HVI Publication 916
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This edition supersedes all previous editions.

HVI® AIRFLOW TEST PROCEDURE

This publication specifies prescriptively
HVI's procedures for testing and rating airflow
in accordance with (ANSI) consensus standards.
It applies to residential ventilating products
before HVI Certification.

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HOME VENTILATING INSTITUTE®
AIRFLOW TEST PROCEDURE

The History of HVI®

The Home Ventilating Institute® (HVI®) was incorporated as a trade association in 1955. From the first, it has provided residential ventilating products information for members and consumers.

The History of HVI's Airflow Certification Program

HVI initiated airflow testing and performance certification for residential ventilation products in 1956 following a visit by HVI members to the airflow test laboratory at Texas Engineering Experiment Station (TEES) of Texas A & M University. Airflow testing has for many years been in accordance with *ASHRAE 51 / AMCA 210*, utilizing a nozzle chamber and following narrowly-prescribed HVI procedures for testing consistency. HVI-Certified airflow ratings are uniquely comparable because each certified product has been tested in an HVI-designated test laboratory, using the prescribed setup for the category. HVI's certification programs are continuously refined. This edition of *HVI Publication 916* represents HVI's latest progress.

Disclaimer

Final recourse for consumers, competitors, Members and any other entity seeking any remedy for product certification and/or performance disputes is with the involved parties, not with HVI.

Units of Measure

Units of measure used herein are the inch-pound (IP) system because of present residential preferences. Values in IP units may be converted to the International System of Units (SI) using conversions found in the *ASHRAE Handbook of Fundamentals*, chapter on Units and Conversions.

Related HVI Publications

- *HVI Publication 911:Certified Home Ventilating Products Directory ©*
- *HVI Publication 915: HVI Loudness Testing and Rating Procedure ©*
- *HVI Publication 920: HVI Product Performance Certification Procedure Including Verification and Challenge ©*
- *HVI Publication 925: HVI Label and Logos Requirements ©*

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HOME VENTILATING INSTITUTE®
AIRFLOW TEST PROCEDURE

1. Introduction

1.1. Basis. HVI airflow certification shall be based on ratings determined through testing, calculations, and procedures done in accordance with ANSI consensus standards.

1.1.1. The primary standard for HVI airflow test and calculation is *ANSI/AMCA 210 – ANSI/ASHRAE 51, Laboratory Methods of Testing Fans for Aerodynamic Performance Rating,* jointly published by the Air Movement and Control Association, International Inc., and the American Society of Heating Refrigerating and Air Conditioning Engineers, Inc. ("*210/51*"). *210/51* is an internationally recognized testing standard that describes a variety of test procedures for a broad range of products. HVI prescribes a nozzle chamber testing for most categories.

1.1.2. This publication presents *210/51* references in curly brackets: { }.

1.1.3. This edition of *HVI Publication 916* is based on the 1999 version of *210/51*. In the future, when a later version of that Standard is published, HVI shall analyze applicable changes for adoption.

1.2. Purpose. The purpose of this Procedure is to prescribe uniform methods for measuring and reporting airflow performance of residential ventilating equipment in preparation for HVI Certification.

1.2.1. This publication prescribes the specific procedures to be used for HVI testing under *210/51*.

1.2.2. To maintain rigorous consistency and comparability of HVI-Certified airflow ratings, it is necessary that this publication be exceptionally specific.

1.2.3. This publication is intended for laboratory testing and cannot be used for field testing.

1.2.4. This publication also provides useful airflow measurement information to assist members with airflow testing in their own facilities, and with preparing products for submittal to the HVI-designated laboratory.

1.3. Scope. This procedure describes airflow testing requirements prescribed by HVI before certification of each of its defined categories of catalogued powered and static residential ventilation equipment. It identifies those parts of *210/51* that HVI utilizes for airflow testing, and it establishes testing procedures based on those parts. This publication intentionally limits and omits certain features and options of *210/51*.

1.3.1. A notable limitation is that this publication only allows testing in the region where air is considered an incompressible fluid (P_{sx} is less than 4 inches of water or 1 *kPa*).

1.3.2. HVI Verification and HVI Challenge testing is done at the HVI-designated laboratory, without member involvement, by testing the product exactly as its certification test unit was tested. By referring to the test report and its photographs, the HVI-designated test lab can confirm duplication of the certification test. Any remaining decisions regarding such tests shall be based on this procedure.

1.3.3. This procedure covers testing for HVI certification of ventilation products intended for permanent installation in residential buildings.

1.3.4. Portable fans and ceiling (paddle) fans, and heating and air conditioning equipment are not within the scope of this procedure.

1.3.5. Heat recovery ventilators, energy recovery ventilators and similar product categories are tested for HVI Certification in accordance with other HVI publications. The only exception covers two-duct ceiling/wall insert HRV and ERV products which can be tested for HVI Certification in accordance with this Procedure.

1.3.6. HVI Certification procedures are for residential ventilating products. Non-residential products may be more appropriately rated and certified by other organizations' procedures.

1.4. Certification and relationship with other HVI publications. Sound (loudness) testing as described in *HVI Publication 915, HVI Loudness Testing and Rating Procedure©* shall follow as soon as possible the airflow testing under this procedure, and the product shall not be altered between tests. For most product categories, HVI requires both airflow and sound ratings. Further requirements for HVI product rating and certification, using test reports from this procedure, are described in *HVI Publication 920, HVI Product Performance Certification Procedure Including Verification and Challenge©.*

2. Definitions

2.1. Refer to *HVI Publication 920©* for general definitions and definitions of HVI's product categories and other HVI nomenclature.

2.2. Inlet chamber: airflow test chamber with nozzle(s), arranged for connection to the inlet of a fan. The chamber outlet is connected to the fan inlet.

2.3. HVI-designated laboratory: A test laboratory designated for HVI certification testing. HVI designates a laboratory by official action after evaluating the laboratory's integrity and understanding of HVI requirements.

2.4. HVI product categories: names HVI assigns to product types (e.g., "bathroom exhaust fans").

2.5. Outlet chamber: airflow test chamber with nozzle(s), arranged for connection to the outlet of a fan. The chamber inlet is connected to the fan outlet.

2.6. Piezometer ring: a series (usually four) of interconnected static pressure taps in a common plane of an airflow test chamber.

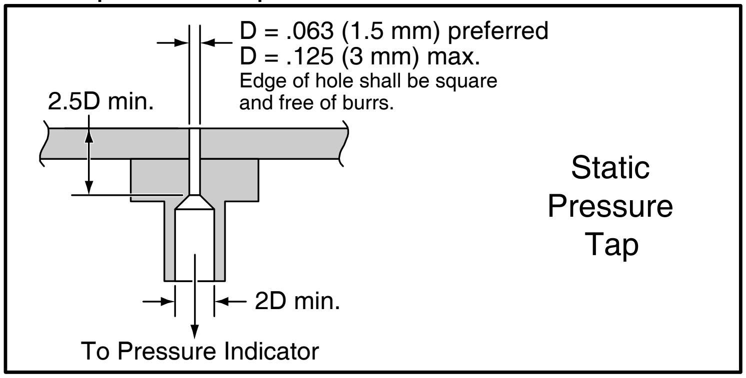
2.7. Standard air and standard atmospheric conditions: standard air is air with density of 0.075 lbm/ft^3 (1.2 kg/m^3). Standard atmospheric conditions in IP units are 68° *F*, 50% relative humidity, and 29.92 inches of mercury, and in SI units are 20° *C*, 50% relative humidity and 101.325 *kPa* barometric pressure. HVI consistently presents its certified ratings at standard atmospheric conditions so that direct comparisons can be made.

3. Equipment and Instrumentation

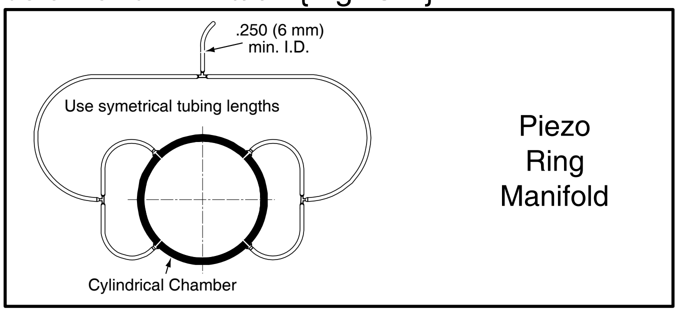
3.1. Multiple-nozzle chambers are used for airflow testing most HVI product categories, and are this publication's primary focus. For detailed requirements, refer to *210/51*, specifically {Figures 12 and 15} and the calculations described for multiple-nozzle chambers.

3.1.1. As an exception, when the airflow of a whole house comfort ventilator exceeds the available nozzle chamber's capacity, airflow may be measured by pitot traverse in a duct between a variable supply system and the fan inlet chamber. For that test procedure and related calculations, see *210/51* {Figure 13}.

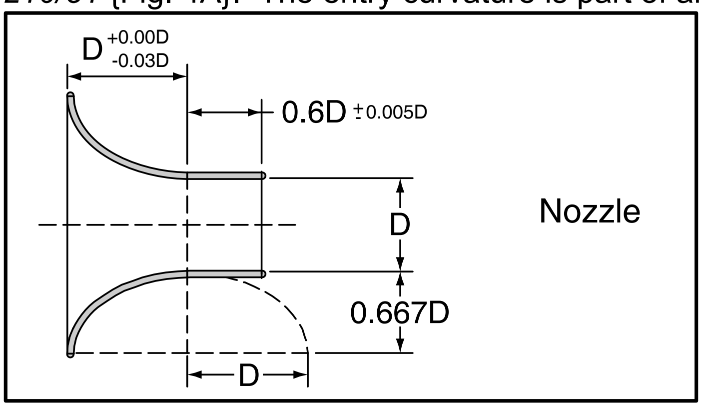
3.2. Static pressure taps shall be as shown below and in *210/51* {Fig. 2A}.



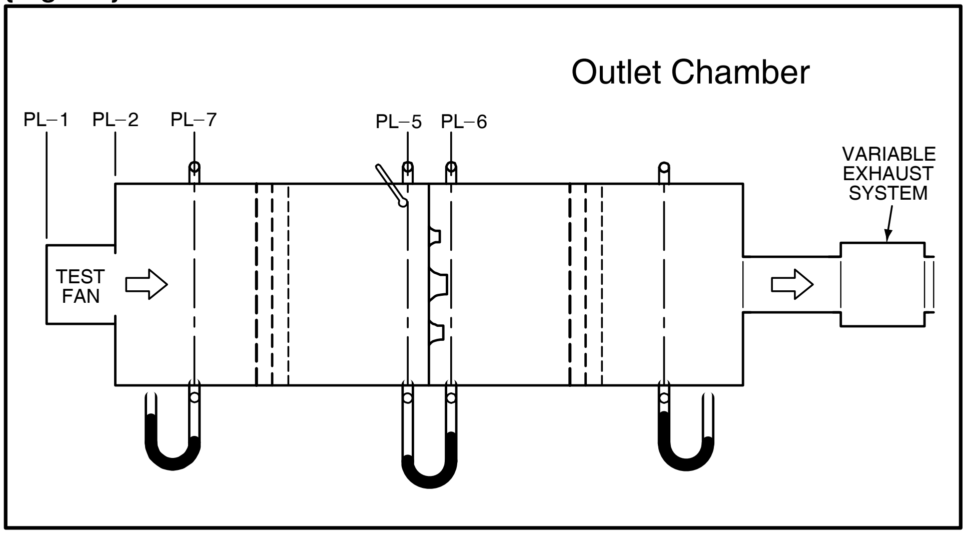
3.3. Piezometer ring manifolds on flow measurement chambers shall be as shown below and in *210/51* {Fig. G-1}.



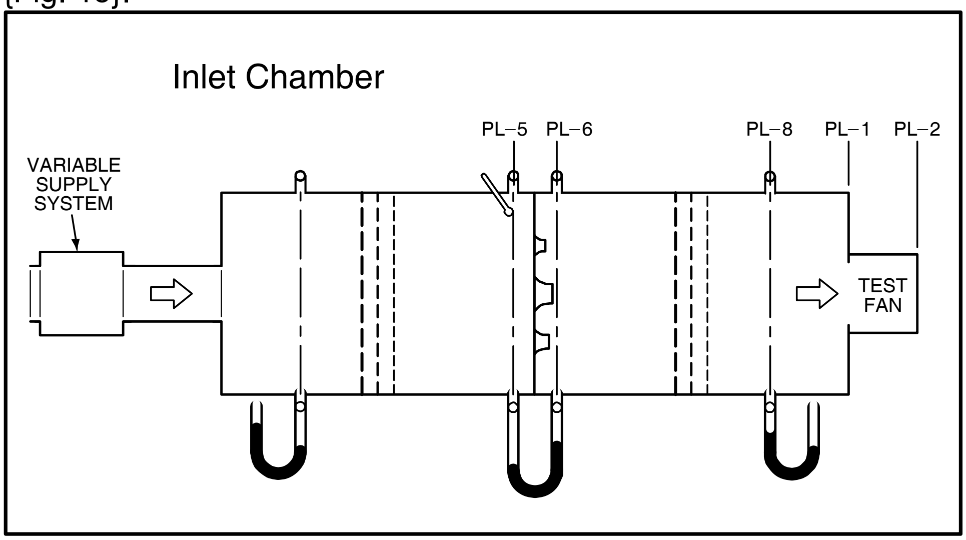
3.4. Nozzles for flow measurement chambers shall be as shown below and in *210/51* {Fig. 4A}. The entry curvature is part of an ellipse.



3.5. An <u>outlet</u> airflow measurement chamber shall be as shown below and in *210/51* {Fig. 12}.



3.6. An <u>inlet</u> airflow measurement chamber shall be as shown below and in *210/51* {Fig. 15}.



3.6.1. The two preceding illustrations show a single airflow measurement chamber constructed so that it may be used as either an outlet chamber or an inlet chamber. To convert the chamber from one type to the other, the variable (“boost”) blower connection is moved from one end to the other. Thus, one chamber meets the requirements of both an outlet chamber {Fig. 12} and an inlet chamber {Fig. 15}. (The terms “inlet” and “outlet” refer to the fan, not the chamber.)

3.6.2. An airflow measurement chamber may be round or rectangular. For a rectangular chamber the hydraulic diameter, dimension M in *210/51*, is calculated from inside width *a* and height *b*.

$M = \sqrt{4ab/\pi}$

3.6.3. Exception. Reflecting common practice, the inlet chamber utilizes a piezometer ring rather than the total pressure tube shown in *210/51*. (This arrangement is established in *ANSI/ASHRAE 120-1999*, Figure 14 and related calculations, as well as other references.)

3.7. Electrical voltage for fan testing shall be regulated within ±1%.

3.8. Other equipment and instruments and their tolerances and calibration are described in *210/51*. Included are those for measuring pressures, electrical parameters, temperature, dew point, barometric pressure, and rotating speed.

3.9. Some of the test setups described in the following parts of this publication require equipment unique to that setup; such equipment is shown in conjunction with the setup.

4. Equations and Calculations

4.1. Equations and symbols used for HVI testing are selected from *210/51*. They are specified below for chamber testing by equation number (and/or paragraph number) in curly brackets. (*210/51* presents equations in both SI and IP versions and assigns the same equation number to both.)

4.1.1. Testing and calculating may be done in either the IP or the SI system of units. HVI rating is standardized in IP units. Care must be taken to use one system of units throughout the test and, if conversion is required, to convert only after all testing and calculating is concluded.

4.2. Included as part of this publication as “Appendix I, HVI Airflow Test Calculations” is a practical guideline for airflow test calculations for the most frequently used setups. Actual equations are listed for those calculations.

4.3. Assumptions adopted for HVI calculations include the following.

4.3.1. Pressures are less than 4 inches of water so compressibility is ignored.

4.3.2. Chamber velocity is less than 400 feet per minute.

4.3.3. Chamber, equipment and instruments are as established in *210/51*.

4.3.4. Since no duct sections longer than 4D are used, duct friction calculations are not used.

4.4. Flow rate shall be mathematically referenced to the inlet or outlet of the test ventilator.

4.5. Symbols and subscripts are found in *210/51*: {¶ 4.}

4.6. Equations for outlet and inlet type multiple nozzle chambers follow.

4.6.1. Atmospheric air density: {8.1, 8.2, 8.3}

4.6.2. Air density at any plane: {8.4}

4.6.3. Dynamic air viscosity for laboratory conditions: {8.6}

4.6.4. Alpha ratio for a chamber: {8.12}

4.6.5. Beta ratio for a chamber is zero: {¶ 8.3.2.2.}

4.6.6. Expansion factor: {8.15}

4.6.7. Reynolds number: {8.18}

4.6.8. Nozzle discharge coefficient (L/D = 0.6): {8.19}

4.6.9. Airflow rate for chamber nozzles: {8.22}

4.6.10. Fan airflow rate at test conditions. These are the reportable numbers: {8.23}

4.6.11. Fan velocity pressure at test conditions: {8.28}

4.7. Fan pressures for an <u>outlet chamber</u> follow.

4.7.1. Fan is open to environment, so inlet pressure is zero: {¶ 8.5.3.1.}

4.7.2. Fan static pressure (positive values) and total pressure: {¶ 8.5.4.2 & 8.40}

4.8. Fan pressures for an <u>inlet chamber</u> follow.

4.8.1. Fan total inlet pressure: {8.37}

4.8.2. Fan static pressure is the value measured at the piezometer ring, plus calculated chamber velocity pressure. {From *ASHRAE 120*, Fig. 14 and Equation 37} Note that inlet chamber static pressure will be negative for fans and positive for static devices.

4.8.2.1. Chamber velocity pressure will slightly lessen negative static pressure for fans, and slightly increase positive static pressure for static devices.

4.8.3. Inlet chamber - Fan outlet total pressure equals fan outlet velocity pressure: {8.39}

4.9. The following apply to both outlet and inlet chambers.

4.9.1. Fan total pressure: {8.43}

4.9.2. Fan static pressure at test conditions: {8.44}

4.10. Equations for pitot traverse in the duct supplying an inlet chamber are found in *210/51*.

4.11. Pressure values (and electrical energy) are converted to standard atmospheric density. (Density is the only conversion; conversion to other speeds, and compressibility conversion are not to be used for HVI ratings.)

4.11.1. Total pressure – density only: {8.60}

4.11.2. Velocity pressure – density only: {8.61}

4.11.3. Static pressure – density only: {8.62}

4.11.4. Amps and watts at standard conditions are estimated by the same density ratio: {as in 8.60}

4.12. Airflow, *Q*, at test conditions needs no conversion because nozzle testing is a mass flow test.

4.13. Cfm per watt is calculated using standard density.

4.14. Specific procedures for **non-powered kitchen ventilator** calculations follow.

4.14.1. Non-powered kitchen ventilators are tested for airflow resistance as a “system”, normally on the outlet chamber.

4.14.1.1. Calculations for non-powered kitchen ventilators are the same as for powered devices, but static pressure will have the opposite sign. (Static pressure is actually a differential pressure referenced to atmosphere.)

4.14.2. Non-powered kitchen ventilators are tested as a “system”, measuring 10 points more or less equally spaced between zero airflow and the maximum desired airflow value requested by the member submitting the product. Special considerations for the test report are described in that section.

4.15. Specific procedures for **static vent NFA calculations** follow.

4.15.1. Static vents are tested for airflow resistance as a “system”, normally on the inlet chamber. Net Free Area (NFA) calculations are the same for either chamber.

4.15.1.1. Calculations for static vents are the same as for powered devices, but static pressure will have the opposite sign. (Static pressure is actually a differential pressure referenced to atmosphere.)

4.15.2. To calculate *NFA* for static vents, use static pressure from the airflow test as the *ΔP* component; it must first be converted to standard atmospheric density. Airflow, *Q*, at test conditions is used. Other values are described below. Calculate *NFA* of the static device using {Eq. 8.22} rearranged as follows:

$$NFA = \frac{Q}{1096.7 C_{SD} Y_{SD} \sqrt{\Delta P / \rho_s}}$$

4.15.2.1. *NFA* is in square inches of the test device, often a partial segment.

4.15.2.2. The subscript, *SD*, denotes values adopted by HVI for static devices.

4.15.2.3. Coefficient, C_{SD}, is taken as 0.61 for all static devices by consensus for HVI rating. (It is actually indeterminate because “aerodynamic cross sectional area” is indeterminate.)

4.15.2.4. Expansion factor, Y_{SD}, of the static device is taken as 0.995 by consensus for HVI rating. (Static devices encounter very low pressures.)

4.15.2.5. Differential pressure, *ΔP*, is the static pressure at standard atmospheric density from the chamber airflow test.

4.15.2.6. Standard atmospheric density, ρ_s, is 0.075 lbm/ft^3.

4.15.3. Incorporating the known values, the *NFA* equation is simplified.

$$NFA = \frac{0.0592 Q}{\sqrt{\Delta P}}$$

4.15.4. *NFA* is calculated for each of four lab test determinations. If the four values are within 5%, the test is considered successful.

4.15.5. The four are then arithmetically averaged, producing a single number *NFA* for submittal to HVI for certified rating.

5. HVI Product Categories and Their Setups

5.1. The test setups established by HVI for each product category are presented in the chart below. It is assumed that every condition for each product category is covered.

5.1.1. All HVI product categories are listed in *HVI Publication 920*, the publication that primarily governs categories and their descriptions.

5.1.2. Certain categories are not governed by this publication, including Energy Recovery Ventilators, Heat Recovery Ventilators, and Integrated Supply and Exhaust Ventilators, are covered by other HVI publications. The only exception covers two-duct ceiling/wall insert HRV and ERV products which can be tested for HVI Certification in accordance with this Procedure.

5.1.2.1. Certain parts of certain categories are not HVI-Certified, and thus are not covered by this publication, such as the heater portion of a heat-fan-light combination unit.

5.1.3. If no test setup appears satisfactory for a product that a member desires to test for HVI certification, a setup intended for a different category or a new setup may be used, provided it produces results that are realistic and comparable to established setups. Any such new setup shall be thoroughly documented.

5.1.3.1. Any new test setup shall be submitted to the HVI Engineering Committee, which will decide whether to recommend adoption by the general membership of HVI. If adopted, it will be included in this publication at a suitable time.

5.2. Standard HVI product categories and test setups covered by this procedure are as listed below. Standard HVI names of all product categories covered by the scope of HVI are found in *HVI Publication 920*.

HVI PRODUCT CATEGORY	SETUP NUMBER
Bathroom exhaust fans incl. combination units	1, 3, 4
Downdraft kitchen exhausters incl. non-powered*	6
Fresh air inlets	13
Inline fans (one inlet – one outlet)	16
Inline fans (multiple inlet – one outlet)	17
Inline fans (one inlet – multiple outlets)	18
Kitchen exhaust fans	1, 3, 4, 8, 9
Kitchen range hoods incl. combo hoods and non-powered*	2,5
Other room exhaust fans	1, 3, 4
Powered attic ventilators	10, 11
Range hood power units	2, 5, 6
Remote exterior mounted ventilators	7
Static vents	12
Whole house comfort ventilators	14, 15
Heat/energy recovery ventilator (two-duct ceiling/wall insert only)	1, 7

*Non-Powered Kitchen Ventilators are not a stand-alone product category, but are static devices to be tested for Combination Rating in conjunction with powered kitchen ventilators of various types. See *HVI Publication 920* for HVI rating and certification procedures.

“Kitchen power units” is a term used to include all power units offered for kitchen ventilation: remote exterior mounted ventilators and inline fans may be kitchen power units. Range hood power units are always kitchen power units.

6. Test Setups and Diagrams

6.1. Each setup shall be as shown in the Setup Figures, and shall simulate as nearly as practical actual field installation of the product under test, in accordance with the product’s installation instructions.

6.2. Tested product shall consist of a complete product as shipped and as expected to be installed in the field. Products with grilles, filters, dampers or other accessories in the same package shall be tested with those items in place.

6.2.1. Usually all parts will be together in one package; if they are not, the member shall furnish all of the parts required to make a complete fan as expected to be installed.

6.3. When a product is offered with more than one type of restrictive device (e.g., range hoods with different filters or dampers) the product shall be tested and rated with each, or the member may opt to rate the product with the most restrictive option.

6.3.1. Non-powered kitchen ventilators and separate power units for kitchen ventilation are tested separately and combination rated. Combination rating requires that both units be tested with the same duct size. When the regular duct size differs, members may request that one product be tested with a transition piece.

6.4. Fans with one discharge designed to be mounted in either the ceiling or the wall shall be tested with horizontal discharge simulating ceiling installation.

6.5. For all fans intended to be mounted in a ceiling, wall or other surface, the fan shall be mounted on setup material to simulate the surfaces. Normally 2 ft x 2 ft of ¾-inch plywood is used, or larger size if required by fan or grill.

6.5.1. Fans shall be mounted flush with the finished wall or ceiling surface unless otherwise specified in the instructions.

6.6. Kitchen range hoods shall be tested in 30-inch width, or the next largest width available.

6.6.1. Normally range hoods are mounted on two 2x4's that overhang both sides of the hood for test stand support. In addition, two front-to-back pieces of 2x4 approximately 12 inches long may be installed between hood and cross pieces.

6.7. In the test setup diagrams that follow, some fans are mounted directly onto the test chamber. For such test setups, impact pressure on static taps and obstructions to fan airflow are to be avoided.

6.8. When attached or fitted into a test setup, joints and duct connections shall be taped to prevent leakage that might cause an unrealistic fan airflow rating.

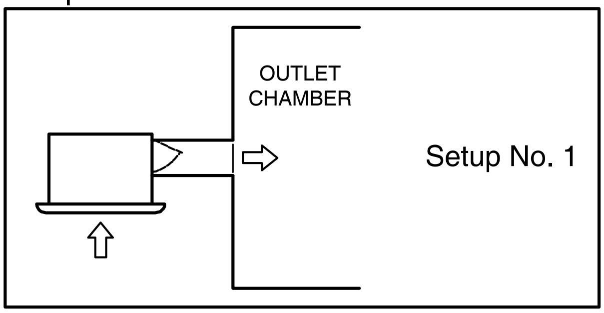
6.9. In the following setups, when a ducted test fan is connected to the outlet chamber, the inlet chamber, and/or an inlet smoothing device, a short section (2.5 to 4 diameters or hydraulic diameters) of the fan's designed duct size may be used at the member's option.

6.9.1. When a short section is used, its resistance shall be considered zero.

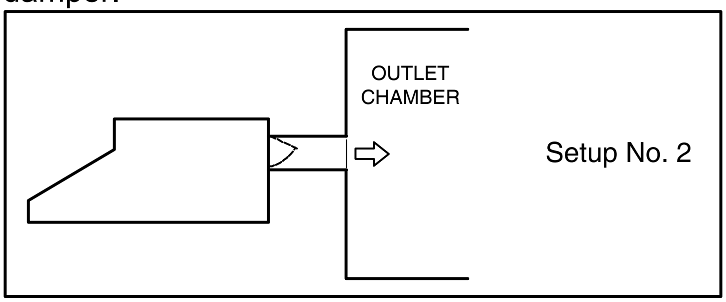
6.9.2. If the member does not specify otherwise, inclusion of the short section of duct shall be considered the normal setup.

6.10. All powered fans will be tested at 120 volts, or at rated voltage if higher than 120 volts.

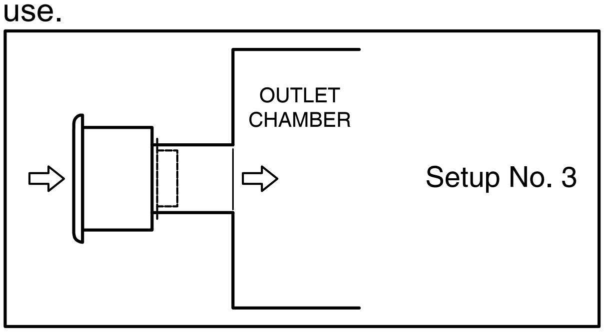
6.11. Setup No. 1: Outlet chamber, horizontally ducted exhaust fan, with or without damper.



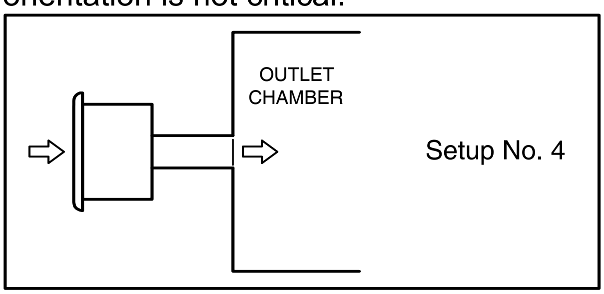
6.12. Setup No. 2: Outlet chamber, horizontally ducted range hood, with or without damper.



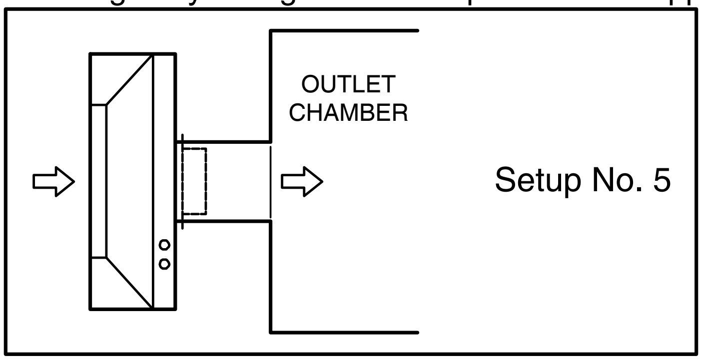
6.13. Setup No. 3: Outlet chamber, vertically ducted exhaust fan, with damper. When a vertically ducted fan has a damper, the fan shall be positioned with the damper axis vertical, to simulate the near neutral gravity on the damper in actual use.



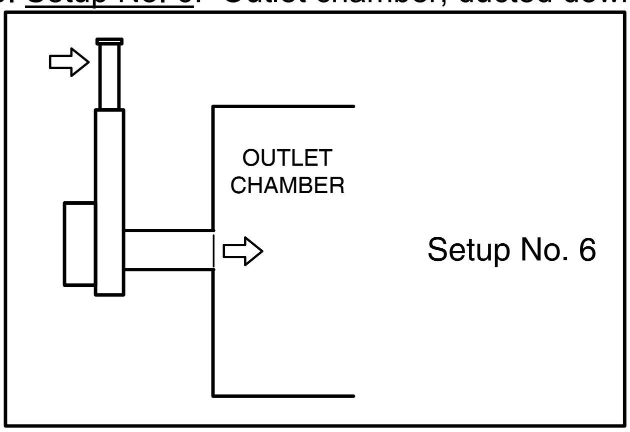
6.14. Setup No. 4: Outlet chamber, vertically ducted exhaust fan, with no included damper. When a fan has a vertical discharge with no damper, its rotational orientation is not critical.



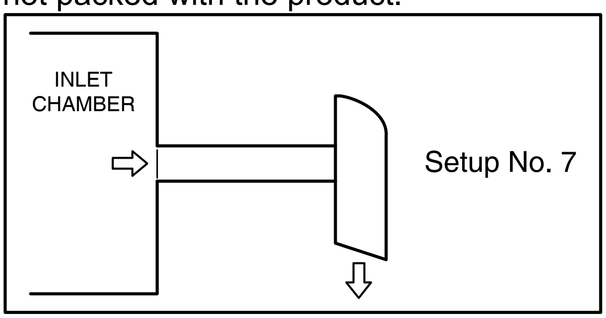
6.15. Setup No. 5: Outlet chamber, vertically ducted range hood, with damper. When a range hood has a vertical discharge with a damper, the hood shall be positioned so the axis of the damper is vertical in the test, to simulate the near neutral gravity acting on the damper in actual application.



6.16. Setup No. 6: Outlet chamber, ducted downdraft kitchen exhauster.

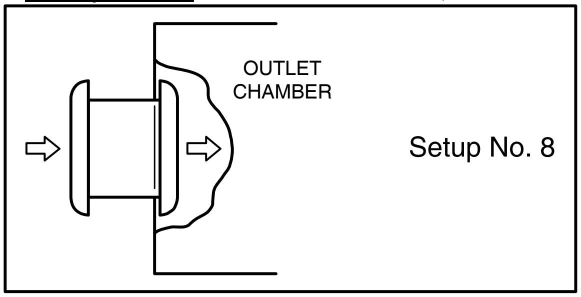


6.17. Setup No. 7: Inlet chamber, ducted remote exterior mounted ventilator. Manufacturer's recommended damper shall be included in the test, even if it is not packed with the product.

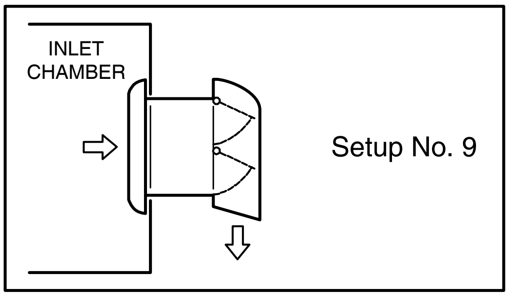


6.17.1. "Type B" remote mounted exterior ventilators, as defined in Section 3.21.16.1 of *HVI Publication 920*, shall be tested alone and not in conjunction with any other components included in the box.

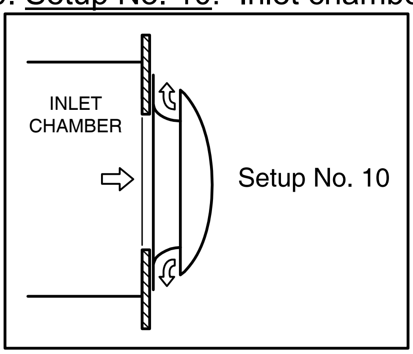
6.18. Setup No. 8: Outlet chamber, direct discharge through-wall fan.



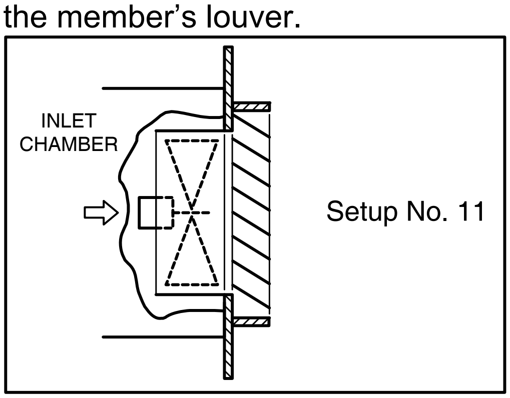
6.19. Setup No. 9: Inlet chamber, direct discharge wall fan with outside hood or door.



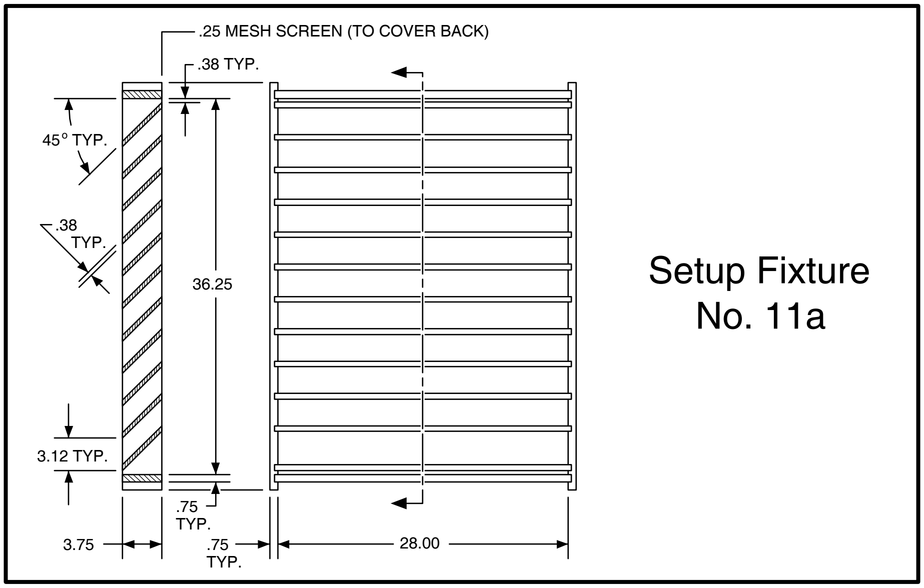
6.20. Setup No. 10: Inlet chamber, roof-mounted powered attic ventilator.



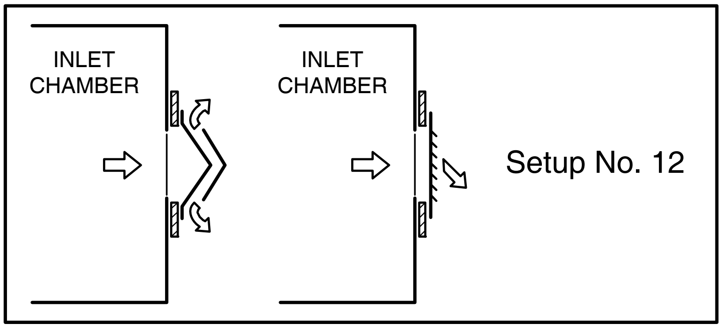
6.21. Setup No. 11: Inlet chamber, gable-mounted powered attic ventilator with louver. Gable mounted power attic ventilators are usually intended for mounting behind a louver shall be tested with the standard HVI louver, and optionally with the member's louver.



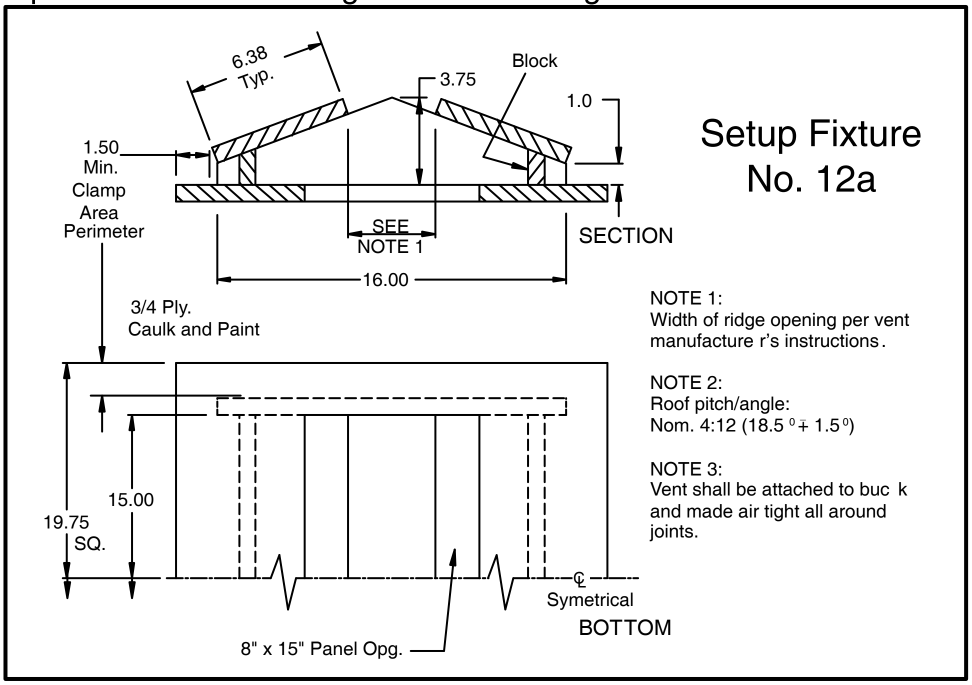
6.21.1. Setup Fixture No. 11a, the standard HVI test louver is constructed of wood with the dimensions shown.



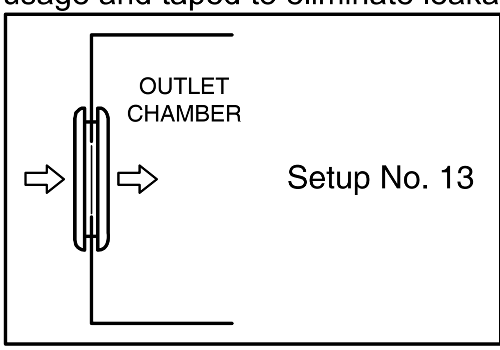
6.22. Setup No. 12: Inlet chamber, static louvers and ridge vents. These products are first tested for airflow, normally on the inlet chamber, mounted to simulate actual installation and taped to prevent leakage, especially at the edges. When the device has a special shape, a special fixture simulating actual installation shall be used.



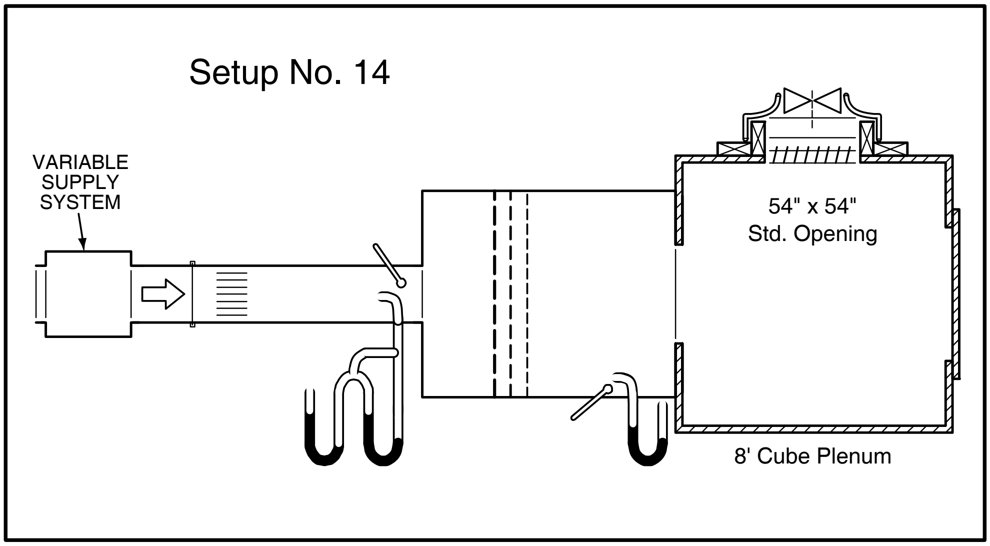
6.22.1. Setup Fixture No. 12a: Ridge vents shall be realistically mounted on the standard ridge vent test fixture described above. Tested product shall be taped to eliminate leakage around the edges.



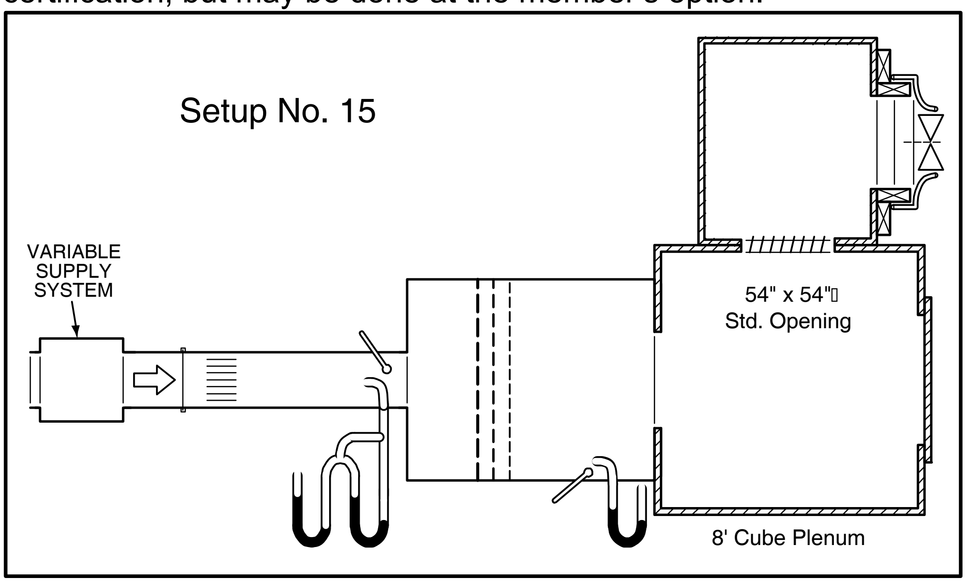
6.23. Setup No. 13: Outlet chamber, static fresh air inlet. Static fresh air inlets are normally tested on the outlet chamber, but may be tested on the inlet chamber. In either case, the device being tested shall be mounted to simulate actual usage and taped to eliminate leakage.



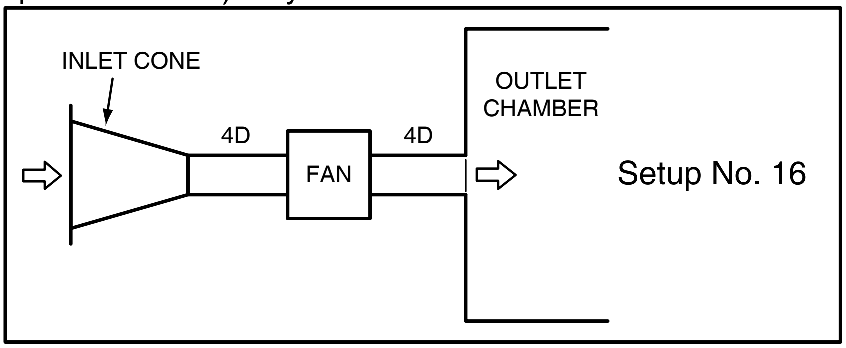
6.24. Setup No. 14: Ducted inlet chamber with pitot traverse, whole house comfort ventilator mounted in “ceiling” of 8-ft. cube, plywood inlet chamber. Whole house comfort ventilators shall be tested with the shutter shipped with the fan or the smallest net free area shutter the member offers with the fan or recommends.



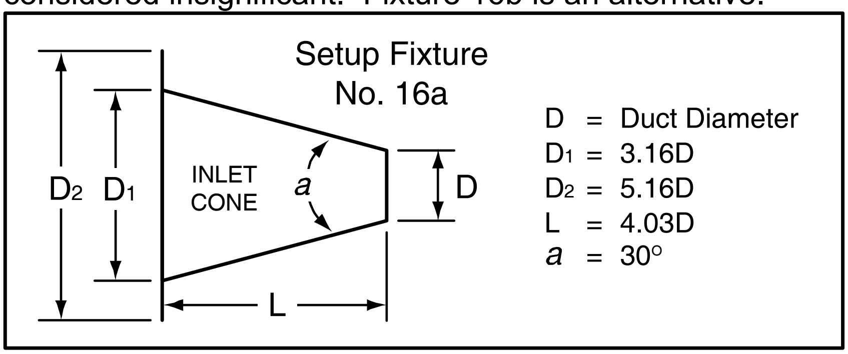
6.25. Setup No. 15: Ducted inlet chamber with pitot traverse, whole house comfort ventilator mounted in “wall” of a plenum chamber constructed above the 8-ft. cube, plywood inlet chamber. This alternate setup is not required for HVI certification, but may be done at the member’s option.



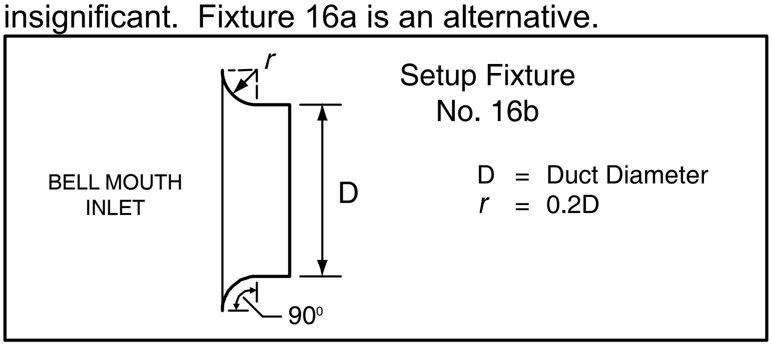
6.26. Setup No. 16: Outlet chamber, inline fan with one inlet duct and one outlet duct, fan may be with or without damper. For this, and all other setups, it is HVI's practice to reduce duct inlet, as well as outlet, losses to the degree that they do not need to be added to fan performance by calculation. To reduce inlet losses either the velocity-reducing inlet cone or a large bell-mouth inlet (both specified below) may be used.



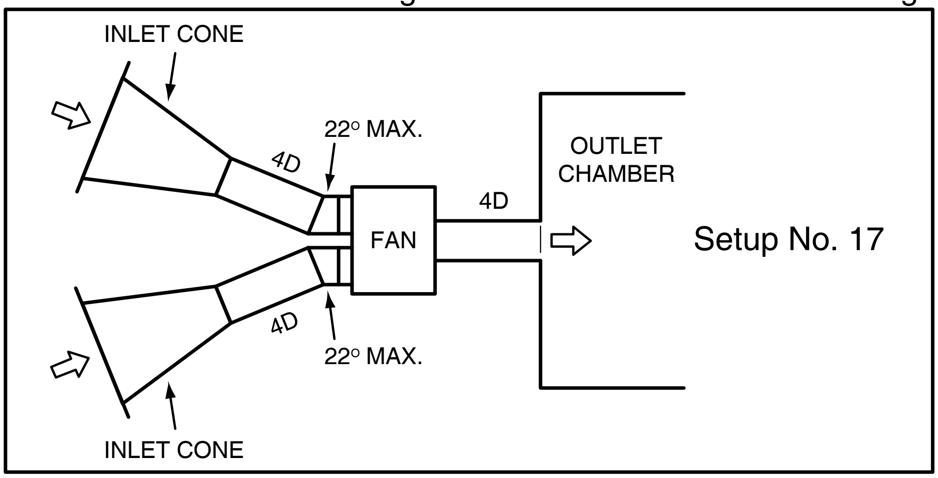
6.26.1. Setup Fixture No. 16a: Inlet cone proportions shall be based on nominal duct diameter, *D*. Inlet diameter shall be *3.16 D*, reducing inlet velocity to 1/10 fan inlet velocity, and duct inlet losses are ignored for HVI rating. As a result, the static pressure will be understated by $0.1\ P_v$, an amount considered insignificant. Fixture 16b is an alternative.



6.26.2. Setup Fixture No. 16b: Bell-mouth inlet(s) may be used for all setups where inlet cone(s) are illustrated. Bell-mouth inlet proportions shall be based on nominal duct diameter, *D*. Inlet radius, *r*, shall be *0.2D*; ASHRAE states that C_o=0.03 for this proportion, a value small enough to consider insignificant. Fixture 16a is an alternative.

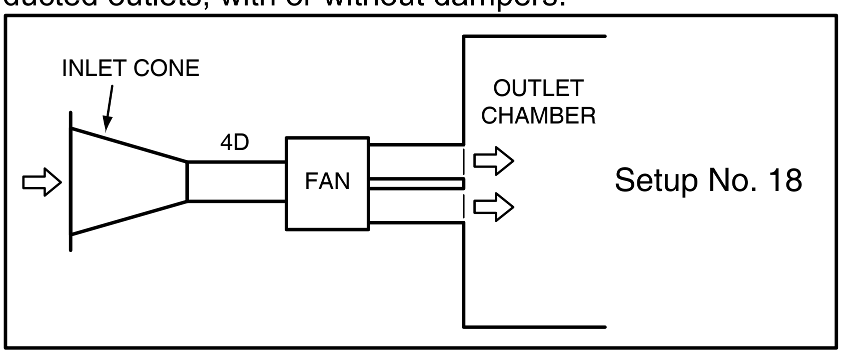


6.27. Setup No. 17: Outlet chamber, inline fan with multiple ducted inlets and single ducted outlet, fan may be with or without damper. Use of inlet cones with this setup may necessitate the use of elbows; if so they shall be smooth elbows of 22° maximum. Bell-mount inlets, being of smaller diameter, may eliminate the need for elbows. Connecting ductwork shall be 4 diameters long.



6.27.1. When product and inlet fixture configuration require longer than 4D duct(s), friction is to be ignored.

6.28. Setup No. 18: Outlet chamber, inline fan with one ducted inlet and multiple ducted outlets, with or without dampers.



7. Test Conduct and Report

7.1. General rules for conducting airflow tests follow. Additional rules for certain categories may be found with the test setups specified for the category and in other locations.

7.1.1. Products with multiple speeds shall be tested at maximum speed. In some categories, HVI has provisions for certified ratings at additional speeds, at the member's option.

7.1.1.1. Kitchen Range Hoods may be tested at working speed, in addition to maximum speed, at the member's option. The procedure is described below.

7.1.1.2. For other optional speeds permitted by HVI, see *HVI Publication 920*.

7.1.2. For powered products, a minimum of 10 more-or-less evenly spaced test points shall be measured, from approximately zero static pressure to maximum (shut-off) pressure.

7.1.3. For non-powered kitchen ventilators a minimum of 10 more-or-less evenly spaced test points shall be measured, from approximately zero static pressure to the maximum airflow requested by the member submitting the test request.

7.1.4. For static vent products, airflow shall be measured, at four static pressures more or less evenly spaced between 0.5 and 2.0 inches of water.

7.1.5. For static fresh air inlets, the test shall include measurements near the following points: 0.02, 0.03, 0.04, 0.06, 0.08, 0.1, 0.2, 0.4, 0.6, and 0.8 inches static pressure.

7.1.6. Test points described above are the measured values, which will adjust when converted to standard atmospheric density. It is understood that the lower measured pressures may sometimes become negative static pressure when converted.

7.1.7. Tests pressures shall be limited to less than 4 inches of water (1 *kPa*).

7.1.8. Tests for sound (loudness) rating shall be run as soon as possible after airflow tests, and the product shall not be altered between the two tests. Note: This requirement does not apply to products without HVI sound rating procedures. (See also *HVI Publication 915* and *HVI Publication 920*.)

7.1.9. For two-duct ceiling/wall insert HRV and ERV products, the outlet or discharge duct is connected to the Figure 12 outlet chamber and the inlet or supply duct is connected to the Figure 15 inlet chamber. The unit is operated at its highest speed and both chambers are adjusted to similar pressures. At least five measurements shall be taken from approximately zero static pressure to maximum (shut-off) pressure.

7.2. Kitchen range hood working speed rating tests are optional for range hoods with multiple speeds. The purpose is to provide sound ratings more closely related to consumers' actual experience.

7.2.1. Working Speed, as adopted by HVI, is defined as the speed that produces 100 cfm, or the lowest speed above 100 cfm that a hood can produce, when working on the same duct system as the maximum speed test. The airflow test requires a specific test sequence, which follows.

7.2.2. In each selected range hood configuration (vertical, horizontal, etc.) the normal maximum speed airflow test is conducted first, then the working speed test while in the same setup. Although working speed is a single point, conversion to standard density may require that two points be established with the point interpolated between them. Detailed procedures for various types of adjustable speed range hoods follow.

7.2.2.1. For multiple speed range hoods, switch the hood to the lowest speed producing 100 cfm or more and adjust static pressure to the same system curve as the maximum speed test. Record motor rpm in addition to airflow and static pressure.

7.2.2.2. For range hoods with infinitely variable speeds, first adjust the speed to 100 cfm, then the static pressure to the same system curve (see system curve, below) as the maximum speed test. If the range hood is not capable of turning down to 100 cfm, record the results at the lowest possible speed setting. Record rpm and voltage to the motor in addition to airflow and static pressure.

7.2.2.3. For 2-speed range hoods, switch hood to low speed and adjust static pressure to the same system curve as the maximum speed test. Two-speed hoods are required to produce at least 90 cfm for HVI working speed certification. Record motor rpm in addition to airflow and static pressure.

7.2.3. Establishing working speed on the system curve presumes the HVI static pressure rating point (usually 0.1 inches of water) represents the duct system that will be used for the hood in the field. When the hood speed is reduced, the hood is on the same system and the system curve relationship will continue.

7.2.3.1. First, using maximum speed test results nearest the rating point, corrected to standard atmosphere, calculate the system curve constant as follows. (P_{smax} will normally be approximately 0.1 inches, and Q_{max} the corresponding airflow, where "max" indicates maximum speed.)

$$K = Q_{\max} \Big/ \sqrt{P_{s\max}}$$

7.2.3.2. Then, using the target airflow, Q_{ws}, or 100 cfm, calculate the required test static pressure for working speed.

$$P_{sws} = \left(Q_{ws} / K \right)^2$$

7.2.3.3. Adjust the static pressure on the chamber and re-adjust the airflow until the above calculation, using measured static pressure and airflow values, returns the same system curve constant. (Note: Working speed static pressure will be quite low, sometimes in the order of 0.01 inches of water. It is also possible that some hoods will have a working speed considerably higher than 100 cfm.)

7.2.4. When the hood is at working speed on the same system curve as the maximum speed test, record the results both for rating and for use in the HVI sound test, which follows immediately. (See *HVI Publication 915*.)

7.3. <u>The test report will include the following</u>.

7.3.1. A copy of the HVI fan test data submittal form shall be attached.

7.3.2. Information to identify the test, including date, fan or ventilator brand name, model number, HVI category name, and name of person conducting test shall be recorded.

7.3.3. Condition of product as received shall be noted (e.g., ". . . received in good condition.").

7.3.4. Fan measurements including impeller diameter and number of blades, outlet and inlet area, and duct size shall be recorded for identification.

7.3.4.1. For static devices and non-powered kitchen ventilators, major aerodynamic dimensions, including duct size if ducted, shall be recorded for identification.

7.3.5. Fan accessories, such as grille and damper, and test duct diameter and length, and/or fixtures used for the test, shall be identified by general description.

7.3.6. Test setup information (i.e. Setup Number as illustrated in this Procedure), and product discharge (i.e. horizontal, vertical, etc., for products with more than one discharge) shall be recorded.

7.3.7. Test equipment used shall be listed, including inlet or outlet chamber type, nozzles used, measuring equipment used, etc.

7.3.8. Photograph(s) of product as tested shall be included, showing the product and test setup in sufficient detail.

7.3.9. The primary reason for including test setup information and photograph(s) of the test are to create a record in sufficient detail to be able to duplicate the setup for verification tests in the future. There is no need for redundant information.

7.3.10. Atmospheric density data, as measured in the test environment shall be recorded.

7.3.11. For all test points, measured data, calculated results at test conditions, and results at standard air shall be listed.

7.3.12. Fan power shall be recorded as motor input in watts at each test point and converted to standard atmospheric conditions using density ratio.

7.3.13. Test results shall be reported in terms of standard air density of 0.075 lbm/ft^3 (1.2 kg/m^3).

7.3.14. The test report shall include a plot of airflow in cfm, static pressure in inches of water, total pressure in inches of water, fan power input in watts, and speed in rpm, with airflow on the horizontal axis.

7.3.15. When two or more test reports will be used for combination rating, the graphic plot of airflow versus static pressure shall be the same scale, size, and zero for products that will be overlaid. (A mathematical "overlay" may be acceptable.)

7.3.15.1. In order to enable overlaying the test plots, the static pressure of a non-powered ventilator is required to be negative rather than positive as it is with a fan plot.

7.3.16. The test report shall be signed by the person responsible, preferably a Professional Engineer.

7.3.17. The test report shall be furnished in two copies to the member who ordered the test.

7.3.18. The member will retain one copy for their records and submit the other to HVI for their retention with the certification application. (See *HVI Publication 920*.)

APPENDIX I. HVI AIRFLOW TEST CALCULATIONS

1. Appendix I. Introduction

1.1. The calculations described herein are in accordance with the 1999 version of *ANSI/AMCA 210 – ANSI/ASHRAE 51*, and are test calculations that apply to HVI certification. That publication is abbreviated herein as *210/51*.

1.2. This appendix provides a practical replacement for the 'Formulae' section of prior editions of the HVI Airflow Test Procedure.

1.3. Paragraph and equation numbers from *210/51* appear in curly brackets, e.g. {9.9.9}, for reference.

1.4. Purpose

1.4.1. By describing the calculations used for HVI airflow testing, this appendix broadens the understanding of the test and calculation process in general.

1.4.2. This appendix describes air test calculations that HVI members may use to set up math for their own laboratories.

1.5. Scope

1.5.1. This description starts with calculations for tests performed on an outlet chamber as described in this publication.

1.5.1.1. Additional information is provided for testing fans using an inlet chamber with a piezometer ring as described in this Publication and shown in *ASHRAE 120*, Fig. 14.

1.5.1.2. Additional information is provided for testing static devices using an inlet chamber with a piezometer ring.

2. Appendix I. General Information

2.1. Calculations are based on several assumptions, including those listed below.

2.1.1. Pressures through the system are less than 4 inches of water, so compressibility may be ignored. In practice, pressures are often limited to 2 inches of water.

2.1.2. Velocity through the chamber is less than 400 feet per minute. (In practice, chamber velocity is usually less than 200 fpm.)

2.1.3. Chamber design dimensions conform to details described in *210/51*.

2.1.3.1. Hydraulic diameter of a rectangular chamber of uniform cross section with width *a*, and height *b*, is as follows.

$$D_h = \sqrt{4ab/\pi}$$

2.1.4. Friction in short duct sections (2.5 to 4 times D_h) between test fan and chamber are ignored.

2.1.4.1. Duct sections longer than $4D_h$ are generally not used.

2.2. A calculation example is provided at the end of this Appendix for further explanation.

3. Appendix I. Symbols

Symbols consistent with *210/51* are included in this publication for convenience and as reference. For a more complete listing of symbols see *210/51*.

SYMBOL	DESCRIPTION	IP UNITS	SI UNITS
A	Area of cross section	*feet²*	*m²*
C	Nozzle discharge coefficient	*dimensionless*	
C_{SD}	Static device discharge coefficient	*dimensionless*	
D	Diameter and equivalent diameter	ft	M
P_s	Fan static pressure	inches water	Pa
P_{sx}	Static pressure at plane x	inches water	Pa
P_t	Fan total pressure	inches water	Pa
P_{tx}	Total pressure at plane x	inches water	Pa
P_v	Fan velocity pressure	inches water	Pa
P_{vx}	Velocity pressure at plane x	inches water	Pa
p_b	Absolute local barometric pressure	inches Hg	Pa
p_e	Saturated vapor pressure at t_w	inches Hg	Pa
p_p	Partial vapor pressure	inches Hg	Pa
Q	Fan airflow rate	$feet^3$/min	l/s
Q_x	Airflow rate at plane x	$feet^3$/min	l/s
R	Gas constant	ft·lb/lbm·°R	J/kg·K
Re	Reynolds number	*dimensionless*	
t_d	Dry-bulb temperature	°F	°C
t_w	Wet-bulb temperature	°F	°C
V	Velocity	feet/min	m/s
Y	Nozzle expansion factor	*dimensionless*	
Y_{SD}	Expansion factor, static device	*dimensionless*	
A	Static pressure ration for nozzles	*dimensionless*	
B	Diameter ratio for nozzles	*dimensionless*	
ΔP	Pressure differential	inches water	Pa
M	Dynamic air viscosity	lbm/ft·sec	Pa·s
P	Fan air density	lbm/ft^3	kg/m^3
ρ_x	Air density at plane x	lbm/ft^3	kg/m^3
ρ_S	Density of Standard Air	lbm/ft^3	kg/m^3

SUBSCRIPT SYMBOL	DESCRIPTION
c	Converted value (i.e., to Standard Atmospheric Conditions)
e	Estimated
x	Plane 0, 1, 2, . . . as appropriate
0	Plane 0 (general test area)
1	Plane 1 (fan inlet)
2	Plane 2 (fan outlet)
5	Plane 5 (nozzle inlet station in chamber)
6	Plane 6 (nozzle discharge station)
7	Plane 7 (outlet chamber measurement station)
8	Plane 8 (inlet chamber measurement station)
SD	Static device

4. Overview of Calculations for Airflow Testing

4.1. Air test calculations are divided into the following steps that must be followed for each test.

4.1.1. Air density in the test environment is calculated.

4.1.2. Flow rate, pressure, and fan power input are measured in the test.

4.1.3. Flow rate at test conditions is calculated.

4.1.4. Pressures at test conditions are calculated.

4.1.5. Pressures and fan power input are converted to standard air density.

5. General Equations for Outlet Chamber

5.1. Atmospheric air density, ρ_0. First, the following three parameters are measured in the general test area.

5.1.1. Dry-bulb temperature, measured with a precision thermometer.

5.1.2. Wet-bulb temperature, measured with a precision psychrometer.

5.1.3. Barometric pressure, measured with a barometer, or by obtaining a value from a nearby weather station, adjusted to local elevation and conditions.

5.1.4. The gas constant, R, may be taken as 53.35 in IP units and 287.1 in SI units. {¶ 8.2.1.}

APPENDIX I.

5.1.5. Then the following are used to calculate atmospheric air density. {8.1, 8.2, 8.3}

$$p_e = \left(2.96\times10^{-4}\right)t_{w0}^{\ 2} - \left(1.59\times10^{-2}\right)t_{w0} + 0.41$$

(SI:) $p_e = 3.25\,t_{w0}^{\ 2} + 18.6\,t_{w0} + 692$ Pa

$$p_p = p_e - p_b\left(\frac{t_{d0}-t_{w0}}{2700}\right) \quad \text{(SI:)} \quad p_p = p_e - p_b\left(\frac{t_{d0}-t_{w0}}{1500}\right)$$

$$\rho_0 = \frac{70.73\left(p_b - 0.378\,p_p\right)}{R\left(t_{d0}+459.67\right)} \quad \text{(SI:)} \quad \rho_0 = \frac{\left(p_b - 0.378\,p_p\right)}{R\left(t_{d0}+273.15\right)}$$

5.1.6. Air density at any plane, ρ_x. Air density at the measuring plane may be lower than atmospheric air density in the general test area because of energy added to the air as it passes through the test chamber, warming it. {8.4}

$$\rho_x = \rho_0\left(\frac{t_{d0}+459.67}{t_{dx}+459.67}\right)\left(\frac{P_{sx}+13.63p_b}{13.63p_b}\right) \text{(SI:)} \quad \rho_x = \rho_0\left(\frac{t_{d0}+273.15}{t_{dx}+273.15}\right)\left(\frac{P_{sx}+p_b}{p_b}\right)$$

5.1.7. Dynamic air viscosity, μ, is calculated using dry-bulb temperature. The value for viscosity at 68° F, 1.222 x 10^{-5}, is sometimes used as a constant for temperatures from 40° F and 100° F. Dynamic air viscosity varies from 1.17 x 10^{-5} at 40° F, to 1.28 x 10^{-5} at 100° F. {8.6}

$$\mu = \left(11.00 + 0.018\,t_d\right)\times10^{-6} \quad \text{(SI:)} \quad \mu = \left(17.23 + 0.018\,t_d\right)\times10^{-6}$$

5.2. Fan flow rate at test conditions, for nozzles, is then calculated.

5.2.1. Alpha ratio for chamber, α,, is the ratio of absolute nozzle exit pressure to absolute approach pressure. Typical values from 0.999 to 0.995 are calculated as follows. {8.12}

$$\alpha = 1 - \frac{5.187\Delta P}{53.35\rho_5\left(t_{d5}+459.67\right)} \quad \text{(SI:)} \quad \alpha = 1 - \frac{\Delta P}{\rho_5 R\left(t_{d5}+273.15\right)}$$

5.2.2. Beta ratio is taken as zero (0) for a chamber. {¶ 8.3.2.2.}

5.2.3. Expansion factor, *Y*, is dimensionless. Calculation is simplified because β=0. Typical values are from .999 to .997. {8.15}

$$Y = 1 - 0.548\left(1-\alpha\right)$$

5.2.4. Reynolds number, *Re*. Reynolds number and nozzle discharge coefficient are interdependent. The iterative equations shown assume the calculations are to be done using a capable computer. See *210/51* for other methods. {8.18}

$$\mathrm{Re} = \frac{1096.7}{60\mu} C D_6 Y \sqrt{\Delta P \rho_5} \qquad \text{(SI:)} \quad \mathrm{Re} = \frac{\sqrt{2}}{\mu} C D_6 Y \sqrt{\Delta P \rho_5}$$

5.2.5. Nozzle discharge coefficient, *C*, is dimensionless. If pressures are between 0.25 and 2 inches of water, values may range from 0.963 to 0.977. {8.19}

$$C = 0.9986 - \frac{7.006}{\sqrt{\mathrm{Re}}} + \frac{134.6}{\mathrm{Re}}$$

5.2.6. Airflow rate for chamber nozzles, Q_5, is calculated as follows. If multiple nozzles are used, *C* and *A* for each must be determined and their products summed. {8.22}

$$Q_5 = 1097 Y \sqrt{\frac{\Delta P}{\rho_5}} \Sigma(C A_6) \qquad \text{(SI:)} \quad Q_5 = Y \sqrt{\frac{\Delta P}{\rho_5}} \Sigma(C A_6)$$

5.2.7. Fan airflow rate, *Q*, at test conditions. **This is the value to plot as a test report.** {8.23}

$$Q = Q_5 \left(\rho_5 / \rho \right)$$

5.3. Fan pressures at test conditions for an outlet chamber are then calculated.

5.3.1. Fan velocity pressure, P_v, at test conditions is calculated. Note that A_2 is the fan outlet area and $\rho_2 = \rho_5$. {8.28}

$$P_v = \left(\frac{Q\rho}{1096.7 A_2} \right)^2 \frac{1}{\rho_2} \qquad \text{(SI:)} \quad P_v = \left(\frac{Q\rho}{A_2} \right)^2 \frac{1}{2\rho_2}$$

5.3.2. Fan static pressure, P_s, is the measured static pressure at the plane 5 chamber piezometer ring. {¶ 8.5.1.3.}

5.3.3. Fan total pressure, P_t, is the sum of P_s and P_v. {8.40}

$$P_t = P_s + P_v$$

5.4. Convert pressures at test conditions to pressures at standard atmospheric conditions.

5.4.1. Standard atmospheric density is established as ρ_c = 0.075 *lbm/ft*^{3} . Conversion is by density ratio. Electrical values are similarly converted by density ratio. **These are the values to plot on the test report.**

$$P_{tc} = P_t \left(\frac{\rho_c}{\rho_0} \right)$$

$$P_{vc} = P_v \left(\frac{\rho_c}{\rho_0} \right)$$

$$P_{sc} = P_s \left(\frac{\rho_c}{\rho_0} \right)$$

$$Amps_c = Amps \left(\frac{\rho_c}{\rho_0} \right)$$

$$Watts_c = Watts \left(\frac{\rho_c}{\rho_0} \right)$$

5.4.2. Fan speed measured value needs no conversion. **This is the value to plot.**

5.4.3. Fan cfm per watt is calculated using the converted value for watts. This parameter is not included in the test report because cfm is the "normalized" value described in *HVI Publication 920*, and may also be de-rated by the member.

5.5. Inlet chamber considerations are described in detail in *210/51* and *ASHRAE 120*.

5.5.1. When a fan is tested on the inlet chamber, the static pressure will appear to be negative. However, since the static pressure is actually the differential pressure relative to the general test area, it is treated as a positive number in the same way it is on the outlet chamber.

5.5.2. When using the inlet chamber with piezometer ring, a very small amount of chamber velocity pressure exists and affects fan total pressure. However, since residential fan ratings rarely, if ever, are affected by total pressure, chamber velocity pressure may be ignored.

5.6. Static vent airflow testing considerations follow.

5.6.1. Velocity pressure and total pressure are not relevant for rating static vents, and the vent outlet area is not defined before the test. Therefore, outlet area is not used, and velocity pressure and total pressure are not addressed. For static vents, static pressure is the relevant parameter.

5.6.2. Specific calculation procedures using airflow for measuring Net Free Area, *NFA*, of static vents are found in the "Equations and Calculations" section of this publication, and are not repeated here. An overview of the steps for measuring static vents *NFA* is as follows.

5.6.2.1. First, they are classically tested for airflow, usually on the inlet chamber, at four static pressures.

5.6.2.2. Airflow is stated "at test conditions" and static pressure is converted to standard atmospheric density.

5.6.2.3. Finally, *NFA* is calculated by rearranging the classical airflow equation {Eq. 8.22} to solve for area. This area, normally nozzle area, is the *NFA* of the static device. Other factors used in the rearranged equation are explained below.

5.6.2.3.1. The coefficient, *C*, is taken as 0.61 by HVI consensus as a result of testing experience.

5.6.2.3.2. The expansion factor, *Y*, is taken as 0.995 by HVI consensus.

5.6.2.3.3. Density, ρ, is standard atmospheric density, 0.075 lbm/ft^3.

5.6.2.3.4. The rearranged equation is then simplified to the form below.

$$NFA = 0.0592 \frac{Q}{\Delta P}$$

5.6.2.3.5. The airflow, *Q*, is used directly from the test.

5.6.2.3.6. For differential pressure, use static pressure at standard density.

5.6.2.3.7. After calculating *NFA* for each of the four determinations, the four numbers are arithmetically averaged.

5.6.2.3.8. The result is actual net free area exactly as the product will perform in actual usage.

6. Calculation Program

A Microsoft Excel spreadsheet calculation program is available to members for no charge from HVI Headquarters.

APPENDIX I.

7. Sample Calculations

7.1. Outlet chamber calculation sample.

	A	B	C	D	E	F	G	H
1	OUTLET CHAMBER	CALCULATION EXAMPLE			version	14-Mar-05		
2								
3				For each Determinaton				
4	Description	Sym-bol	In-put	Value	Value	Value		Equation
5	Input Known values:							
6	Diameter of first nozzle, in.		1.600					
7	Diameter of second nozzle, in.		2.000					
8	Diameter of first nozzle, ft.	D_6		0.1333	0.1333	0.1333		=C6/12
9	Diameter of second nozzle, ft.	D_6		0.1667	0.1667	0.1667		=C7/12
10	Area of first nozzle, ft^2	A_6		0.0140	0.0140	0.0140		=(D8/2)^2*PI()
11	Area of second nozzle, ft^2	A_6		0.0218	0.0218	0.0218		=(D9/2)^2*PI()
12	Fan outlet nom. diameter, in.		8.00					
13	Fan outlet diameter, ft.			0.6667	0.6667	0.6667		=C12/12
14	Fan outlet area. ft^2	A_2		0.3491	0.3491	0.3491		=(D13/2)^2*PI()
15	Estimated C for Reynolds no.	C_e	0.970	0.970	0.970	0.970		
16	Barometric pressure	p_b	29.08	29.08	29.08	29.08		
17								
18	Measurements for Each Determination in the General Test Area:							
19	Wet-bulb temp.	t_w		52.8	52.7	52.7		
20	Dry-bulb temp.	t_d		72.3	72.1	72.2		
21								
22	Chamber Measurements for Each Determination:							
23	Static pressure	P_s		0.002	0.159	0.329		
24	Differential pressure	P_d		2.928	1.627	0.336		
25	Dry-bulb temp, meas. plane	t_{d5}		72.7	72.9	72.9		
26	Fan input, true RMS watts			80	81	82		
27	Fan speed, rpm			2000	2000	2000		
28	Note: Full test has more determinations (10).							
29								
30	Calculations, Airflow:							
31	Saturated vapor pressure	p_e		0.39568	0.39415	0.39415		=(0.000296*D19^2)-(0.0159*D19)+0.41
32	Parital vapor pressure	p_p		0.18566	0.18520	0.18413		=+D31-D16*((D20-D19)/2700)
33	Atmospheric air density	ρ_0		0.07230	0.07233	0.07231		=+(70.73*(D16-0.378*D32))/(53.35*(D20+459.67))
34	Air density at meas. plane 5	ρ_5		0.07224	0.07225	0.07228		=D33*((D20+459.67)/(D25+459.67))*((D23+13.63*D16)/(13.63*D16))
35	Dynamic air viscosity	μ		1.231E-05	1.231E-05	1.231E-05		=+(11+0.018*D25)*0.000001
36	Alpha ratio	α		0.99260	0.99589	0.99915		=1-(5.187*D24)/(D34*53.35*(D25+459.67))
37	Expansion factor	Y		0.99594	0.99775	0.99953		=1-0.548*(1-D36)
38	Reynolds number, first nozzle	Re		87,975	65,680	29,908		=+(1096.7/(60*D35))*D15*D8*D37*(D24*D34)^0.5
39	Discharge coeff., first nozzle	C		0.9765	0.9733	0.9626		=0.9986-(7.006/D38^0.5)+(134.6/D38)
40	Reynolds number,2nd nozzle	Re		109,969	82,100	37,385		=+(1096.7/(60*D35))*D15*D9*D37*(D24*D34)^0.5
41	Discharge coeff., 2nd nozzle	C		0.9787	0.9758	0.9660		=0.9986-(7.006/D40^0.5)+(134.6/D40)
42	Airflow rate for nozzles	Q_5		243.281	181.114	81.574		=1096.7*D37*(D24/D34)^0.5*(D39*D10+D41*D11)
43	Fan airflow rate at test cond.	Q		243.099	180.914	81.534		=D42*(D34/D33)
44								
45	Calculations, Pressures:							
46	Fan velocity pressure	p_v		0.029	0.016	0.003		=+((D42*D34)/(1096.7*D14))^2/(D34)
47	Fan total pressure	p_t		0.031	0.175	0.332		=D46+D23
48								
49	Conversion to Standard Atmospheric Density (Test Report Values):							
50	Fan airflow rate at test cond.	Q		243	181	82		=D43
51	Static pressure, converted	p_{sc}		0.002	0.165	0.341		=D23*(0.075/D33)
52	Fan input power, converted	W		82.990	83.995	85.047		=D26*(0.075/D33)
53	Velocity pressure, converted	p_{vc}		0.030	0.017	0.003		=D46*(0.075/D33)
54	Total pressure, converted	p_{tc}		0.032	0.182	0.345		=D47*(0.075/D33)

APPENDIX I.

7.2. Inlet Chamber Calculation Sample.

	A	B	C	D	E	F	G	H
1	INLET CHAMBER	CALCULATION EXAMPLE			version	14-Mar-05		verify by use-testing
2								
3				For each Determinaton				
4	Description	Sym-bol	In-put	Value	Value	Value		Equation
5	Input Known values:							
6	Diameter of first nozzle, in.		1.600					
7	Diameter of second nozzle, in.		1.000					
8	Diameter of first nozzle, ft.	D_6		0.1333	0.1333	0.1333		=C6/12
9	Diameter of second nozzle, ft.	D_6		0.0833	0.0833	0.0833		=C7/12
10	Area of first nozzle, ft^2	A_6		0.0140	0.0140	0.0140		=(D8/2)^2*PI()
11	Area of second nozzle, ft^2	A_6		0.0055	0.0055	0.0055		=(D9/2)^2*PI()
12	Fan outlet nom. diameter, in.		6.00					
13	Fan outlet diameter, ft.			0.5000	0.5000	0.5000		=C12/12
14	Fan outlet area. ft^2	A_2		0.1963	0.1963	0.1963		=(D13/2)^2*PI()
15	Estimated C for Reynolds no.	C_e	0.970	0.970	0.970	0.970		
16	Barometric pressure	p_b	29.08	29.08	29.08	29.08		
17	Chamber cross-sectional area			12.00				
18								
19	Measurements for Each Determination in the General Test Area:							
20	Wet-bulb temp.	t_w		52.8	52.7	52.7		
21	Dry-bulb temp.	t_d		72.3	72.2	72.3		
22								
23	Chamber Measurements for Each Determination:							
24	Static pressure	P_s		0.002	0.159	0.329		
25	Differential pressure	P_d		1.900	1.125	0.250		
26	Dry-bulb temp, meas. plane	t_{d5}		73.0	73.5	73.7		
27	Fan input, true RMS watts			40	35	30		
28	Fan speed, rpm			1500	1600	1700		
29	Note: Full test has more determinations (10).							
30								
31	Calculations, Airflow:							
32	Saturated vapor pressure	p_e		0.39568	0.39415	0.39415		=(0.000296*D19^2)-(0.0159*D19)+0.41
33	Parital vapor pressure	p_p		0.18566	0.18413	0.18305		=+D31-D16*((D20-D19)/2700)
34	Atmospheric air density	ρ_0		0.07230	0.07231	0.07230		=+(70.73*(D16-0.378*D32))/(53.35*(D20+459.67))
35	Air density at meas. plane 5	ρ_5		0.07220	0.07217	0.07217		=D33*((D20+459.67)/(D25+459.67))*((D23+13.63*D16)/(13.63*D16))
36	Dynamic air viscosity	μ		1.231E-05	1.232E-05	1.233E-05		=+(11+0.018*D25)*0.000001
37	Alpha ratio	α		0.99520	0.99716	0.99937		=1-(5.187*D24)/(D34*53.35*(D25+459.67))
38	Expansion factor	Y		0.99737	0.99844	0.99965		=1-0.548*(1-D36)
39	Reynolds number, first nozzle	Re		70,918	54,575	25,752		=+(1096.7/(60*D35))*D15*D8*D37*(D24*D34)^0.5
40	Discharge coeff., first nozzle	C		0.9742	0.9711	0.9602		=0.9986-(7.006/D38^0.5)+(134.6/D38)
41	Reynolds number,2nd nozzle	Re		44,324	34,110	16,095		=+(1096.7/(60*D35))*D15*D9*D37*(D24*D34)^0.5
42	Discharge coeff., 2nd nozzle	C		0.9684	0.9646	0.9517		=0.9986-(7.006/D40^0.5)+(134.6/D40)
43	Airflow rate for nozzles	Q_5		105.957	81.365	37.947		=1096.7*D37*(D24/D34)^0.5*(D39*D10+D41*D11)
44	Fan airflow rate at test cond.	Q		105.819	81.199	37.879		=D42*(D34/D33)
45								
46	Calculations, Pressures:							
47	Chamber velocity pressure	p_{vch}		0.000005				
48	Fan velocity pressure	p_v		0.017	0.010	0.002		=+(D42*D34)/(1096.7*D14)^2/(D34)
49	Fan total pressure	p_t		0.019	0.169	0.331		=D46+D23
50								
51	Conversion to Standard Atmospheric Density (Test Report Values):							
52	Fan airflow rate at test cond.	Q		106	81	38		=D43
53	Static pressure, converted	p_{sc}		0.002	0.165	0.341		=D23*(0.075/D33)
54	Fan input power, converted	W		41.495	36.300	31.120		=D26*(0.075/D33)
55	Velocity pressure, converted	p_{vc}		0.018	0.011	0.002		=D46*(0.075/D33)
56	Total pressure, converted	p_{tc}		0.020	0.176	0.344		=D47*(0.075/D33)

APPENDIX I.