Energy Research and Development Division
FINAL PROJECT REPORT

EVALUATION OF AIR FLOW MEASUREMENT METHODS FOR RESIDENTIAL HVAC RETURNS FOR NEW INSTRUMENT STANDARDS

Appendices A - F

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Prepared by: Lawrence Berkeley National Laboratory

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LIST OF APPENDICES

APPENDIX A:
Measuring average face velocity and calculating volumetric flow with Testo 417

Making a measurement with the Testo 417
Large vane Anemometer

1) Determine the **OPEN AREA** as follows:
On **RETURNS**, the **OPEN AREA** is the 100% of the full measured area of the grille, as the air is flowing first through the 417 measuring vanes, then into the return duct.
On **SUPPLIES**, the **OPEN AREA** is the fraction or percentage of the grille that the air passes through, before moving through the 417 measuring vanes.
See grille manufacturers product info for open area data **.
Then **Multiply** the **Duct dimensions** (Height and width) in inches by multiply of the **OPEN AREA** factor.

FOR EXAMPLE:
We have a supply grille that is 6x10 inches with 65% open area. The open area is 6 x 10 x 0.65 = 39 sq inches open area

2) **ENTER** the **OPEN AREA** into the 417.
Turn ON the 417, after a few seconds the display comes up. **PRESS AND HOLD** the **RETURN ARROW** (Hold/Max/Min Key) until a number appears on the display and the in2 label is blinking.
Use the **UP** or **DOWN** arrows (VOL and MEAN keys) to adjust the number in the display your open area.
I*N THE EXAMPLE ABOVE* adjust it to ***39.0***

3) **EXIT** to measuring mode by pressing the **RETURN ARROW** (Hold/Max/Min Key) **5** times

4) **MEASURE**: Place the 4" vane into the air stream in front of the grille position it at one corner of the grille, perpendicular to the grille surface.
a) Press the MEAN key TWICE to enter the timed average mode.
b) Press the RETURN key (Hold/Max/Min Key) when you want to start collecting data.

c) Keep the 417's measuring head about 1" away from the face of the grille. Move the 417 head across the grille at a rate of about 1 foot (12") over 4 seconds. (note the timer on the 417's screen)
d) Be sure to "paint" the entire grille face with head of the 417 to account for total flow through the grille. DO NOT paint any area more than once!
e) When you are done covering the entire grille area, press the RETURN key (Hold/Max/Min Key) again to pause the reading on the display.

OPTIONAL: You can measure again (re-paint the ***entire*** area) to improve the reading. Just start at step 4b.

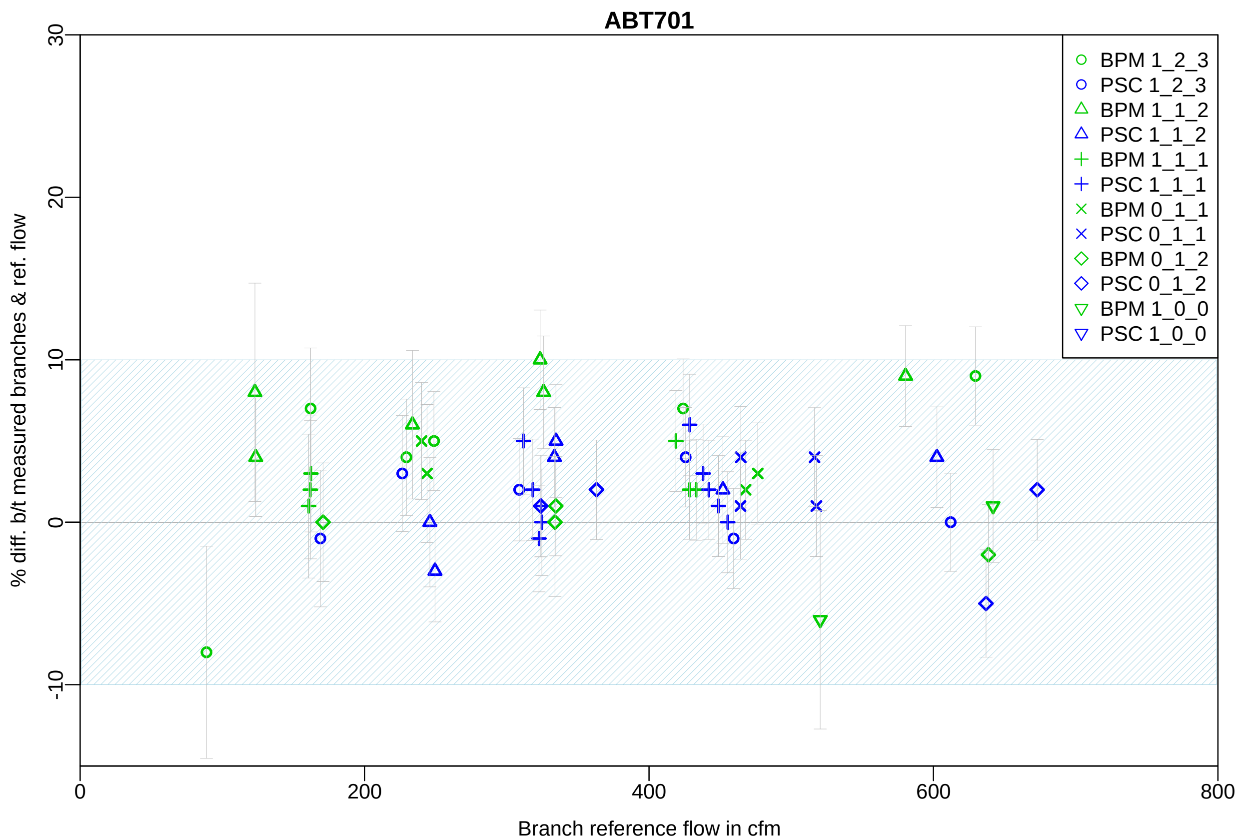
5) **DISPLAY** the average values by pressing the **MEAN** key. The Timed MEAN icon will flash and the average Feet Per Minute (FPM) will be displayed.
Tap the VOL key once to see the Average CFM for this test.
Tap the VOL key again to see the Average Temperature for this test.
Tapping the VOL key continues rotating thru these three results.

NOTE *BE SURE to record the data, as there is NO memory storage in the 417. Once you tap the MEAN key again, the data is gone.*

6) **CLEAR** the data and prepare for another measurement by tapping the **MEAN** key

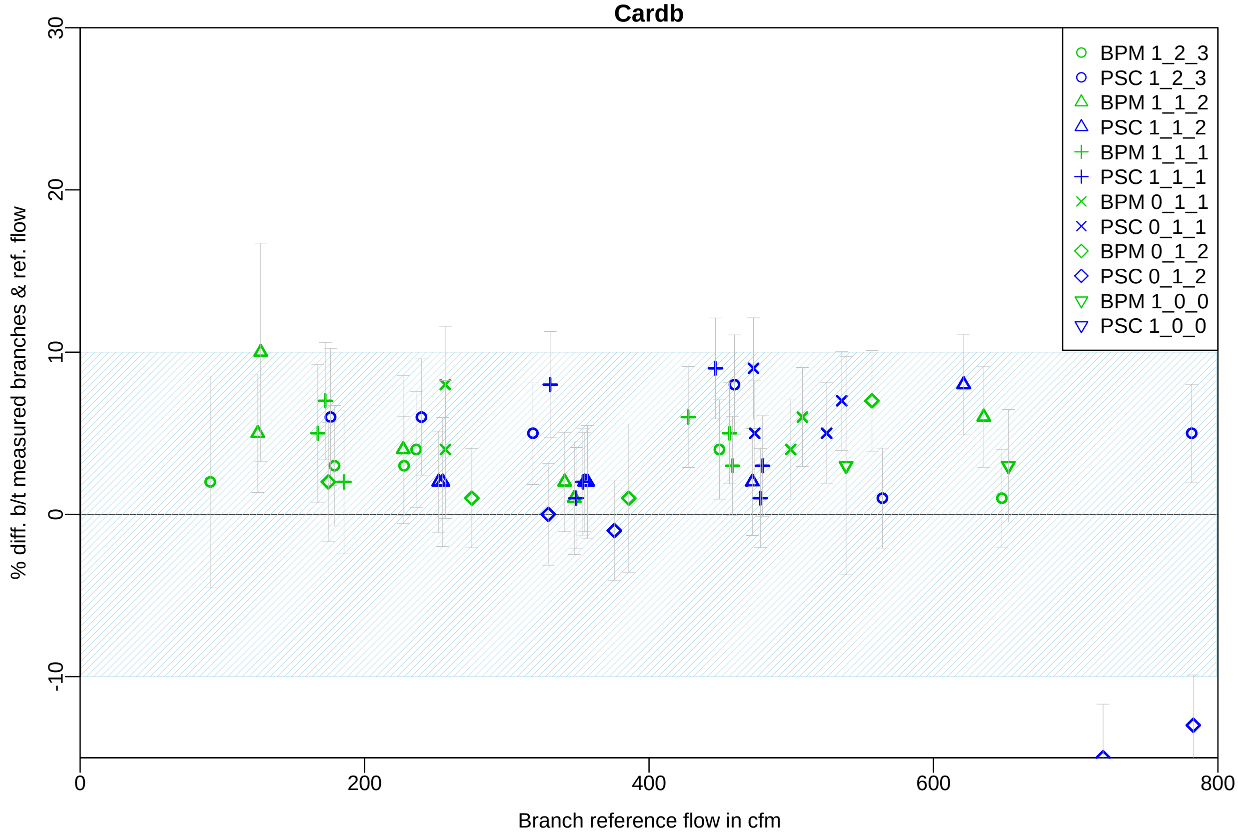
** One manufacturer's data books give open area factors of from 71% to 75% for one type of floor diffuser (depending on size), 66% to 75% for another model and 65% to 75% for another model.
While a heavy duty, dual shutter floor grille from the same manufacturer has a range of 48% to 52% open area factor.
Generally speaking, the larger the grille dimension, the small the open area factor.

APPENDIX B: Branch Airflow Measurements Compared to Test Condition Reference Flow



Device-measured flows are compared to reference flow under test conditions. Test configuration indicated by symbol color and shape, uncertainty of reference flow indicated by error bars.

Source: LBNL



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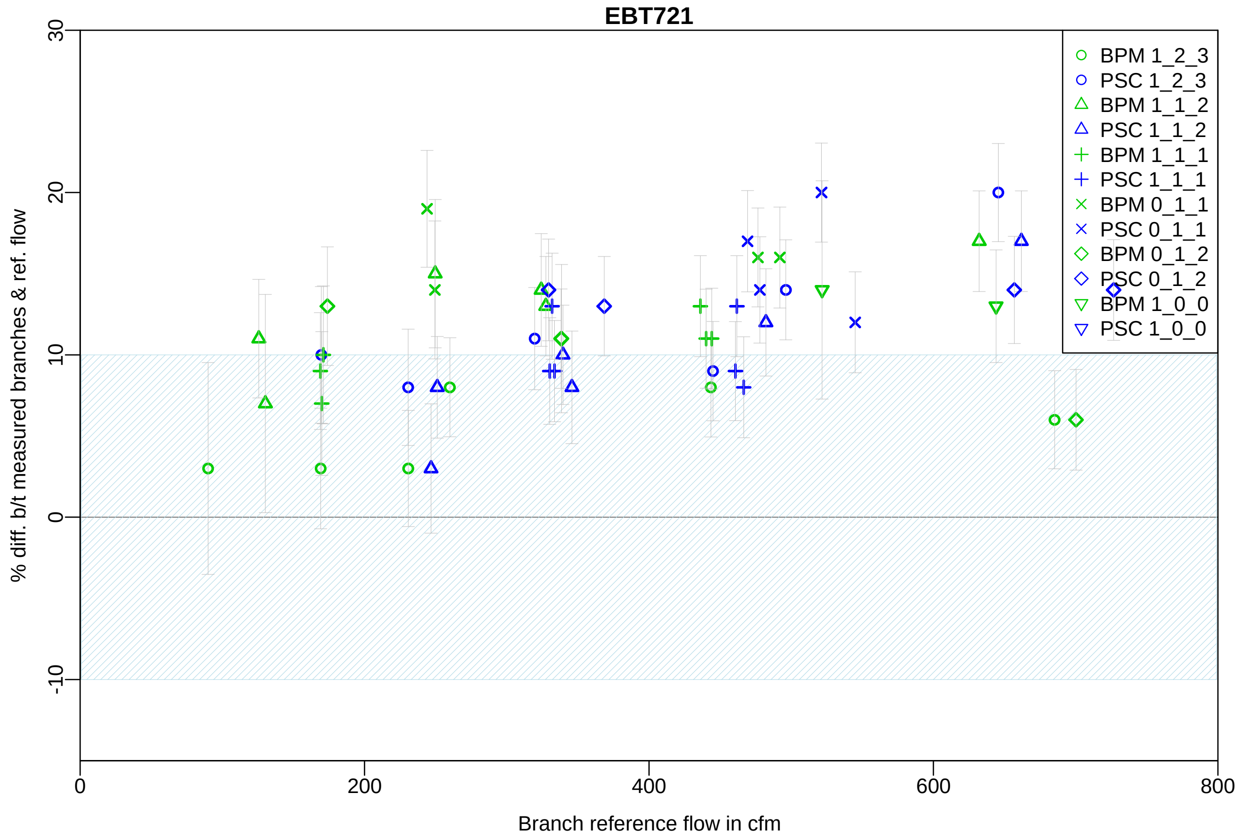

Device-measured flows are compared to reference flow under test conditions. Test configuration indicated by symbol color and shape, uncertainty of reference flow indicated by error bars.

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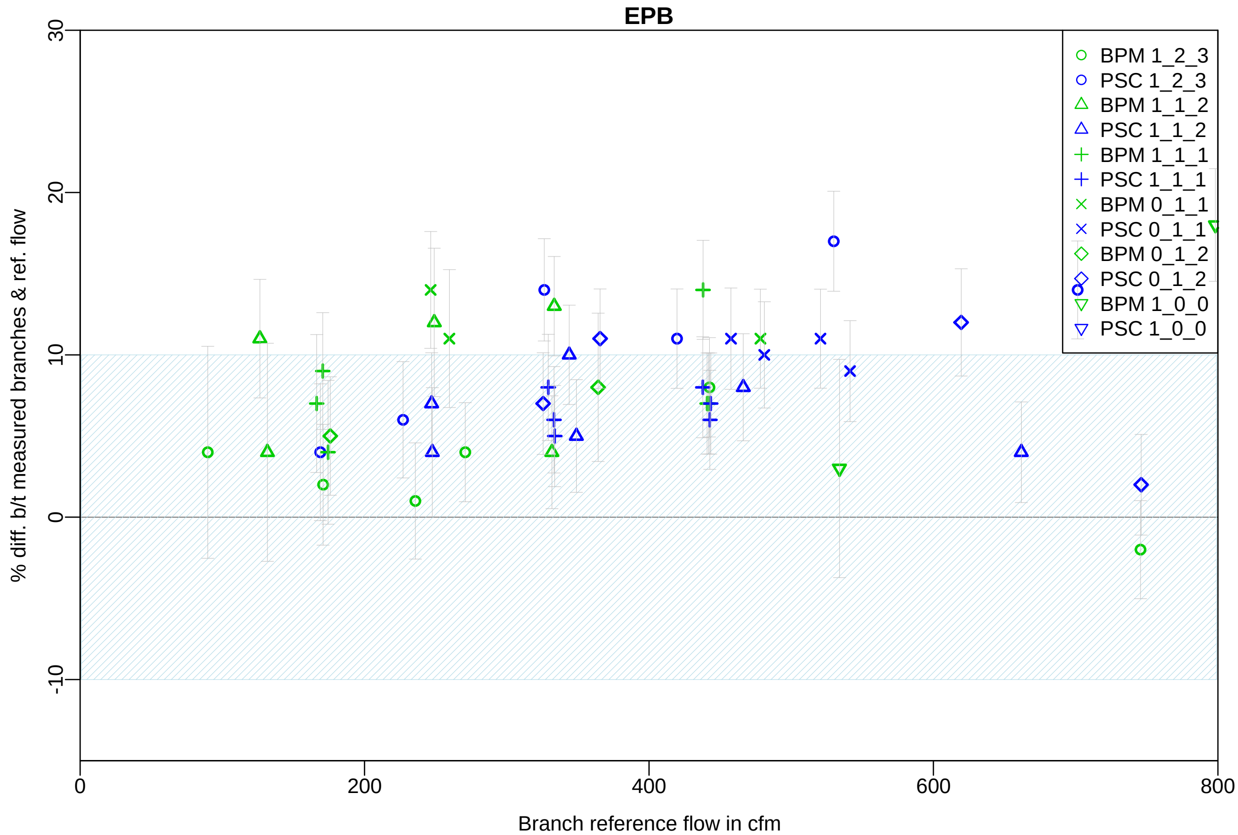

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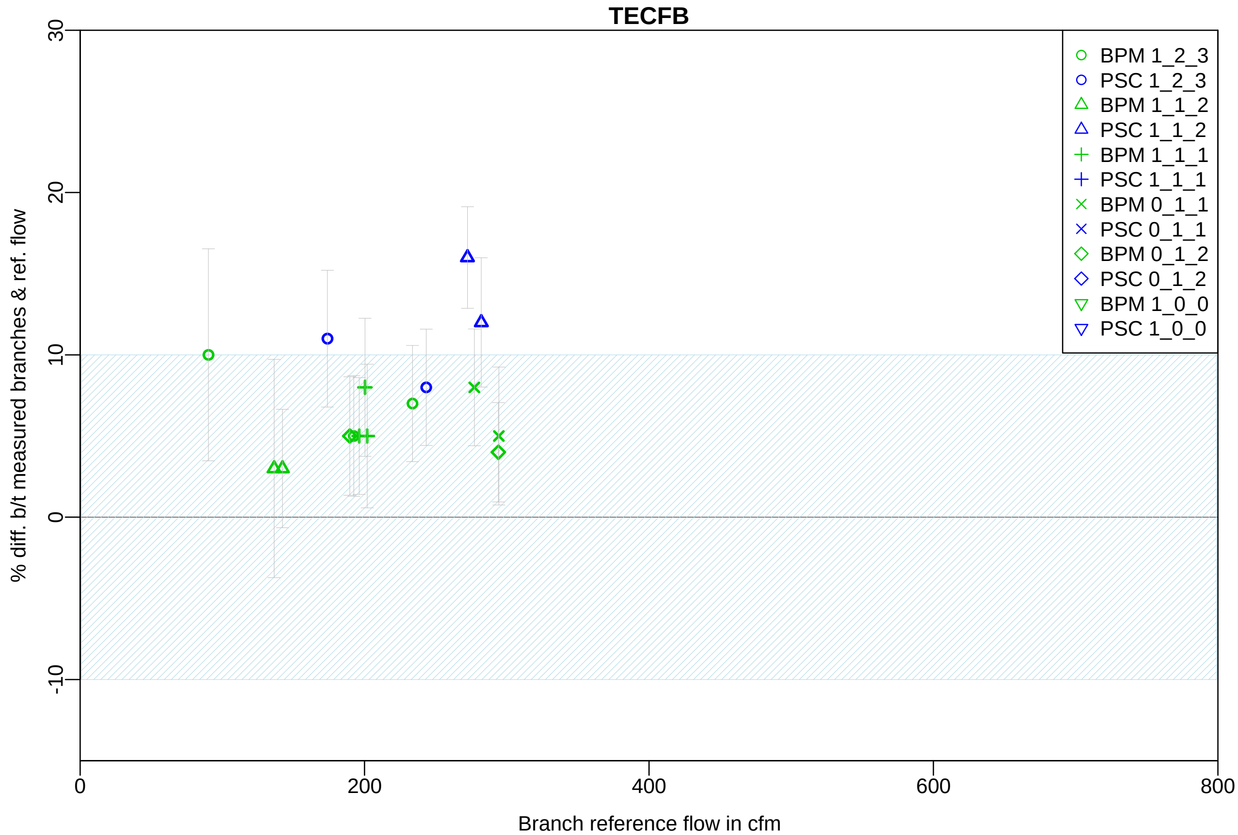
Source: LBNL



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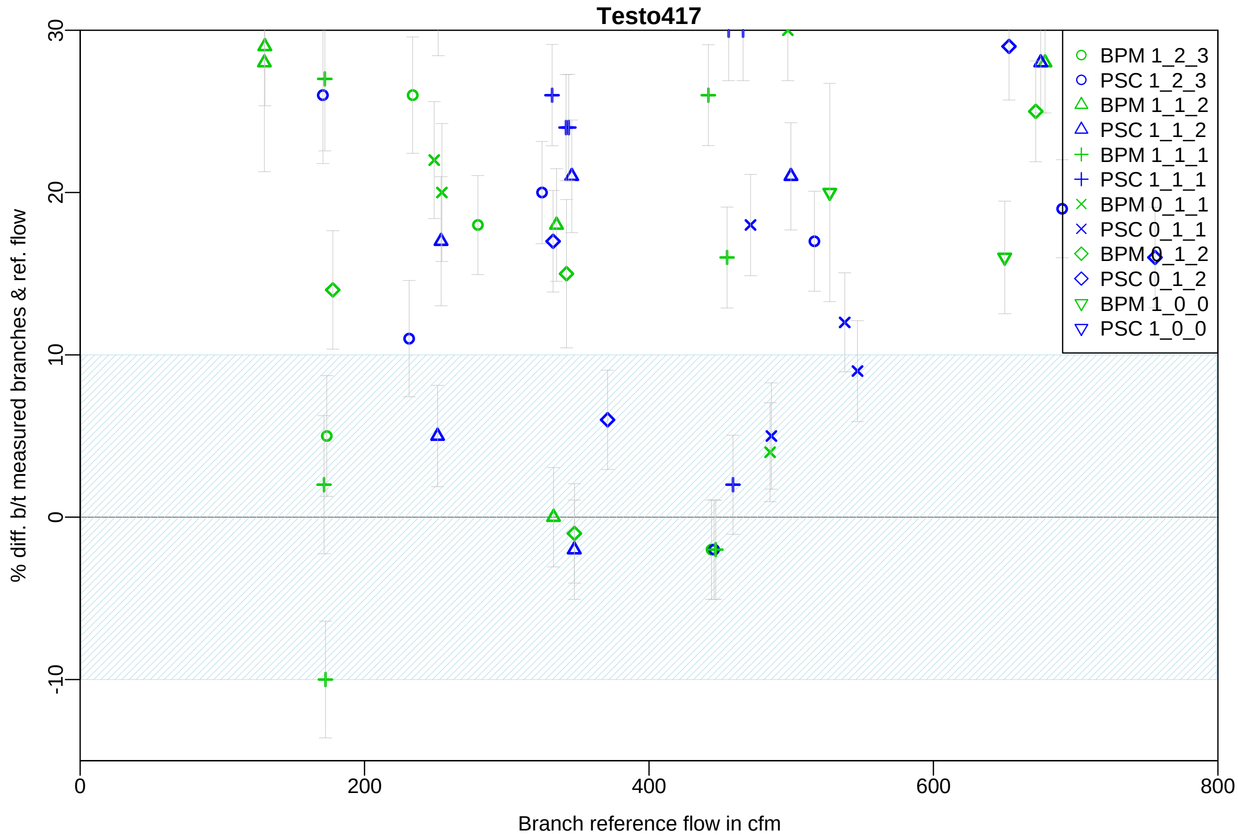

Device-measured flows are compared to reference flow under test conditions. Test configuration indicated by symbol color and shape, uncertainty of reference flow indicated by error bars.

Source: LBNL

APPENDIX C:
Bias and Accuracy for Individual Measurements Compared to Test Condition Reference Airflow

	Individual					
	mean (bias)			RMS (accuracy)		
Flow hood	**perc.**	**cfm**	**L/s**	**perc.**	**cfm**	**L/s**
ABT701	2.3%	8.4	4.0	4.2%	16.4	7.7
CFF	3.3%	11.0	5.2	5.3%	28.0	13.2
EBT721	11.4%	49.7	23.4	12.1%	60.1	28.3
LBNL hybrid	10.8%	45.5	21.4	16.0%	78.3	36.8
TECFB	6.4%	11.7	5.5	6.9%	12.8	6.0
testo417	16.6%	74.1	34.8	19.9%	99.8	46.9

APPENDIX D:
Draft ASTM Test Procedure

Method of Test for Determining the Measurement Uncertainty of Devices Used to Measure Airflow through Residential HVAC Terminals

1. Purpose

1.1 This standard provides a method of test for determining the measurement uncertainty of devices used to measure airflows through air inlets and outlets that terminate ducted systems for air distribution in buildings.
1.2 This standard establishes performance specifications for equipment required to test measurement devices, defines methods of calculating and reporting the results obtained using the test data (including accounting for the effects of air density on airflow measurements), and establishes an accuracy reporting system that can be applied to devices covered by this standard.

2. Scope

2.1 This standard applies to the testing of airflow measurement devices that are intended for field application to residential heating, cooling, and ventilation air distribution systems.
2.2 This standard is for use in the laboratory and is not intended for use in field calibration of airflow measurement devices.
2.3 This standard applies to measurement devices for flows less than 500 L/s (1060 cfm).

3. Definitions (TBD)

4. Summary of Test Method

4.1 The test method compares the airflow rates reported by measuring devices to a reference flow meter in a laboratory test apparatus. The comparison is performed for a range of residential HVAC terminals and system air flows characteristic of residential HVAC systems. The testing also includes the effects of placement of the device under test relative to each register. Some tests include the evaluation of insertion loss effects using multi-branch systems. In addition to reporting the errors for individual test configurations, this test method also reports the bias and root mean square error over all tests. The errors are reported separately for air flows into and out of the device under test.

5. Significance and Use

5.1 The measurement of air flows in residential heating and cooling systems has several applications: measuring total air flow of the system to ensure good equipment performance and measuring the air flows in and out of rooms to ensure individual room loads are met. Some building energy codes are requiring the measurement of total system airflow as part of code compliance.

5.2 The measurement of ventilation system airflows is required to demonstrate compliance with standards, such as ASHRAE 62.2-2013.

5.3 The measurement of ventilation, and heating and cooling system airflows is required in energy and indoor air quality related standards, such as RESNET 301 (2013) and BPI Standard 1100 (2012) and ACCA Standard 5 (2010).

6. Laboratory Test Apparatus

6.1 Two test apparatus configurations are required: one for single-branch testing (see Section 6.2) and one for multi-branch testing (See Section 6.3). The apparatus components in section 6.1 are common to both configurations and shall meet the following specifications.

6.1.1 A reference air flow meter capable of measuring the air flow through a terminal with an accuracy of +/- 3% or +/- 0.5 L/s (1cfm). Flow straighteners shall be used upstream and downstream of the reference flow meter. A straight undisturbed duct run meeting the reference flow meter manufacturers specifications (but at least 2m (6 ft.) in length) shall be installed upstream and downstream of the reference flow meter. Some flow meters are unidirectional. For flow meters of this type they shall be installed following manufacturer's instructions and shall be configured correctly for each flow direction.

6.1.2 An air leakage flow meter that can measure air flows with an accuracy of ±10% or ±0.1 L/s (0.2 cfm).

6.1.3 A differential pressure gauge capable of measuring pressure to an with an accuracy of +/- 1% or +/- 0.1 Pa (0.004 in. water) – whichever is greater. The pressure in the duct shall be measured within 100 mm (4in.) of the terminal.

6.1.4 A fan or blower with a flow control mechanism that can be adjusted to provide specified air flows through the apparatus. It is possible that two fan or blower devices may be needed – one for the air leakage testing and one for air flow testing.

6.1.5 The terminals used for testing as shown in Table 1. Terminals 1 to 5 are used for ventilation applications. Terminals 6 to 9 are for heating and cooling applications.

6.1.6 Air temperature measuring equipment with an accuracy of +/-1°C (+/-0.5°F). Air temperatures in the duct shall be measured upstream and downstream of the reference flow meter within 1m (3 ft.) of the reference flow meter. Room air temperatures shall be measured not more then 3 m (9 ft.) from the terminal at the same height above the floor as the terminal.

6.1.7 A barometric pressure measuring device with an accuracy of +/-250 Pa (+/- 1.00 in. water).

6.1.8 All temperature, pressure, and flow measurements shall be a one minute average of points taken at least once every five seconds.

6.1.9 Sheet metal air ducting, boots and collars required to connect the fan, reference flow meter and the terminals.

Table 1. Terminals to be tested

Terminal Number	Terminal Description	Flow Direction	Air flow test points (L/s)	Single or Multi-Branch	Duct diameter
T1	Bathroom exhaust fan with face dimensions of at least 380 mm by 380 mm (15 in. by 15 in.)	Into terminal	15, 20, 30, 40, 50	Single	100 mm (4 in.)
T2	HRV/ERV return	Into terminal	5, 15, 25, 40, 50	Multi	100 mm (4 in.)
T3	HRV/ERV supply	Out of terminal	5, 15, 25, 40, 50	Multi	100 mm (4 in.)
T4	Exterior wall #1 – 100 mm duct – with backdraft damper	Out of terminal	15, 25, 50, 100, 150	Single	100 mm (4 in.)
T5	Exterior wall #2 – 150 mm duct – with backdraft damper	Out of terminal	15, 25, 50, 100, 150	Single	150 mm (6 in.)
T6	Fixed vane 1 – way supply grille (400 mm × 190 mm, 15.5” × 7.5”)	Out of terminal	10, 20, 30, 40, 50	Multi	100 mm (4 in.)
T7	Fixed vane 2 – way supply grille (400 mm × 190 mm, 15.5” × 7.5”)	Out of terminal	10, 20, 30, 40, 50	Multi	100 mm (4 in.)
T8	Fixed vane 3 – way supply grille (400 mm × 190 mm, 15.5” × 7.5”)	Out of terminal	10, 20, 30, 40, 50	Multi	100 mm (4 in.)
T9	Fixed vane 4 – way swirl-inducing supply grille	Out of terminal	10, 20, 30, 40, 50	Multi	100 mm (4 in.)

6.2 Single-branch apparatus

For the single-branch apparatus all the air shall flow through a single terminal. The single-branch test apparatus shall be constructed such that the fan or blower moves air through a duct containing the reference flow meter that terminates in the terminal used for each test configuration. The terminal shall be mounted in a flat surface with dimensions of at least 1m x 1m (3 ft. x 3 ft.). Figure 1 is an illustration of a typical single-branch test apparatus.

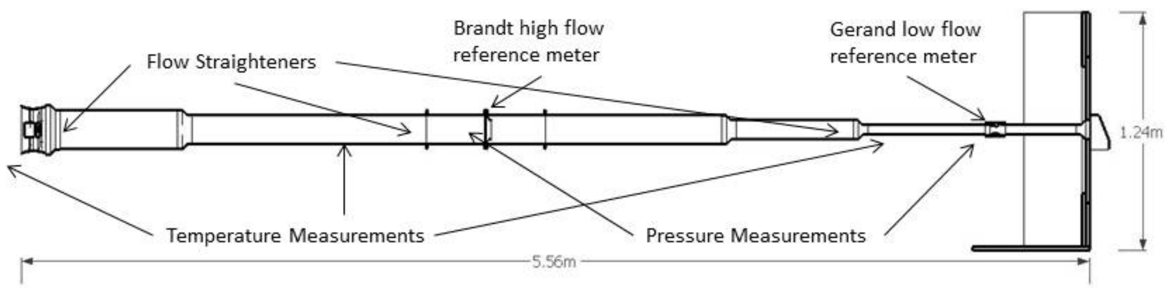

Figure 1. Test Apparatus for Single-Branch Testing

6.3 Multi-branch apparatus.

The multi-branch test apparatus shall be constructed such that the fan or blower moves air through a duct containing the reference flow meter and then through three equal length ducts – each of which has a terminal attached. For multi-branch testing the air shall flow through the terminal being measured by the device under test and two other terminal(s) that are not measured by the device under test. Each branch shall have the same terminal. Each terminal shall be mounted in a flat surface with dimensions of at least 1m x 1m (3 ft. x 3 ft.). Each branch shall be 3 m (9 ft.) in length and have ducts of the same diameter (either 100 mm or 150 mm (4 in. or 6 in.)). Figure 2 is an illustration of a typical single-branch test apparatus.

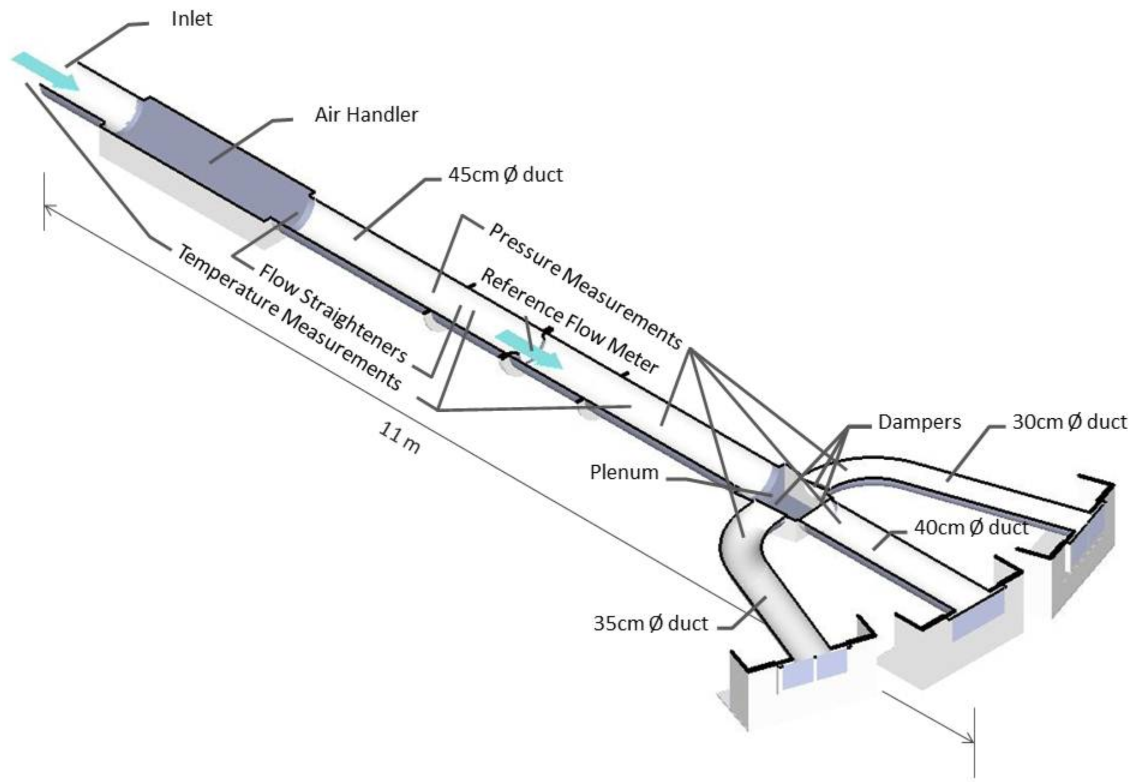

Figure 2. Test Apparatus for Multi-Branch Testing

6.4 Air Leakage of Test Apparatus.
6.4.1 The test apparatus shall be tested for air leakage after initial construction and any time a configuration change is made to the apparatus that could affect its airtightness – such as changing air terminals or reference air flow meters.
6.4.2 Seal all the terminals.
6.4.3 A differential pressure gauge shall be connected to the test apparatus to measure the pressure difference between inside the test apparatus and the room.
6.4.4 A fan or blower and air flow measurement system meeting the specifications of 6.2.1 shall be attached to the test apparatus so as to pressurize the apparatus.
6.4.5 The fan or blower shall be adjusted to maintain a 25 Pa (0.1 in. water) test pressure between the inside of the test apparatus and the room.
6.5.5 The air flow required to maintain the test pressure shall be recorded.
6.5.6 The maximum allowable air flow shall be 0.5 L/s (1 cfm).
6.5.7 If the air leakage is above the maximum, then the apparatus shall be further air sealed and retested until the above maximum allowable air leakage level is met.
6.5.8 After air leakage testing is complete the terminal seals shall be removed.

7. Hazards

7.1 Eye Protection—Some tests may require the use of high airflows that may result in airborne debris. Adequate precautions, such as the use of eye protection shall be taken.

7.2 Safety Clothing—Use safety equipment required for general laboratory work, such as safety shoes.
7.3 Equipment Guards—The air-moving equipment shall have a proper guard or cage to house the fan or blower and damper to prevent accidental access to any moving parts of the equipment.
7.4 Noise Protection—Exposure to the noise level generated by fans can be hazardous to the hearing of involved personnel and hearing protection is recommended.

8. Procedure

8.1 Single Branch Testing. The single branch test apparatus shall be used. The single-branch test procedure shall be repeated for T1, T4, and T5 with the air flow direction through the apparatus matching the requirement in Table 1. For each terminal the test shall be repeated for each air flow test point in Table 1. For each air flow test point the test shall be performed for three relative locations of the terminal and device under test: centered over the terminal, with the terminal on one edge of the device under test and with the terminal in one corner of the device under test. The barometric pressure shall be recorded for each test.
8.1.1 The following procedure shall be followed for each, terminal, air flow test point and relative location of terminal and device under test.
8.1.1.1 The device under test shall be placed over the terminal.
8.1.1.2 The fan or blower shall be adjusted such that the flow though the reference flow meter is within 1 L/s (2 cfm) of each test point.
8.1.1.3 The following shall be recorded: air flow through the reference flow meter (Qref), the flow through the device under test (Q), the temperature of air flowing through the device under test, and the pressure difference between the apparatus downstream of the flow meter and the ambient (Ptest).
8.2 Multi-Branch Testing. The multi-branch test apparatus shall be used. The multi-branch test procedure shall be repeated for T2, T3, T6, T7, T8, and T9 with the air flow direction through the apparatus matching the requirement in Table 1. For each terminal the test shall be repeated for each air flow test point in Table 1. For each air flow test point the test shall be performed for three relative locations of the terminal and device under test: centered over the terminal, with the terminal on one edge of the device under test and with the terminal in one corner of the device under test. The barometric pressure shall be recorded for each test.
8.2.1 The following procedure shall be followed for each, terminal, air flow test point and relative location of terminal and device under test.
8.2.1.1 Without the device under test in place, the fan or blower shall be adjusted such that the flow though the reference flow meter is within 1 L/s (2 cfm) of each test point. Record the air flow through the reference flow meter (Q_{ref}). The blower or fan and dampers shall not be adjusted when the device under test is placed over the terminal.
8.2.1.2 The device under test shall be placed over the terminal.
8.2.1.3 The following shall be recorded: the flow through the device under test (Q), the temperature of air flowing through the device under test, and the pressure difference between the apparatus downstream of the flow meter and the ambient (P_{test}).

9. Data Analysis and Calculations

9.1 Convert the device-measured airflows (Q and Q_{ref}) to actual volumetric flow using manufacturers' instructions and the measured temperatures and barometric pressures.

9.2 The difference (Q_{diff}) between the corrected device-measured airflow and the reference airflow shall be calculated for each terminal, test flow rate, and relative position of the terminal and device under test. The square of the difference (Q^2_{diff}) between the corrected device-measured airflow and the reference airflow shall be calculated for each terminal, test flow rate, and relative position of the terminal and device under test.

9.2.1 The errors for all tests shall be calculated using 9.2.1.1 through 9.2.1.4.

9.2.1.1 The bias for the device under test shall be calculated using Equation 1.

$$Q_{bias} = \frac{\sum_{all\ tests} Q_{diff}}{N} \tag{1}$$

where N is the total number of tests.

9.2.1.2 The RMS error for the device under test shall be calculated using Equation 2.

$$Q_{rms} = \sqrt{\frac{\sum_{all\ tests} Q^2_{diff}}{N}} \tag{2}$$

9.2.1.3 The fractional bias shall be calculated using Equation 3.

$$Q_{bias,\%} = 100 \times \frac{\sum_{all\ tests} Q_{diff}}{\sum_{all\ tests} Q_{ref}} \tag{3}$$

9.2.1.4 The fractional RMS error shall be calculated using Equation 4.

$$Q_{rms,\%} = 100 \times \frac{N \times Q_{rms}}{\sum_{all\ tests} Q_{ref}} \tag{4}$$

9.2.2 The errors for each individual terminal shall be calculated using 9.2.2.1 through 9.2.2.4.

9.2.2.1 The bias for the each terminal shall be calculated using Equation 5.

$$Q_{bias,terminal\ i} = \frac{\sum_{n\ tests} Q_{diff}}{n} \tag{5}$$

where n is the number of air flow test points for the ith terminal.

9.2.2.2 The RMS error for each terminal test shall be calculated using Equation 6.

$$Q_{rms,terminal\ i} = \sqrt{\frac{\sum_{n\ tests} Q^2_{diff}}{n}} \tag{6}$$

9.2.2.3 The fractional bias for each terminal shall be calculated using Equation 7.

$$Q_{bias,\%,terminal\ i} = 100 \times \frac{\sum_{n\ tests} Q_{diff}}{\sum_{n\ tests} Q_{ref}} \tag{7}$$

9.2.2.4 The fractional RMS error for each terminal shall be calculated using Equation 8.

$$Q_{rms,\%,terminal\ i} = 100 \times \frac{n \times Q_{rms,terminal\ i}}{\sum_{n\ tests} Q_{ref}} \qquad (8)$$

10. Report

10.1 The report shall contain the following information:
10.1.1 The date, time, and location of the test.
10.1.2 The make, model number and calibration date for the reference meter.
10.1.3 The make and model number of the device under test.
10.1.4 A list of the terminals used to develop the rating and the test air flows used for each terminal.
10.1.5 The test results: Qbias, Qbias,%, Qrms, Qrms,% for all tests and for each individual terminal.

11. Precision and Bias

11.1 The primary source of uncertainty in the reported airflows is the +/-3% accuracy specification for the air flow meter. Assembly leakage is a secondary source of uncertainty, on the order of +/- 1-2% of the reference flow.

12. Keywords

Flow hood, calibration, terminal, register, air inlet, air outlet

13. References

ACCA Standard 5-2010. HVAC Quality Installation Specification. Air-conditioning Contractors of America. Arlington, VA.

ASHRAE Standard 62.2-2013, "Ventilation for Acceptable Indoor Air Quality in Low-Rise Residential Buildings, ASHRAE, Atlanta, GA.

BPI-1100-T-2012. Home Energy Auditing Standard. Building Performance Institute, Inc.

BSR/RESNET 301-2013: Standard for the Calculation and Labeling of the Energy Performance of Low-Rise Residential Buildings using the HERS Index. Residential Energy Services Network,

APPENDIX E: IRIS DAMPER BRANCH MEASUREMENT ACCURACY

Table 8: Difference between iris calculated airflow and reference calibrated airflow

Mean (bias) (n=1120)	11.6%
RMS (accuracy) (n=1120)	1.1%

Mean and root mean squared (RMS) differences between iris airflows calculated using manufacturer's formula and airflows calculated using calibrated reference meter.

Source: LBNL

APPENDIX F:
Test Apparatus Leakage Measurements

Figure F1. Pressurized test apparatus leakage measurements

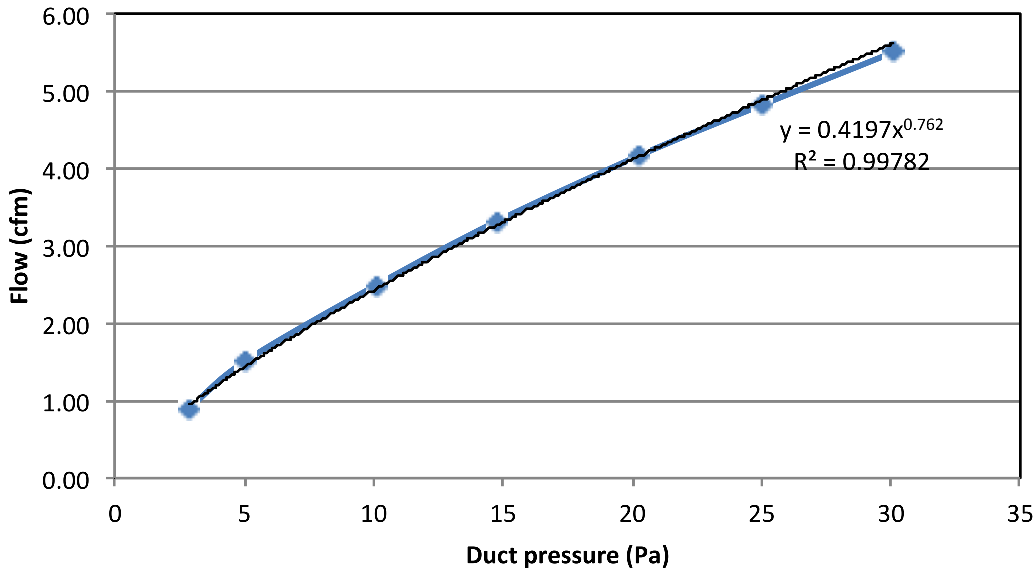

Figure F2. Depressurized test apparatus leakage measurements