results required.

B.1.1 Temperature	Thermo-metrics Precision Thermometer TS8504 /S10
Using GE Type S/AS/ES Precision	Ultrastable NTC Standards
Stability (Type AS):	0.002° C/year
Range (Type S/AS)	0 - 60.° C
3-pt Water Cal to NIST Standards	0.005%
Accuracy	0.001 °C
Comments	

B.1.2 Pressure

B.1.2.1 Duct Pressure

MKS 698A Series Baratron® (Differential) Pressure Transducer + MKS 270A High Accuracy Signal Conditioner	
1 Torr Units Only	0.05 of reading ±zero/span coeff. Unidirectional calibration only
Resolution (of FS)	1 x 10-6
Sensor Temperature	Regulated at 45°C
Sensor Type	Single sided, dual electrode

Temperature Effects on Span,1 Torr range	<0.002% R / °C (20 ppm)
Temperature Effects on Zero,1 Torr range at 0.05% or 0.08% of Reading accuracy	<4 PPM, F.S./ °C
Ambient Operating Temperature	15° to 40°C (59° to 104°F)
Comments: Although not required, this type of sensor is used for both differential (velocity) pressure measurements and duct static pressure.	

B.1.2.2 Barometric Pressure

MKS 627B Series process capacitance manometer.	
Full-scale Ranges	0.02, 0.05, 0.1, 1, 2, 10, 20, 100, & 1,000 Torr
Resolution	0.001% of F.S. (0.1 Torr or greater), 0.002% of F.S. {0.02, 0.05 Torr)
Accuracy (% of reading)	0.12% (1 - 1,000 Torr FS) 0.15% (0.1, 0.05 Torr FS) 0.25% (0.02 Torr FS)
Temperature Coefficient Zero (%FS/ °C)	0.002% (1-1,000 Torr FS) 0.005% (0.1 Torr) 0.015% (0.05 Torr) 0.03% (0.02 Torr)
Span	0.02% of reading °C
Ambient Operating Temperature	15-40 °C
Input Power	t15 VDC :t:5% @0.25 Amax
Output (into 10K ohm load)	0-10 VDC
Comments	

B.1.3 Relative Humidity (RH)Vaisala Humicap 180	
Performance at -20…+40 °C:	± (1.0+0.008 x reading)% RH (0 – 100% RH)
Factory Cal Uncertainty (+20°C):	± 0.06% RH (0 – 40% RH) ± 1.0% RH (40 – 97% RH)
Operating Range (display)	+32 – 140°F

Comments

B.1.4 Air Velocity Reference

Type - **Orifice Plates / Orifice Tube**	
Performance	1% flow accuracy
Calibrated Range	3000 and 7000 fpm 1.875" diameter: 55 – 135 cfm 2.75" diameter: 125 – 290 cfm 4.0" diameter: 260 – 610 cfm 6.0" diameter: 590 – 1375 cfm 8.0"diameter: 1045 – 2440 cfm
Comments: Calibrate with the differential pressure transducer to conform to the standard. Orifice size selected to fit flow rate of test.	

MKS 698A Series Baratron® Velocity Pressure Transducer + MKS 270A High Accuracy Signal Conditioner	
1 Torr Units Only	**0.05 of reading** ±zero/span coeff. Unidirectional calibration only
Resolution (of FS)	1 x 10-6
Sensor Temperature	Regulated at 45°C
Sensor Type	Single sided, dual electrode
Temperature Effects on Span,1 Torr range	<0.002% R / °C (20 ppm)
Temperature Effects on Zero,1 Torr range at 0.05% or 0.08% of Reading accuracy	<4 PPM, F.S./ °C
Ambient Operating Temperature	15° to 40°C (59° to 104°F)
Comments: Calibrate with the orifice tube to conform to the standard.	

This reference airflow measuring system measures velocity (or velocity pressure requiring conversion). References to volumetric equivalent units are conversions based on duct free area and air density. This is true of most airflow sensors.

The orifice tube is one of the velocity pressure based velocity sensing technologies. It generates a pressure signal that is read with a differential pressure transducer. The characteristics of the differential pressure transducer can significantly affect overall system accuracy. At airflows low in the sensing range, the system accuracy is particularly sensitive to offset errors in the differential pressure transducer. Components of error expressed in percent of reading indicate no offset error. Components of error expressed in percent of full scale indicate the possibility of offset errors.

For sensors whose velocity performance is limited in range, multiple devices with overlapping ranges may be necessary to perform the tests required by this standard, e.g., differential pressure sensors.

B.1.5 Voltage

Agilent 34410A	**24 hr Tcal +/-1ºC**
DC Voltage 10.0000V:	± 0.0015% + 0.0064%FS
AC Voltage 100mV-750V (10Hz-20 kHz):	± 0.02% + 0.02%FS
Resistance 10.0000 kΩ@100 A:	± 0.0028% + 0.0005%FS

B.2 Data Acquisition

Data may be recorded manually or automatically. The more consistent, reliable, and most accurate method is automatic data recording, which can take many shapes. One of the simpler and least expensive is to use the data logging capability of HVAC control networks and digital outputs. Simple and custom data structure can be designed to suit the laboratory and testing requirements. It also eliminates output/input resolution issues, which can make significant differences in the uncertainty of the data.

B.3 Test System Capability

The standard requires 4:1 superiority of the reference airflow measuring system, over the test tolerance. This restricts application of a test system to tolerance levels at least 4 times greater than the accuracy of the reference, at the flow rate used in the test.

The table below presents calibration data for the reference airflow measuring system and relates it to the test tolerance that the test system can support. The supported tolerance can vary with airflow because the accuracy of the reference can vary with airflow.

Nominal airflow	Calibrated accuracy	Tolerance supported
0 to 55 cfm	not calibrated	none
55 to 2400 cfm	1.5% of reading	4 x 1.5% = 6%
> 2400 cfm	not calibrated	none

The performance of the reference measurement instrument is most reliably established by calibrating as an assembly, all components required to produce a measurement result. The standard requires this approach. The alternative is to calculate the system accuracy by combining the accuracy values for each component. In this case, it would be necessary to combine the accuracy of the orifice tube with the accuracy of the velocity pressure sensing transducer.

B.4 General Guidelines for Measuring Airflow

The difficulties in reliably measuring velocities less than 700 fpm requires a combination of higher quality and higher performing instruments to make the uncertainties of the measurement practical to deal with. Some of the steps labs should consider in their low flow measurement system design are as follows.

1. Automate data collection to eliminate some potential for human errors.
2. Follow the manufacturer's published instructions to maximize reference and test measurement device performance.
3. Make the test configuration a straight path, without elbows or changes in size, shape, or elevation, if at all possible.
    a. If an elbow is required, a vaned elbow produces less turbulence and error than a radiused elbow, when measuring downstream.
    b. Place any elbow as far as possible upstream of the air terminal or downstream of the Reference.

4. Use settling means (filters, Hexcel straighteners, screens, etc., or combination) to shield the reference airflow measuring system from disruption by the fan.
5. Use a flared opening (or bell mouth) and avoid sharp edge entrance conditions.
6. Place the reference instrument as far as possible downstream of the fan, while remaining about 1/3 the total distance upstream of the unit under test.
7. Transition from the fan discharge to the size of duct under test should be as gradual or shallow angles as possible and therefore longer overall than normal commercial duct transitions.
8. When practical, limit test duct sizes to those used most often - notably 8 and 10" round - if possible. More combinations lead to greater unreliability in comparison.
9. Total size of test setup grows in length proportionately when larger ducts are needed for larger inlets to terminal units. Overall test configuration for 8" diameter terminal inlet, from exit at the settled air source transition to the inlet of the unit under test, should be no less than 25 ft total (or >30 equivalent diameters).
10. Seal the duct thoroughly and test it for leakage prior to use.
11. Air source (fan) should be controlled with a variable speed drive and duct static pressure regulated with an outlet damper(s).

APPENDIX C – STANDARD TERMINAL UNIT (NORMATIVE)

The Standard Terminal unit shall consist of a multi-point velocity pressure flow probe mounted in an 8” duct, with a butterfly damper and uninsulated casing. Dimensions and location of components shall match Figure C.1.

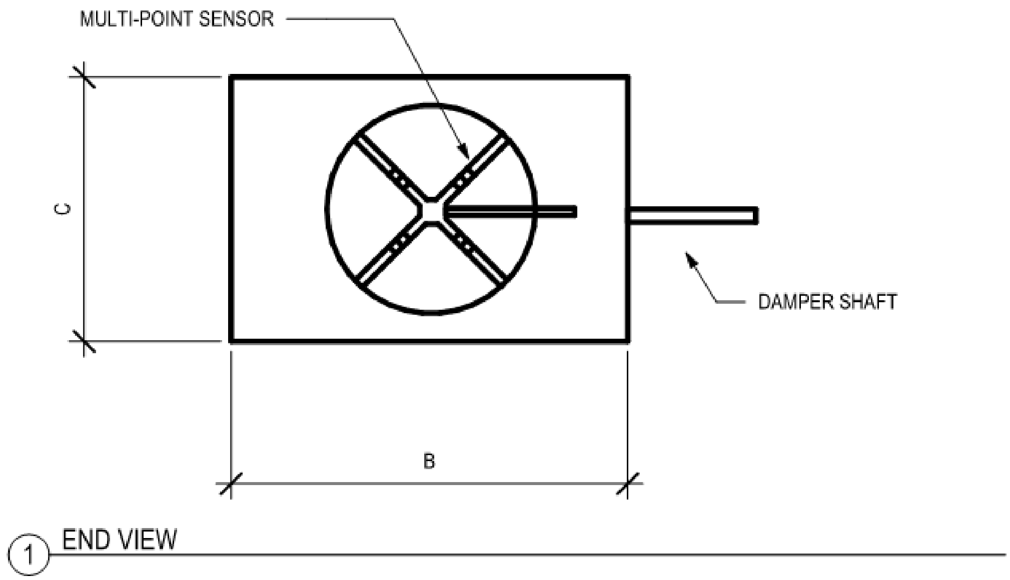
The flow probe shall be a differential pressure airflow device measuring total and static pressures.

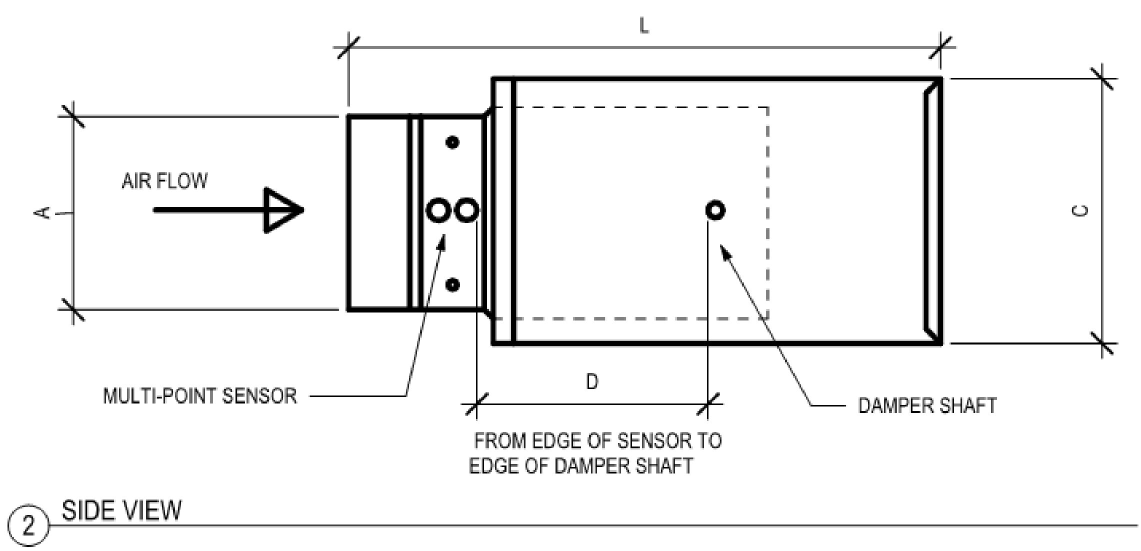
Control tubing shall be protected by grommets at the wall of the housing.

The flow probe shall have K-factor between 800 and 1000 (corresponding to an amplification factor between 3.05 and 1.95)

Figure C.1. Standard Terminal Unit Dimensions and Tolerances

	A	B	C	D	L
IP (in)	8 +/- 0.25	12 +/- 1	10 +/- 1	8 +/- 1	20 +/- 1
SI (mm)	203 +/- 6	305 +/- 25	254 +/- 25	203 +/- 25	508 +/- 25





APPENDIX D – APPLICATION OF THE CONTROLLER-ONLY TEST (INFORMATIVE)

Users should understand that the results of the controller-only test do not directly predict the accuracy of airflow control of the controller-actuator combination for all terminal units. The results of the test indicate the accuracy of control for a given signal pressure differential. The flow probe signal is the difference between the high and low side pressures transmitted from a terminal unit's flow probe.

Flow probe signal is often confused with velocity pressure. Most terminal unit air pressure (P_{vm}) differential flow probes amplify the velocity pressure. For example, if air is moving through the duct of the terminal unit at 400 SFPM (2.032 m/s), the velocity pressure is $(400/4005)^2$ ($[2.032/40.754]^2$), which equals 0.00998 in. H_20 (0.00249 kPa). The flow probe signal at the controller is this value multiplied by the probe's amplification factor. A typical amplification might be 2.3, so in this case, the flow probe signal would be 2.3 X 0.00998 (2.3 X 0.00249) which equals 0.0229 in. H_20 (0.00573 kPa). Not all probes have the same amplification factor. That value is supplied by the manufacturer of the terminal unit.

Therefore, in order to determine the airflow accuracy of a particular controller paired with a terminal unit, the user must know the amplification factor for that unit's probe and the cross-section area of the duct in which the probe is located.

Example:

- Controller has satisfactory accuracy down to 0.015 in. H_20 (0.00374 kPa)flow probe signal.
- The manufacturer states that the amplification of the probe is 1.85.
- The manufacturer's size 12 single duct terminal unit has a duct internal diameter of 11.875" (0.3016 m) where the probe is located.

I-P Units

Area of the duct = $((11.875/2)^2 \times \pi) / 144 = 0.77$ ft^2

Lowest velocity pressure which can be controlled = 0.015 in. H_20 / 1.85 = 0.0081 in. H_20

Lowest air velocity that can be controlled = 4005 X $0.0081^{0.5}$ = 360.6 SFPM

Lowest airflow that can be controlled = 360.6 SFPM X 0.77 ft^2 = 277.7 SCFM

S-I Units

Area of the duct =$((0.3016/2)^2 \times \pi) = 0.0714$ m^2

Lowest velocity pressure which can be controlled = 0.00374 kPa / 1.85 = 0.00202 kPa

Lowest air velocity that can be controlled = 40.754 X $0.00202^{0.5}$ = 1.8317 m/s

Lowest airflow that can be controlled = 1.8317 m/s X 0.0715 m^2 X 1000= 130.96 L/s