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# Determination of the Airtightness of Building Envelopes by the Fan Depressurization Method

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CAN/CGSB-149.10-M86

NATIONAL STANDARD OF CANADA

# DETERMINATION OF THE AIRTIGHTNESS OF BUILDING ENVELOPES BY THE FAN DEPRESSURIZATION METHOD

**Prepared by**

Canadian General Standards Board

**Approved by**

Standards Council of Canada

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Note: CGSB also recognizes the contributions of D. Saum of Infiltec Inc. to the development of this standard.

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# DETERMINATION OF THE AIRTIGHTNESS OF BUILDING ENVELOPES BY THE FAN DEPRESSURIZATION METHOD

## 1. SCOPE AND FIELD OF APPLICATION

1.1 This is a method for the determination of the airtightness of building envelopes. It is not a method for determining the actual air leakage which occurs through a building envelope under the influence of wind and buoyancy pressures or the operation of heating and ventilation systems.

1.2 The method is applicable to small detached buildings (especially houses) but with appropriate modifications, it can also be used for other buildings or parts of buildings.

## 2. PRINCIPLE

A fan or fans are used to exhaust air from the building at rates required to maintain specified pressure differences across the building envelope. The air flows and the pressure differences are measured. The intention is to subject the complete envelope to a simultaneous and similarly directed air pressure. The flows are corrected to reference temperature and reference pressure. The relationship between flow and pressure difference is used to calculate the equivalent leakage area of the building envelope.

## 3. TERMINOLOGY

3.1 **Airtightness:** the degree to which unintentional openings in the building envelope have been avoided.

**Building envelope:** that portion of the heated structure which separates conditioned from unconditioned space and the soil.

**Intentional opening:** an opening in the building envelope deliberately made to fulfill a particular function.

3.2 Although the definition of each quantity symbol is usually included in the paragraph in which it appears, Table 1 provides a list of quantity definitions for those quantity symbols which are included in the body of the standard.

## 4. APPARATUS

### 4.1 Fan

4.1.1 The fan or fans shall have a total air flow capacity capable of producing a pressure difference of at least 50 Pa between the inside and outside of the building envelope. (Sufficient capacity for testing new detached houses may be about 1500 L/s and for older detached houses it may be about 2500 L/s.)

4.1.2 The fan shall have a variable speed control or a control damper in series with the fan.

4.1.3 The fan shall be calibrated in air flow units or be connected to an air flow metering system.

4.1.4 The accuracy of air flow measurement shall be ±5% of the measured flow rate.

4.2 **Pressure-measuring apparatus** — This device (e.g., a micromanometer) shall be capable of measuring pressure differences from 0 to at least 50 Pa. It shall have an accuracy of ±2 Pa and shall only be operated within its calibration range.

4.3 **Thermometer(s)** — This device shall be used to measure temperature in degrees Celsius and it shall have an accuracy of ±1°C.

4.4 **Sealing apparatus** — This apparatus shall be used to seal the fan into a window or a door.

4.5 **Pressure averaging and damping equipment**

4.5.1 ***Pressure averaging container*** — This device shall be suitable for connection of not less than four tubes from exterior pressure taps and shall be constructed as described in Appendix A.

4.5.2 ***Capillary tubes*** — A pressure averaging container shall not be required if capillary tubing, of dimensions corresponding to those in Table A-1 of Appendix A, is added to the outside ends of the tubes from the pressure taps on the exterior walls of the building (par. 6.1.12). The tubes from the outside pressure taps shall be manifolded together before connecting to the pressure measuring device.

## 5. LABORATORY CALIBRATION OF APPARATUS

5.1 All equipment shall be calibrated originally. Recalibrate all measuring devices when any major component is replaced.

5.2 Calibrate the air flow measuring device in accordance with the manufacturer's instructions or alternatively, calibrate it in accordance with Appendix B-1 and record this fact.

5.3 When the fan is calibrated, calibrate it in accordance with Appendix B-2.

5.4 Calibrate the pressure measuring device in accordance with the manufacturer's instructions or alternatively, calibrate it in accordance with Appendix B-3.

## 6. TESTING

### 6.1 Set-Up Procedures*

6.1.1 Measure and record the outdoor air temperature, $t_o$.

6.1.2 If par. 7.1.3 will be used to calculate corrected volumetric air flow rates at ambient test conditions, record the ambient atmospheric pressure, $P_a$. A report on the atmospheric pressure from the local weather station if not corrected to sea level, should normally be sufficient.

6.1.3 Include in the test all rooms which are heated to more than 10°C except rooms with separate ventilation (e.g., boiler room, enclosed furnace rooms and garages).

6.1.4 Switch off all fuel combustion equipment, exhaust fans, vented dryers and air conditioners.

6.1.5 Shut off all pilot lights on vented gas-fired appliances.

6.1.6 Prepare intentional openings as detailed in Table 2.

6.1.7 Remove or cover ashes in fireplaces. Check chimneys and furnace flues for excessive soot and do not perform the test if soot is likely to enter the building.

6.1.8 Open all interior doors except those to rooms which are not included in the test (par. 6.1.3).

6.1.9 Install the test apparatus such that air will be exhausted from the building. To eliminate the possibility of disturbance of the flow entering the nozzle when using a bell-mouthed nozzle apparatus, ensure that no obstructions are placed within one throat diameter away from the centre of the nozzle entrance as shown in Figure 1A. When using a blower door apparatus, ensure that no obstructions are placed within the width of the door and closer than three quarters of one fan diameter in front of the fan as shown in Figure 1B. Figure 2 shows the general arrangement of the apparatus during the test.

6.1.10 ***Routine Inspection*** — After setting up the apparatus, take the following steps to check all the measuring devices.

6.1.10.1 Visually inspect for various physical defects.

6.1.10.2 Visually inspect for proper installation in accordance with manufacturer's specification.

6.1.10.3 Inspect the levelling of devices which require this precaution (e.g., a manometer).

6.1.10.4 Ensure that all indicators are at zero settings.

6.1.11 Seal the joints between the apparatus and the envelope.

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* *It is recommended that the test not be conducted if the wind speed is greater than* 20 km/h.

6.1.12 Attach the exterior pressure taps to the exterior walls of the building envelope such that all the square-cut ends point upwards or downwards. For detached residences, secure the exterior pressure taps at points at least 2 m above grade if possible, and at the horizontal mid-points of the principal exterior walls facing in each direction. See Figure 3 for the recommended locations of the exterior pressure taps on some common shapes of houses.

6.1.13 Protect the interior and exterior pressure taps from the influence of the fan.

6.1.14 When the building to be tested has walls, ceilings or floors common with rooms that are not included in the test but which are heated to more than 10°C, make provision to reduce the pressure in the adjacent rooms to match the pressure in the rooms under test at each test point.

6.1.15 For fireplace chimneys without a damper, perform the test with no sealing unless the leakage is so large that the test cannot be performed. In this case, seal the fireplace at the opening and report this matter as a deviation from the usual test procedure in the test report. (See par. 8.1, item n.)

6.2 **Test Procedures**

6.2.1 Whenever a pressure reading is taken, it should be taken for a long enough time to be within ±1 Pa of its stable value.

6.2.2 Seal the fan or fans and record the pressure difference across the envelope, $\Delta P_{o,i}$.

6.2.3 Remove all seals on the fan or fans and switch on the fan or fans.

6.2.4 Adjust the air flow to produce a pressure difference of 50 Pa across the envelope. (See par. 6.2.7.)

6.2.5 Adjust the pressure in any adjacent rooms (par. 6.1.14) to achieve a zero pressure difference across common partitions.

6.2.6 When conditions have stabilized, measure and record the air flow rate in litres per second ($Q_m$), the pressure difference ($\Delta P_m$) in Pa and the intake air temperature at the fan in degrees Celsius ($t_i$).

6.2.7 Repeat par. 6.2.4 to 6.2.6 at pressure differences of 45, 40, 35, 30, 25, 20 and 15 Pa, in that order. For each test, the measured value of the pressure difference shall be within ±2.5 Pa of the above specified pressure difference.*

6.2.8 Repeat par. 6.2.2 to measure the pressure difference, $\Delta P_{o,f}$.

6.2.9 Correct the $\Delta P$ readings in accordance with par. 7.5 and the $Q_m$ readings in accordance with par. 7.4.

6.2.10 ***Verification of Data***

6.2.10.1 Using the corrected data from par. 7.4 and 7.5 determine the following in accordance with Appendix C:**

a. the regression coefficients (C and n) and the correlation coefficient (r) of the fit of the data;

b. the percentage difference between the estimated air flow ($\hat{Q}_i$) and the measured air flow ($Q_i$) at each measured pressure difference ($\Delta P_i$);

c. the relative standard error of $\hat{Q}$ at $\Delta P = 10$ Pa (which is also the relative standard error of ELA). (See par. 7.7.2.)

6.2.10.2 Repeat the entire test if any of the following conditions is <u>not</u> met;

a. $0.50 \leq n \leq 1.00$

b. $r > 0.990$

c. $\dfrac{|\hat{Q}_i - Q_i|}{Q_i} < 0.06$ for all i***

d. the relative standard error of $\hat{Q}$ at $\Delta P = 10$ Pa (or ELA) is less than 0.07.

6.2.11 When the purpose of the test is to show an increase in the airtightness of a building envelope as a result of sealing unintentional openings, perform the test as described both before and after the sealing work.

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* *A measurement of air flow rate at a pressure difference of* 10 Pa *may also be included.*
** *The C, $Q_i$ and $\hat{Q}_i$ values determined in accordance with Appendix C are those under reference conditions.*
*** *The $Q_i$ and $\hat{Q}_i$ values in this paragraph are those under reference conditions.*

6.2.12 ***Completion of the Test*** — After the test:

a. remove all seals applied in accordance with Table 2;

b. reopen dampers as necessary;

c. relight the gas pilot light.

## 7. CALCULATIONS

### 7.1 General Description

7.1.1 This method gives an equivalent leakage area (ELA), a $C_r$ value (often used to obtain forced-air change rates) and an air flow rate which are constant for all test ambient conditions.

7.1.2 $\Delta P$, $C_r$ and $Q_r$ are defined as follows:

$\Delta P$ is the corrected pressure difference across the building envelope and is in units of Pa.

$C_r$ is a constant used to determine $Q_r$.

$Q_r$ is a constant used to determine ELA.

7.1.3 The method described in this standard should be used to determine ELA, a constant $C_r$ value and air change rates. If the actual outside air flow under test conditions is required, it can be determined using the following:

$$Q_a = Q_r \sqrt{\frac{101.325}{P_a} \frac{(t_o + 273.15)}{(20 + 273.15)}}$$

where: $Q_a$ is the corrected outside volumetric air flow rate into the building at outdoor test conditions (L/s)

$Q_r$ is as defined above (L/s)

$P_a$ is the ambient atmospheric pressure (kPa) from par. 6.1.2

$t_o$ is the outdoor air temperature (°C) from par. 6.1.1.

### 7.2 Determination of the Area of the Building Envelope

7.2.1 Use interior dimensions when determining the area of the building envelope.

7.2.2 Include all ceilings (flat or sloping), floors and walls (including doors and windows) that are correspondingly below, above and adjacent to unheated spaces and spaces heated to less than 10°C. For example, include:

a. ceilings below unheated attics and roofs;

b. basement floors and floors above unheated basements (or unheated portions thereof), cellars, crawl spaces, cold storage rooms, garages and floors exposed to the ambient environment such as floors above carports, floors of bay windows and floors of buildings (or parts thereof) supported above grade;

c. exterior above grade and below grade walls and walls adjacent to unheated portions of basements, cellars, crawl spaces, cold storage rooms, unheated porches, garages and stairwells to basement entrances.

7.2.3 The area of the building envelope is the total area of all eligible ceilings, floors and walls.

7.3 **Determination of the Interior Volume Enclosed by the Building Envelope** — It is recommended that the interior volume enclosed by the building envelope be determined and recorded. Include the total volume of all rooms specified in accordance with par. 6.1.3.

7.4 **Correction of Air Flow Readings** — Correct each air flow reading for differences in the indoor, outdoor and calibration air temperatures in accordance with Appendix D.

7.5 **Correction of Pressure Difference Readings** — Using the following equation, correct each pressure difference reading, $\Delta P_m$;

$$\Delta P = \Delta P_m - \frac{(\Delta P_{o,i} + \Delta P_{o,f})}{2}$$

7.6 **Determination of Correlation Coefficient** — Applying the procedure described in Appendix C to the corrected data, fit a curve of the form:

$$Q_r = C_r (\Delta P)^n$$

where: $Q_r$, $C_r$ and $\Delta P$ are as defined in par. 7.1.2

n is the flow exponent and is dimensionless.

7.7 **Calculation of Equivalent Leakage Area**

7.7.1 The density of air at the reference conditions of $t_r = 20°C$ and $P_r = 101.325$ kPa, $\rho_r$, is:

$$\rho_r = \frac{P_r}{R\,(t_r + 273.15)}$$

where: $\rho_r$ is in units of $kg/m^3$

R = gas constant for air = 0.287055 J/g·K

$P_r$ = barometric pressure under reference conditions (kPa)

$t_r$ = reference temperature of outside ambient air (°C)

Therefore:

$$\rho_r = \frac{101.325}{.287055 \times 293.15} = 1.204097$$

7.7.2 Calculate the equivalent leakage area, ELA, using the following equation:

$$ELA = .001157 \sqrt{\rho_r} \cdot C_r \cdot 10^{n-0.5}$$

where ELA is in units of $m^2$

$\rho_r$ is the air density at reference conditions, as provided in par. 7.7.1

$C_r$ and n are determined in accordance with par. 7.6.

The above equation is based on the assumption that the leakage openings in the building envelope can be combined and represented by a single sharp-edged orifice.

7.8 **Calculation of Normalized Leakage Area**

When the purpose of the test is to compare the ELA of different buildings, it is recommended that the normalized leakage area, NLA, should be used. To calculate NLA, use the following equation:

$$NLA = \frac{ELA}{\left(\text{Area of the Building Envelope}\right)} \times 10\,000$$

where: NLA is in units of $cm^2/m^2$

ELA is in units of $m^2$

Area of the Building Envelope is in units of $m^2$.

8. **TEST REPORT**

8.1 The test report shall include the following information:

a. The name and address of the company which conducted the test

b. The name of the tester

c. The address of the building under test

d. The date of test and the date of the report

e. The test conditions which include the outdoor temperature in degrees Celsius, comments on the wind speed, direction and variability

f. A description of the building envelope

g. The area in square metres of the building envelope

h. The measured original instrument data (air flow metering device data), the corresponding pressure differences in pascals and the fan intake air temperatures in degrees Celsius

i. The corrected air flow rates in litres per second at each corrected pressure differential

j. Values for $C_r$ and n

k. The determined correlation coefficient, r

l. The equivalent leakage area (ELA) in square metres

m. When applicable, items h. to l. inclusive before and after sealing work

n. Any deviation from the method prescribed.

8.2 It is recommended that the test report include the following:

a. A sketch of the building under test showing the locations of the pressure taps and the location of the fan, if the building is of an unusual shape

b. The ambient atmospheric pressure in kilopascals

c. A plot of the measured air flow rates versus the corresponding pressure differences on log-log paper

d. The interior volume in cubic metres enclosed by the building envelope

e. The normalized leakage area (NLA) in square centimetres per square metre.

8.3 **Specimen Test Report**

It is recommended that the test report follow the format given in Appendix E.

## TABLE 1

## SYMBOLS

| Quantity Symbol | Quantity Definition | SI Unit | Unit Symbol |
|---|---|---|---|
| C, $C_r$ | a regression coefficient; a constant used to determine $Q_r$ (Appendix C) | litres/second·Pascal$^n$ | L/s·Pa$^n$ |
| ELA | equivalent leakage area | metre$^2$ | $m^2$ |
| NLA | normalized leakage area | $\frac{\text{centimetre}^2}{\text{metre}^2}$ | $cm^2/m^2$ |
| n | a regression coefficient; flow exponent; a constant used to determine ELA (Appendix C) | — | — |
| $P_a$ | ambient atmospheric pressure | kilopascals | kPa |
| $\Delta P_{o,i}$ | initial pressure difference across the building envelope with the fan(s) not operating and sealed | Pascals | Pa |
| $\Delta P_{o,f}$ | final pressure difference across the building envelope with the fan(s) not operating and sealed | Pascals | Pa |
| $\Delta P_m$ | measured pressure difference across the building envelope | Pascals | Pa |
| $\Delta P$ | corrected pressure difference across the building envelope | Pascals | Pa |
| $P_r$ | barometric pressure under reference conditions (101.325 kPa) | kilopascals | kPa |
| $Q_a$ | corrected volumetric air flow rate into the building at outdoor test conditions | litres/second | L/s |
| $Q_m$ | measured air flow rate indicated by the flow measuring device before any corrections for the difference in the operating temperature and the calibration temperature | litres/second | L/s |
| Q, $Q_r$ | corrected air flow rate (Appendix C) | litres/second | L/s |
| $\hat{Q}$ | estimated air flow rate (Appendix C) | litres/second | L/s |
| r | correlation coefficient (Appendix C) | — | — |
| R | gas constant for air (0.287055 J/g·K) | joules/gram·Kelvin | J/g·K |
| $t_o$ | outdoor air temperature | degrees Celsius | °C |
| $t_i$ | intake air temperature at the fan | degrees Celsius | °C |
| $t_r$ | reference temperature of outside ambient air (20°C) | degrees Celsius | °C |
| $\rho_r$ | density of air at reference conditions | kilograms/metre$^3$ | $kg/m^3$ |

## TABLE 2

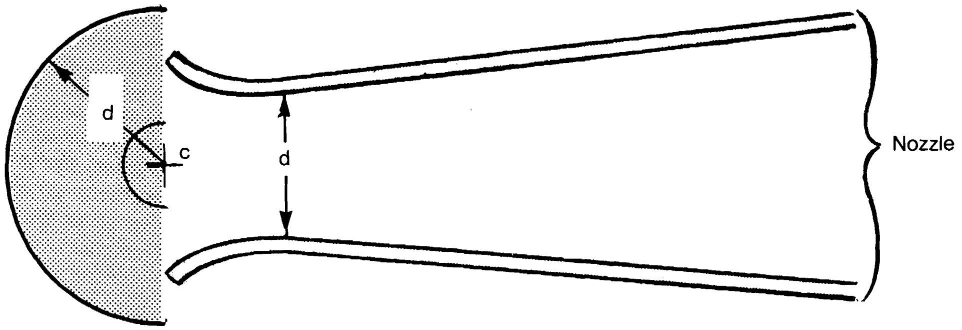
### PREPARATION OF INTENTIONAL OPENINGS

| | |
|---|---|
| fireplace flue | no preparation |
| fireplace | |
| — with damper | CLOSE |
| — with doors | CLOSE |
| — without damper | see par. 6.1.15 |
| doors on enclosed furnace room* | CLOSE |
| fireplace combustion air intake damper | CLOSE |
| fuel fired furnace and/or stove flues | SEAL |
| fuel fired furnace and/or stove flues in enclosed furnace room* | no preparation |
| furnace combustion air intake | |
| — with damper | CLOSE |
| — without damper | SEAL |
| ventilation air intake | |
| — with damper | CLOSE |
| — without damper | SEAL |
| fuel fired hot water system flues | SEAL |
| floor drains | FILL |
| plumbing traps | FILL |
| exhaust fans | |
| — with motorized damper | CLOSE |
| — without motorized damper | no preparation |
| air to air heat exchangers designed to operate continuously | |
| — intake and exhaust openings | SEAL |
| other air to air heat exchangers | |
| — intake and exhaust openings, with motorized damper | CLOSE |
| — intake and exhaust openings, without motorized damper | no preparation |
| dryer vents | |
| — with exhaust divertor | WINTER POSITION |
| — with motorized damper | CLOSE |
| — without motorized damper | no preparation |
| windows and doors | LATCH |
| exhaust systems common to more than one unit | SEAL |
| window air conditioners | SEAL |
| attic hatch | CLOSE |

* *An enclosed furnace room is a room expressly built to contain a furnace and/or stove, with a combustion air intake to the outside of the building, and to prevent air flow to and from the remainder of the building.*

**A.** **Bell-Mouthed Nozzle Apparatus**

**– Top and Side View**




– shaded area shall be free of obstructions.

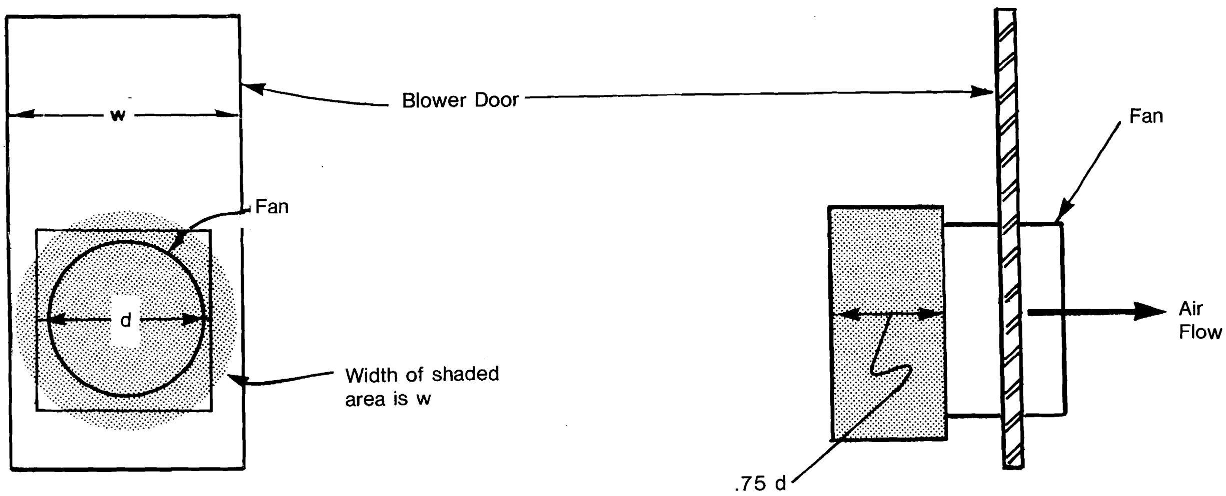
c is the centre of the nozzle entrance.
d is the diameter of the throat of the nozzle.

**B.** **Blower Door Apparatus**

**– Front View**

d is the diameter of the fan.
w is the width of the blower door.

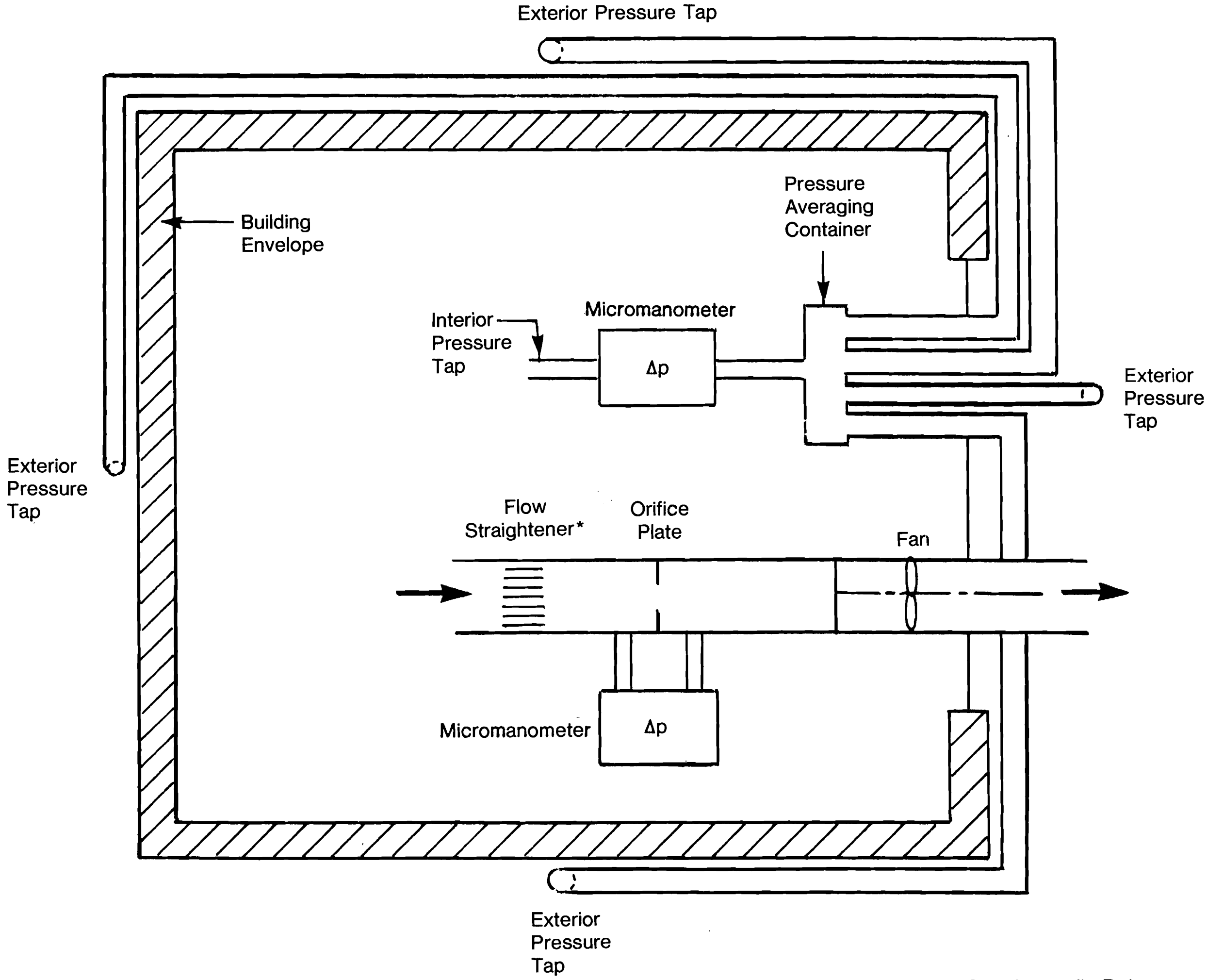
**– Side View**




– Shaded area shall be free of obstructions.

**FIGURE 1**

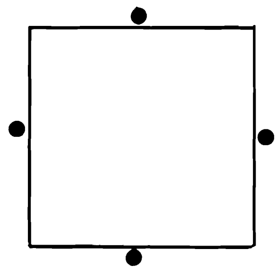
**Area Which Shall Be Free of Obstructions**



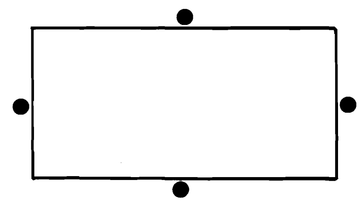

* See Appendix B-4.

**FIGURE 2**

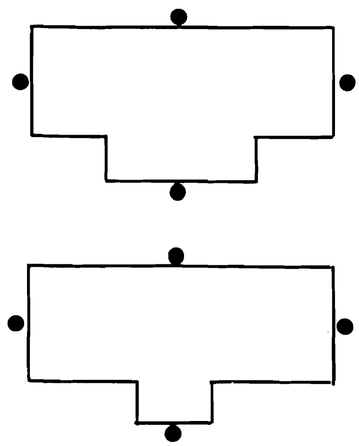
**The General Arrangement of the Equipment during the Test Showing one Possible Air Flow Metering System**



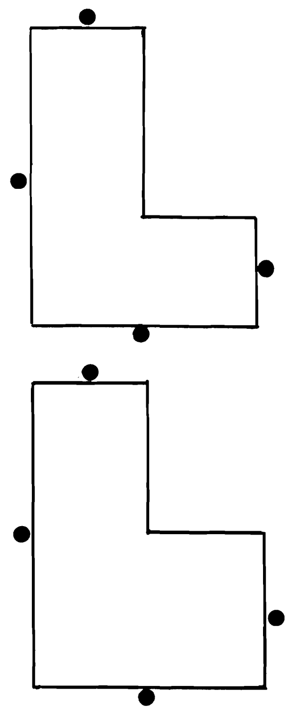
Square



Rectangle



Tee



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NOTE:

1. The heavy dots indicate the recommended locations for the exterior pressure taps.

**FIGURE 3**

**Recommended Locations for Exterior Pressure Taps**

## CONSTRUCTION AND CALIBRATION OF PRESSURE AVERAGING CONTAINER

### A-1 CONSTRUCTION

To reduce the effect of pressure fluctuations from the four static probes placed on the outside walls of the building envelope, a pressure averaging container may be used. (See par. 4.5.2.) It shall be provided with sufficient line losses to result in an averaging of high frequency disturbances, to make reading of pressure easier and more reliable. The selected averaging time shall be in the order of 5 ± 1 s.

The equation relating the time constant of a tube/container system and its critical parameters, assuming adiabatic, laminar, capillary flow, is:

$$t^* = \frac{128}{\pi} \frac{\mu}{\gamma P} \frac{L.V}{d^4}$$

where: $t^*$ = time constant of the tube/container system (s)

$\mu$ = absolute viscosity of the air (Pa.s)

$\gamma$ = specific heat ratio of air = 1.4

P = pressure (Pa)

L = tube length (m)

V = container volume ($m^3$)

d = tube inside diameter (m)

For a 5 s time constant, at room conditions, this reduces to:

$$L \cdot V = 9.16 \cdot 10^8 \, d^4$$

Table A-1 and Figure A-1 give the length versus diameter relationship for a 1 L (0.001$m^3$) container.

A 0.50 mm inside diameter by 57.3 mm long tube should be used.

A typical cylindrical configuration is shown in Figure A-2. Configurations other than this cylindrical one may be used as long as the container is sealed and rigid with an internal volume of I L.

### A-2 CALIBRATION

Because the actual time constant is very sensitive to the value of the inside diameter of the tube, the following calibration procedure shall be undertaken.

1. Attach a length of tube to the container.
2. Seal all leaks except the pressure measurement tap.
3. Pressurize the container to greater than 50 Pa.
4. Uncap the damping capillary tube and record the pressure as the air flows out.
5. Calculate the time constant using the formula below:

$$t^* = \frac{-(t_2 - t_1)}{\ln\left(\frac{\Delta P_2}{\Delta P_1}\right)}$$

where: $t_1$ = time at which $\Delta P_1$ is measured (s)

$t_2$ = time at which $\Delta P_2$ is measured (s)

$\Delta P_1$ = first (higher) pressure difference (Pa)

$\Delta P_2$ = second (lower) pressure difference (Pa)

ln = natural logarithm

NOTE: $(t_2 - t_1)$ should be in the order of 5 s.

6. Shorten the tube and repeat steps 1 to 5 until a time constant of 5 ± 1 s is obtained.

7. Make all other tubes the same length and ensure they are from the same stock as that which was calibrated.
8. Ensure that the entrance and exit edges of the inside diameter of the tubes are sharp and clean.

**TABLE A-1**
**Damping Tube Length VS Inside Diameter**

(5 s time and 1 L container)

| Tube Inside Diameter (mm) | Tube Length(1) (mm) |
|---|---|
| 0.4 | 23.4 |
| 0.5 | 57.3 (2) |
| 0.6 | 119 |
| 0.7 | 220 |
| 0.8 | 375 |
| 1.0 | 916 |

***Note:*** *(1) Lengths should be confirmed by test.*

*(2) The* 0.5 mm *diameter by* 57.3 mm *long tube is recommended.*

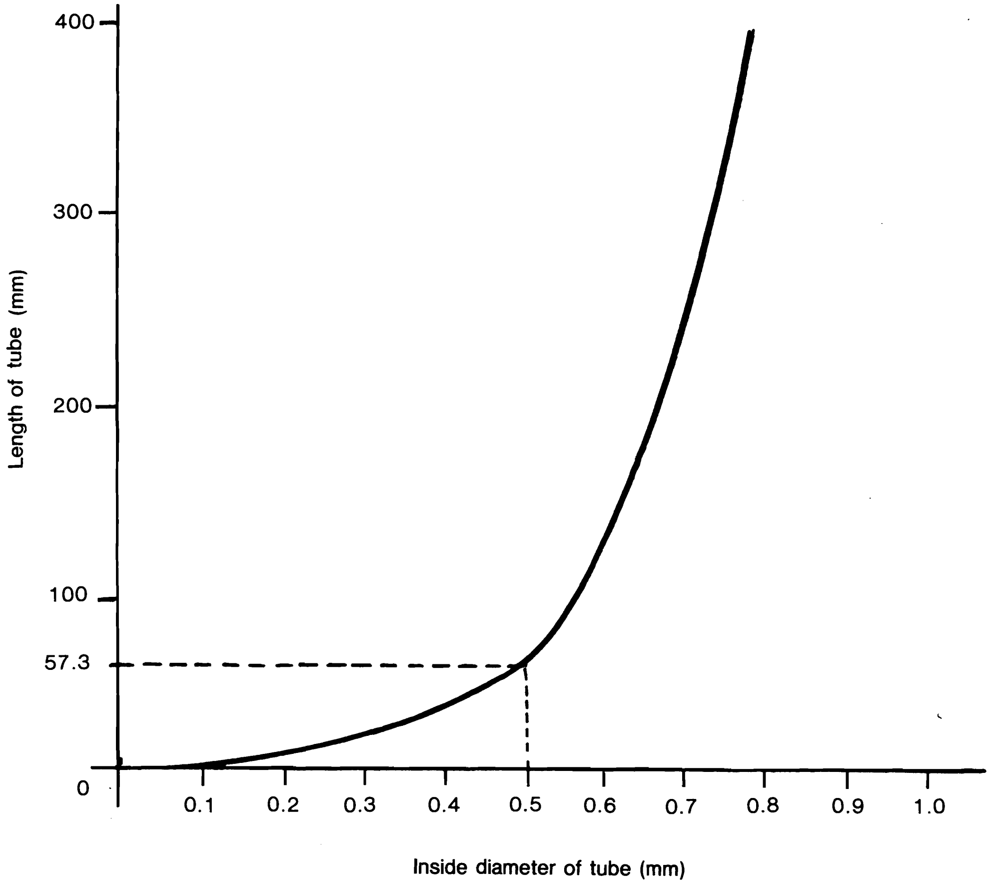
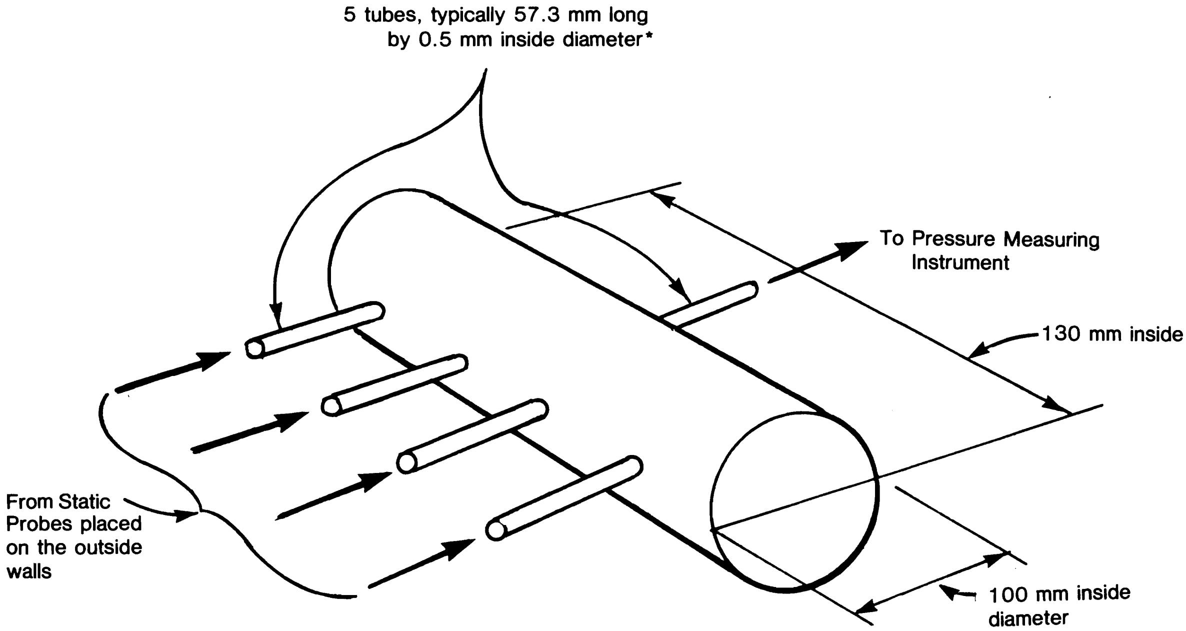



**FIGURE A-1**

**Damping Tube Length VERSUS Tube Inside Diameter**




* Each of the tubes must be of the same length and must be cut from the same stock.

**FIGURE A-2**

**A Typical Cylindrical Configuration for a Pressure Averaging Container**

## CALIBRATION

Reference: Fan Engineering — Seventh Edition

— Published by Canadian Blower and Forge Co. Ltd in 1970.

### B-1 PROCEDURE FOR CALIBRATION OF AIR FLOW MEASURING DEVICE

1. Install the air flow measuring device to be calibrated in the test set-up shown in Figure B-1.1. To eliminate the possibility of disturbance of the flow entering the nozzle when using a bell-mouthed nozzle apparatus, ensure that no obstructions are placed within 1 m of the front of the nozzle or any closer than 0.5 m away from all sides of the nozzle. Seal the joints.
2. Activate the fan and adjust the flow control damper to produce a desirable flow rate. (See step 8.)
3. Measure and record the air temperature ($t_C$) and atmospheric pressure ($P_C$) at the inlet of the device.
4. Perform a pitot static traverse across the horizontal diameter of the tube at the pitot traverse plane shown in Figure B-1.1 and at the horizontal pitot tube stations indicated in Figure B-1.2.
5. As in step 4 above, perform a pitot static traverse down the vertical diameter of the tube at the pitot traverse plane shown in Figure B-1.1 and at the vertical pitot tube stations indicated in Figure B-1.2.
6. Calculate the flow rate, Q, using the equation below:

$$Q = \frac{1}{N} \cdot \sum \sqrt{\frac{2}{\rho_C} \cdot P_{V_i}} \cdot \frac{\pi}{4} \cdot D^2 \cdot 10^3$$

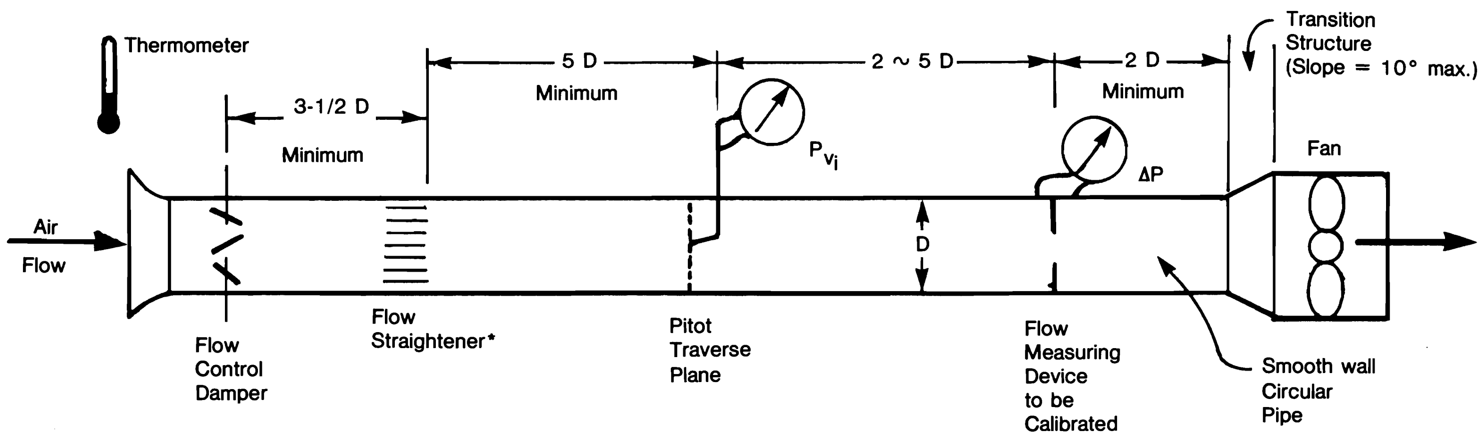
where: N = total number of pitot tube readings

$P_{V_i}$ = velocity pressure of the "i th" pitot tube measurement

$\rho_C$ = density of air at inlet of the calibration apparatus (as calculated using the same equation as in par. 7.7.1)

D = diameter of the device

7. Measure and record $\Delta$ P as indicated in Figure B-1.1.
8. Repeat steps 2 to 7 for at least three more flow rates including the maximum flow rate of the fan. The flow rates selected shall be uniformly spaced within the range of zero to this maximum flow rate.
9. Determine the calibration curve for the air flow measuring device by plotting Q versus $\Delta$ P as shown in Figure B-1.3.




*See Appendix B-4.

**FIGURE B-1.1**

**Test Set-Up for Air Flow Measuring Device Calibration**

Reference: ASHRAE Handbook — 1985 Fundamentals
Published by the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 1791 Tullie Circle, NE, Atlanta, Georgia 30329, U.S.A.

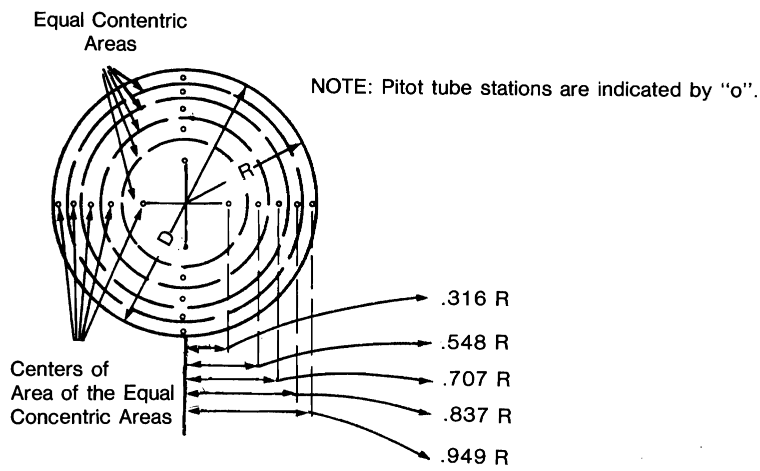



**FIGURE B-1.2**

**Pitot Tube Traverse for Round Tubes**

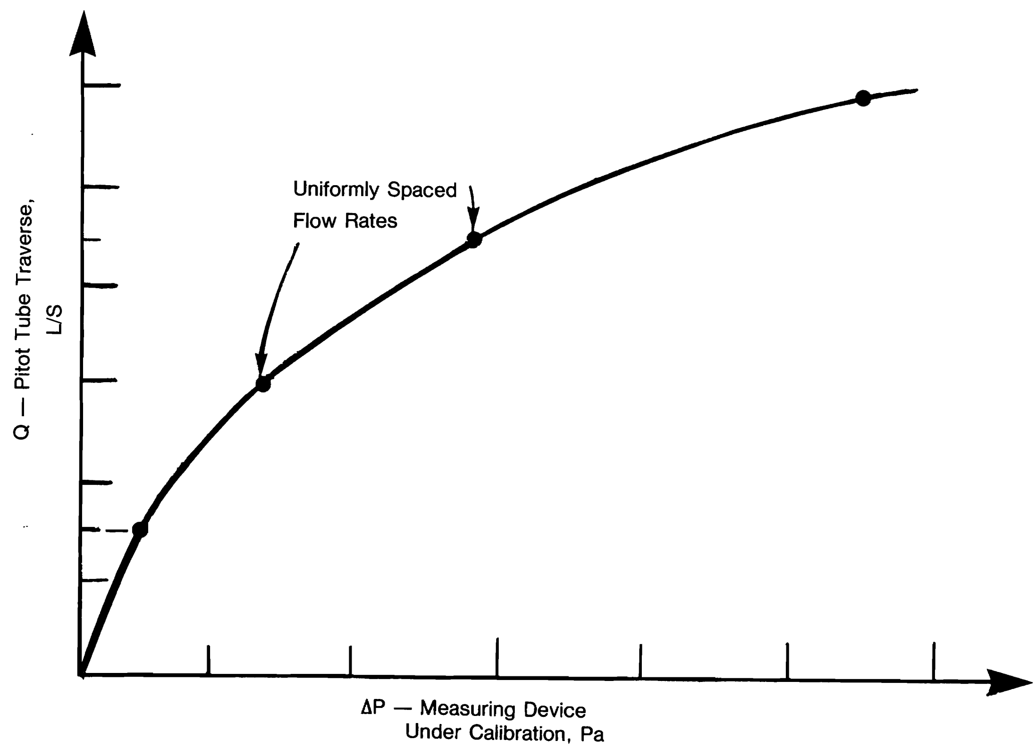


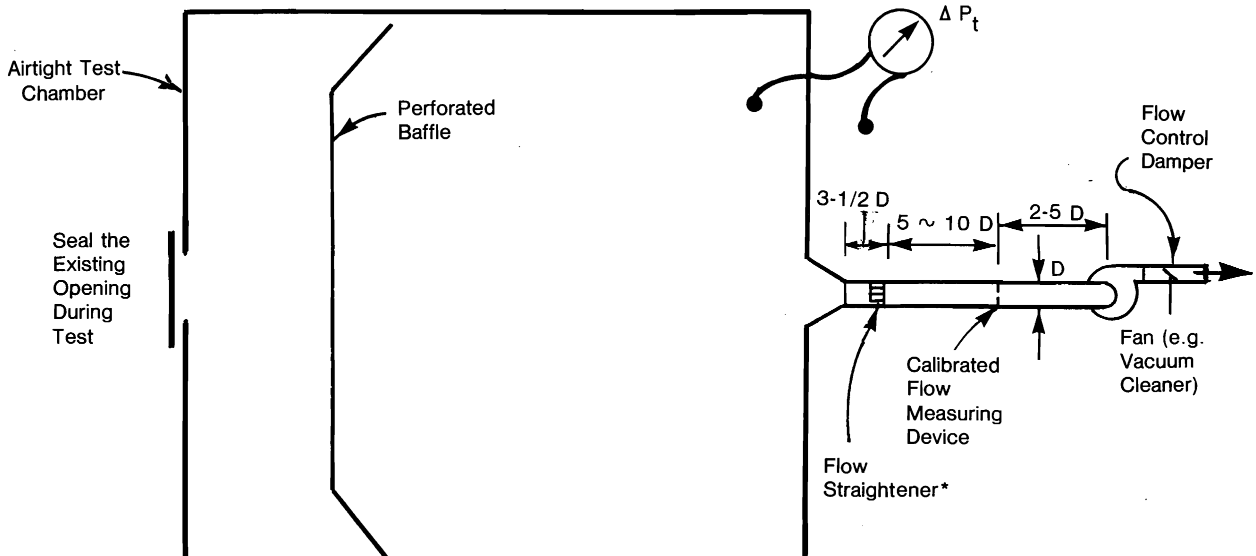

**FIGURE B-1.3**

**Typical Calibration Curve**

## B-2 PROCEDURE FOR CALIBRATION OF FAN

1. Construct an airtight test chamber with painted plywood walls reinforced with "two-by-four" studs and with suggested dimensions of 3 m, 2.5 m, and 2.5 m for length, width and height respectively. Caulk all joints.
2. Determine the leakage air flow rate of the test chamber, $q_\ell$, following the procedures described in pars. 6.2 to 7.6 inclusive and using the set-up shown in Figure B-2.1.
3. Plot $q_\ell$ vs $\Delta$ P.
4. Install the fan and the flow measuring device as shown in Figure B-2.2.
5. Cover both the fan and the duct and set the $\Delta$ P reading on the pressure indicator to zero.
6. Remove the covers, install an appropriate orifice plate and set the damper position.
7. Adjust the fan r/min to obtain a pressure differential of 15 Pa and record the flow rate, Q, as measured by the calibrated flow measuring device.
8. Calculate the net flow rate, $Q_n$ as follows;

   $Q_n = Q + q_\ell$ (at the measured $\Delta$ P)
9. Repeat steps 7 and 8 for pressure differentials of 20, 25, 30, 35, 40, 45 and 50 Pa.
10. Repeat steps 6 to 9 inclusive.
11. Develop calibration curves or an equation of $Q_n$ versus r/min for various $\Delta$ P values (eg., Figure B-2.3).




*See Appendix B-4.

**FIGURE B-2.1**

**Measurement of Leakage Air Flow Rate of Test Chamber**

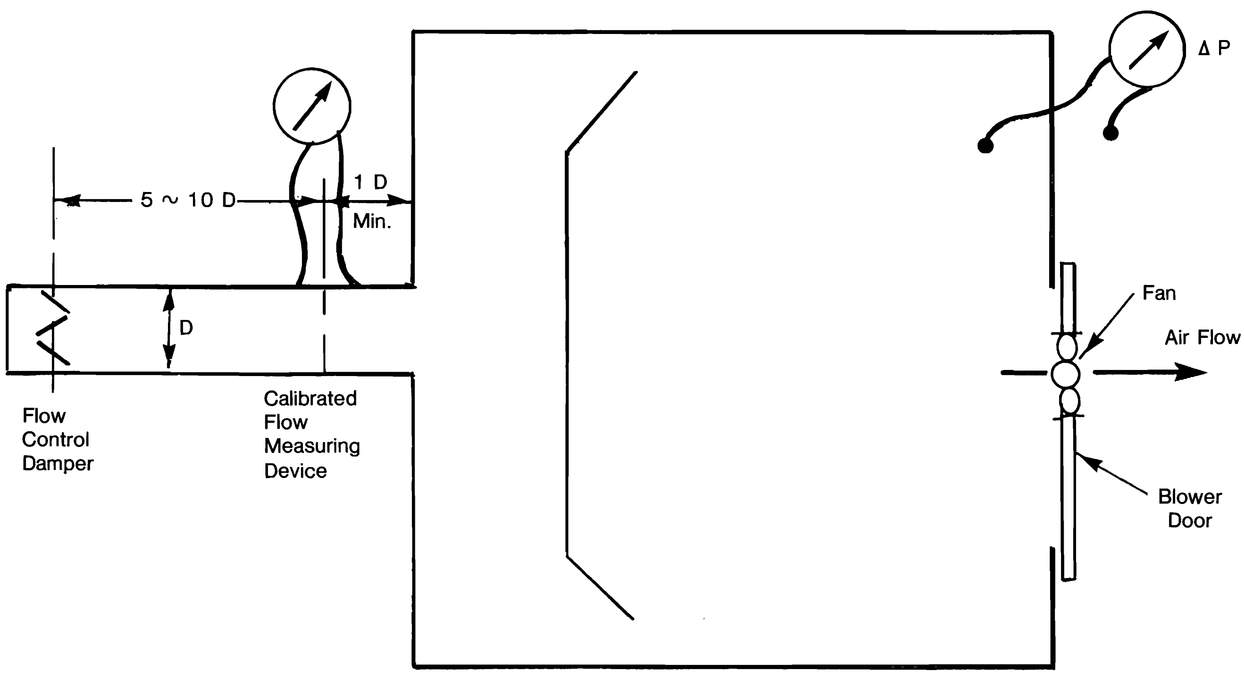



**FIGURE B-2.2**

**Calibration of Fan**

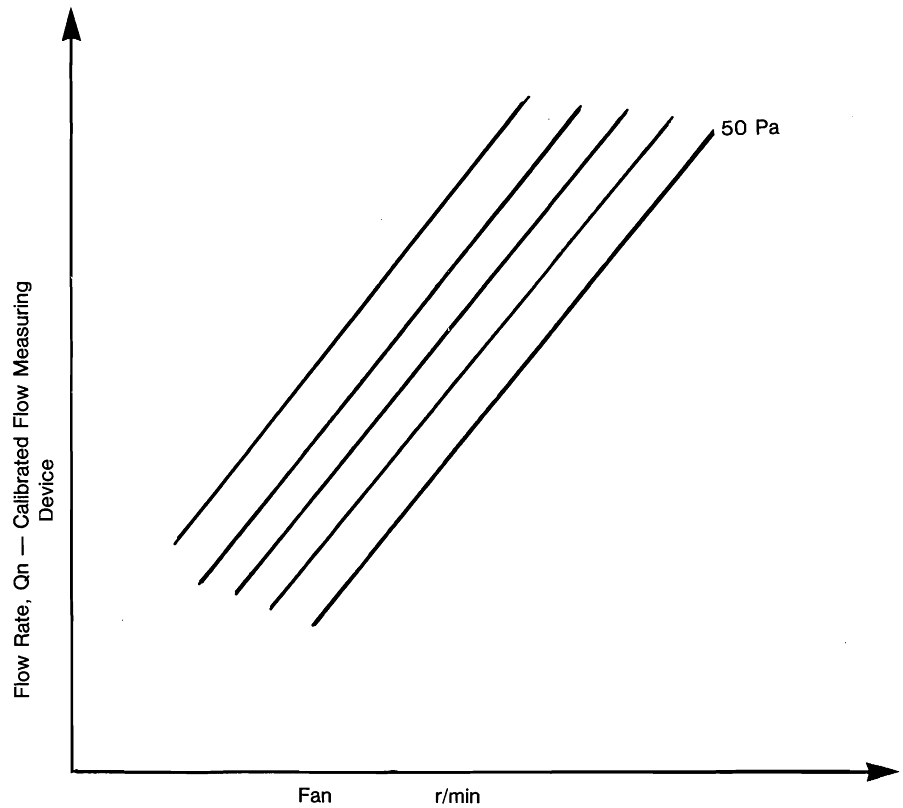



**FIGURE B-2.3**

**Typical Calibration Curve for a Fan**

## B-3 PROCEDURE FOR CALIBRATION OF PRESSURE MEASURING DEVICE

1. Connect the devices as shown in Figure B-3.1.
2. Close valve 3 and adjust valves 1 and 2 to obtain a pressure slightly greater than 50 Pa.
3. Open valve 3 gradually to its fully open position and record both $\Delta P_m$ and $\Delta P$ at uniform intervals.
4. Close valve 3 gradually to its fully closed position and record both $\Delta P_m$ and $\Delta P$ at uniform intervals.
5. Determine the calibration curve by plotting $\Delta P_m$ vs $\Delta P$ as shown in Figure B-3.2.

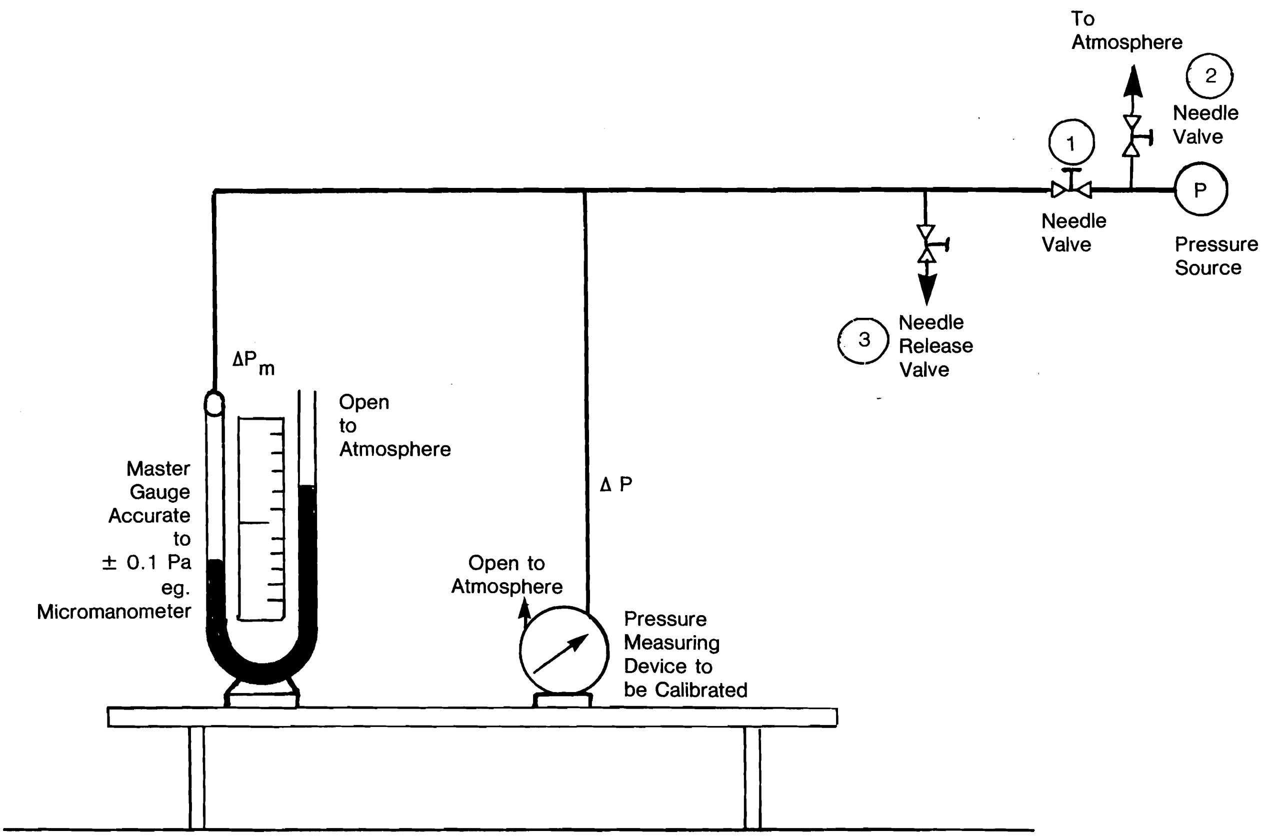



**FIGURE B-3.1**

**Set-Up for Calibration of Pressure Measuring Device**

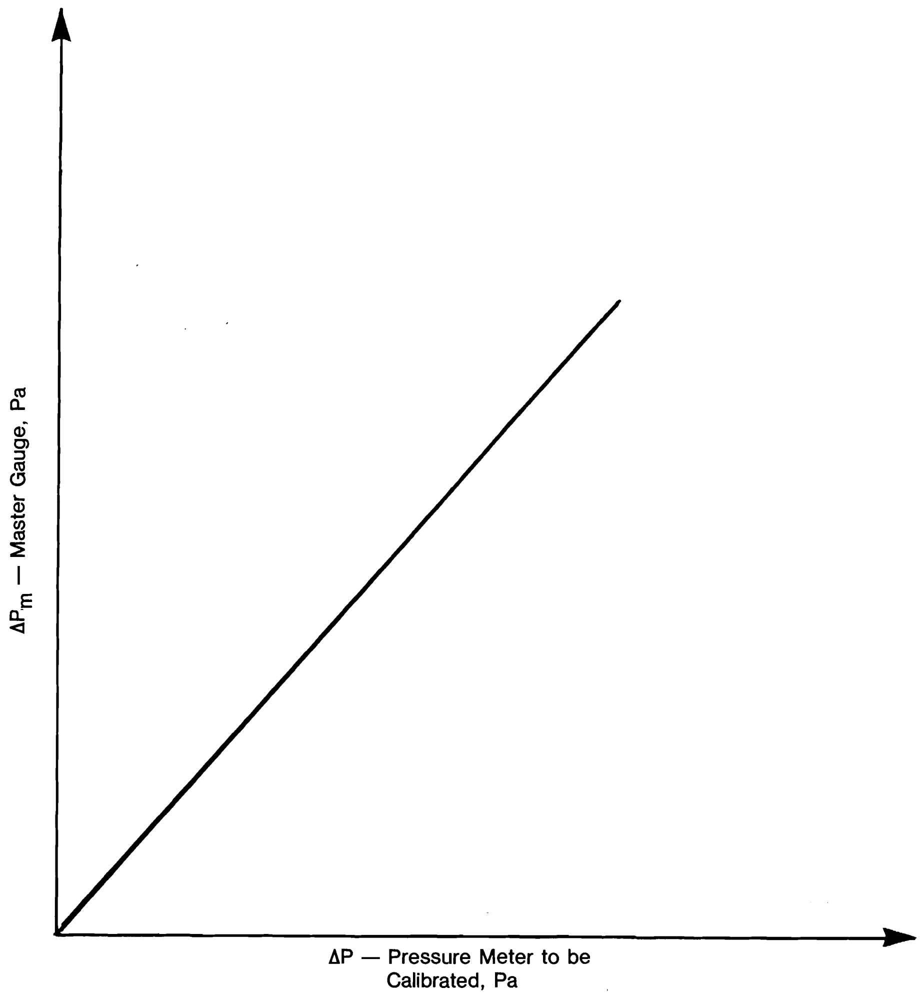



**FIGURE B-3.2**

**Typical Calibration Curve for Pressure Measuring Device**

## B-4 CONSTRUCTION AND LOCATION OF FLOW STRAIGHTENERS

Reference: Laboratory Methods of Testing Fans for Rating

- Published by the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE) as Standard 51-1985
- Published by the Air Moving and Conditioning Association, Inc. (AMCA) as Standard 210-85

- Straighteners shall be used during calibration but their use in the general arrangement of the equipment during the actual test is optional. The downstream plane of the straightener shall be located between 5 and 5.25 duct diameters upstream of the plane of the Pitot traverse or piezometer station. The form of the straightener shall be as specified in Figure B-4.1. The dimension D is the inside diameter of a circular cross-section duct or the equivalent diameter of a rectangular cross-section duct with inside transverse dimensions of a and b where $D = \sqrt{4ab/\pi}$. The dimension y which is the thickness of the straightener elements, shall not exceed 0.005 D.

Reference: AMCA Standard 210-74
ASHRAE Standard 51-74

NOTE: All Dimensions shall be within ± 0.005D
except y which shall not exceed 0.005D.

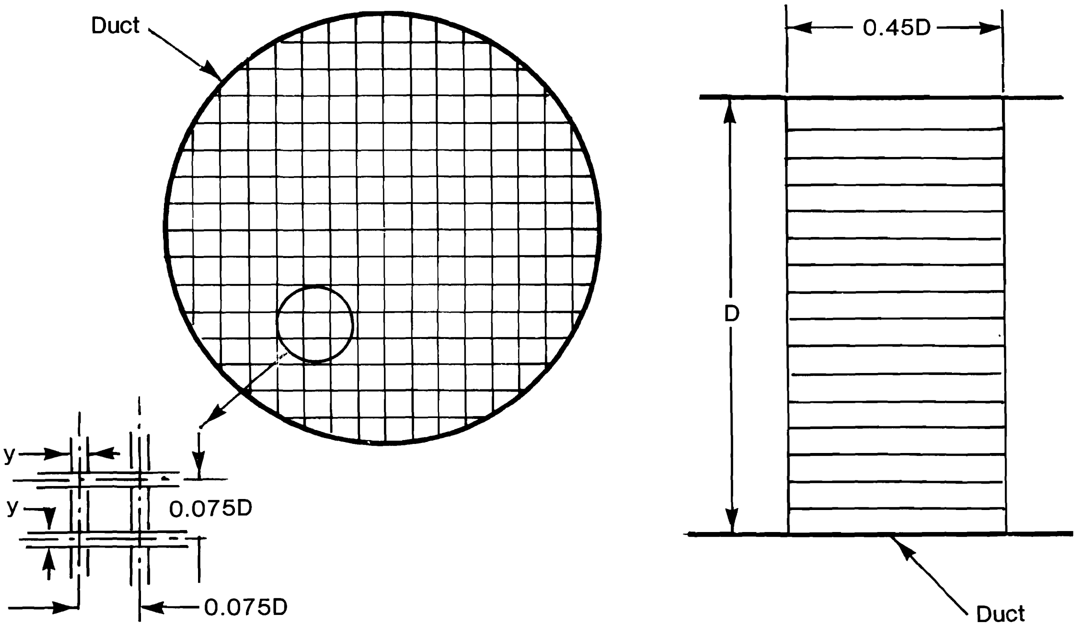



**FIGURE B-4.1**

**Flow Straightener**

## DETERMINATION OF THE FIT OF TEST DATA

If data has been collected at N corrected pressure differentials $\Delta P_1$, $\Delta P_2$ ... $\Delta P_N$ giving corrected air flow rates $Q_1$, $Q_2$...$Q_N$ respectively, the following procedure should be used to fit an equation of the following type:

$$Q = C \Delta P^n \quad *$$

to the data, and to determine the correlation coefficient (r) and various other measures of the goodness of fit. Units of the terms in the equation are given in par. 6.2.6.

1. Calculate the following sums:

$$\sum_{i=1}^{N} Q_i^2 \ln \Delta P_i = Q_1^2 \ln \Delta P_1 + Q_2^2 \ln \Delta P_2 + \ldots + Q_N^2 \ln \Delta P_N$$

$$\sum_{i=1}^{N} Q_i^2 (\ln \Delta P_i)^2 = Q_1^2 (\ln \Delta P_1)^2 + Q_2^2 (\ln \Delta P_2)^2 + \ldots + Q_N^2 (\ln \Delta P_N)^2$$

$$\sum_{i=1}^{N} Q_i^2 \ln Q_i = Q_1^2 \ln Q_1 + Q_2^2 \ln Q_2 + \ldots + Q_N^2 \ln Q_N$$

$$\sum_{i=1}^{N} Q_i^2 (\ln Q_i)^2 = Q_1^2 (\ln Q_1)^2 + Q_2^2 (\ln Q_2)^2 + \ldots + Q_N^2 (\ln Q_N)^2$$

$$\sum_{i=1}^{N} Q_i^2 (\ln \Delta P_i)(\ln Q_i) = Q_1^2 (\ln \Delta P_1)(\ln Q_1) + Q_2^2 (\ln \Delta P_2)(\ln Q_2) + \ldots + Q_N^2 (\ln \Delta P_N)(\ln Q_N)$$

$$\sum_{i=1}^{N} Q_i^2 = Q_1^2 + Q_2^2 + \ldots Q_N^2$$

2. Next calculate the following quantities:

$$s_{xx} = \left(\sum_{i=1}^{N} Q_i^2\right)\left(\sum_{i=1}^{N} Q_i^2 (\ln \Delta P_i)^2\right) - \left(\sum_{i=1}^{N} Q_i^2 \ln \Delta P_i\right)^2$$

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

$$s_{xy} = \left(\sum_{i=1}^{N} Q_i^2\right)\left(\sum_{i=1}^{N} Q_i^2 (\ln \Delta P_i)(\ln Q_i)\right) - \left(\sum_{i=1}^{N} Q_i^2 \ln \Delta P_i\right)\left(\sum_{i=1}^{N} Q_i^2 \ln Q_i\right)$$

* *The measured air flow rates ($Q_m$) are corrected to reference conditions in accordance with Appendix D. Therefore, the C, $Q_i$ and $\hat{Q}_i$ values determined in accordance with Appendix C are those under reference conditions.*

3. Calculate the best fit estimates of the regression coefficients, n and C:

$$n = \frac{S_{xy}}{S_{xx}}$$

$$C = \exp\left[\frac{\sum_{i=1}^{N} Q_i^2 \ln Q_i}{\sum_{i=1}^{N} Q_i^2} - n\,\frac{\sum_{i=1}^{N} Q_i^2 \ln \Delta P_i}{\sum_{i=1}^{N} Q_i^2}\right]$$

4. Calculate the correlation coefficient (r):

$$r = \sqrt{\frac{(S_{xy})^2}{S_{xx}S_{yy}}}$$

5. Calculate the estimated air flow, $\hat{Q}_i$, on the regression line for all measured $\Delta P_i$:

$$\hat{Q}_i = C \Delta P_i^n$$

Then calculate the relative error of each estimate:

$$\frac{|\hat{Q}_i - Q_i|}{Q_i}$$

6. Calculate the standard error of estimate of Q on $\Delta$ P:

$$S_{y/x} = \sqrt{\frac{S_{yy} - n\,S_{xy}}{\left(\sum_{i=1}^{N} Q_i^2\right)\left(N - 2\right)}}$$

Calculate the relative standard error of $\hat{Q}$ at $\Delta P = 10$ Pa ($\hat{Q}_{10}$):

$$\frac{S_{y/x}}{\sqrt{\sum_{i=1}^{N} Q_i^2}}\sqrt{1 + \frac{\left[\left(\sum_{i=1}^{N} Q_i^2\right)\ln 10 - \sum_{i=1}^{N} Q_i^2 \ln \Delta P_i\right]^2}{S_{xx}}}$$

7. For further independent use of the regression coefficients, calculate the standard errors

a. for ln C:

$$S_0 = S_{y/x}\sqrt{\frac{\sum_{i=1}^{N} Q_i^2 (\ln \Delta P_i)^2}{S_{xx}}}$$

Whence the standard error range for C is between exp (lnC + $S_0$) and exp (lnC - $S_0$)

b. for n:

$$S_1 = \frac{S_{y/x}}{\sqrt{\frac{S_{xx}}{\sum_{i=1}^{N} Q_i^2}}}$$

Whence the standard error range for n is n $\pm$ $S_1$

# AIR FLOW CORRECTIONS

## D-1 GENERAL THEORY

The measured air flow rates ($Q_m$) need to be corrected for the differences in air density ($\rho$) between:

a. the reference and calibration conditions, and

b. the indoor air moving out through the measuring device and the outdoor air moving in through the leaks in the building envelope (the air flow of interest).

---

a. In mass flow measuring devices (orifice plates, nozzles, venturis, pitot tubes, etc.);

$$Q \propto 1/\sqrt{\rho} \quad \text{(see Appendix B-1, par. 6).}$$

Because the calibration curve from Appendix B was used to obtain $Q_m$ from the measuring device output;

$$Q_m = \frac{\text{constant}}{\sqrt{\rho_c}}$$

where $\rho_c$ is the calibration air density.

The true air flow rate through the measuring device is

$$Q_i = \frac{\text{constant}}{\sqrt{\rho_i}}$$

where $\rho_i$ is the indoor air density

Thus $Q_i = Q_m \sqrt{\dfrac{\rho_c}{\rho_i}}$

b. Continuity of mass for compressible flow means

$\rho Q$ = constant

Thus, the in-leakage air flow rate,

$$Q = Q_i \frac{\rho_i}{\rho_o}$$

where $\rho_o$ is the outdoor air density

From par 7.7.1;

$$\rho \propto \frac{p}{t + 273.15}$$

Now the indoor and outdoor atmospheric pressures are essentially the same. Thus the full correction to $Q_m$ to give $Q_a$ is;

$$Q_a = Q_m \frac{(t_o + 273.15)}{(t_i + 273.15)} \sqrt{\frac{P_c}{P_a} \quad \frac{(t_i + 273.15)}{(t_c + 273.15)}}$$

where $Q_a$ is the corrected outside volumetric air flow rate into the building at outdoor test conditions, L/s

$Q_m$ is the measured air flow rate indicated by the flow measuring device before any correction for the difference in the operating temperature and the calibration temperature, L/s, from par. 6.2.6

$t_o$ is the outdoor air temperature, °C, from par. 6.1.1

$t_i$ is the indoor air temperature, °C, from par. 6.2.6

$t_c$ is the calibration air temperature, °C, from Appendix B

$P_c$ is the calibration atmospheric pressure, kPa, from Appendix B

$P_a$ is the ambient atmospheric pressure, kPa.

## D-2 AIR FLOW CORRECTIONS FOR CALCULATING ELA

$Q_a$, as determined using the formula derived in D-1 above is corrected to reference conditions of $t_i = t_o = 20°C$ and $P_a = 101.325$ kPa and yields $Q_r$ as follows:

From D-1;

$$Q_a = Q_m \frac{(t_o + 273.15)}{(t_i + 273.15)} \sqrt{\frac{P_c}{P_a} \cdot \frac{(t_i + 273.15)}{(t_c + 273.15)}}$$

Deriving $Q_r$ for estimating ELA:

$$Q_r = Qa \sqrt{\frac{P_a\,(20 + 273.15)}{101.325\,(t_o + 273.15)}}$$

Thus;

$$Q_r = Q_m \frac{(t_o + 273.15)}{(t_i + 273.15)} \sqrt{\frac{P_c}{P_a} \cdot \frac{(t_i + 273.15)}{(t_c + 273.15)}} \sqrt{\frac{P_a}{101.325} \cdot \frac{(20 + 273.15)}{(t_o + 273.15)}}$$

Simplifying;

$$Q_r = Q_m \sqrt{\frac{(t_o + 273.15)}{(t_i + 273.15)} \cdot \frac{P_c}{101.325} \cdot \frac{(20 + 273.15)}{(t_c + 273.15)}}$$

Note that this can be reduced to;

$$Q_r = Q_m \sqrt{\frac{(t_o + 273.15)}{(t_i + 273.15)}} \text{ x constant for any given fan}$$

where $Q_a$, $Q_m$, $t_o$, $t_i$, $t_c$ and $P_a$ and $P_c$ are as defined in D-1.

## SPECIMEN TEST REPORT

NAME OF CO. ____________________

ADDRESS OF CO. ____________________

NAME OF TESTER ____________________

ADDRESS OF
BUILDING ____________________

DATE OF TEST ____________ DATE OF REPORT ____________

WEATHER DATA

OUTDOOR TEMPERATURE ________ °C

WIND SPEED ________ km/h WIND DIRECTION ________

WIND VARIABILITY ________

ENVELOPE

☐ BUILDING ENVELOPE ☐ OTHER ____________

AREA ________ $m^2$ INTERIOR VOLUME ________ $m^3$

**BUILDING SKETCHES**

MEASURED DATA

| $\Delta P_m$ (Pa) | Fan Speed (r/min) or $\Delta P_{nozzle}$ (Pa) | $Q_m$ (L/s) | $t_i$ (°C) |
|---|---|---|---|
| ________ | ________ | ________ | ________ |
| ________ | ________ | ________ | ________ |
| ________ | ________ | ________ | ________ |
| ________ | ________ | ________ | ________ |
| ________ | ________ | ________ | ________ |
| ________ | ________ | ________ | ________ |
| ________ | ________ | ________ | ________ |
| ________ | ________ | ________ | ________ |

CORRECTED DATA

| $\Delta P$ (Pa) | $Q_r$ (L/s) |
|---|---|
| ________ | ________ |
| ________ | ________ |
| ________ | ________ |
| ________ | ________ |
| ________ | ________ |
| ________ | ________ |
| ________ | ________ |
| ________ | ________ |

RELATIVE ERROR

| $\left\| \dfrac{\hat{Q}_{ri} - Q_{ri}}{Q_{ri}} \right\|$ |
|---|
| ________ |
| ________ |
| ________ |
| ________ |
| ________ |
| ________ |
| ________ |
| ________ |

$\Delta P_{o,i}$ ________

$\Delta P_{o,f}$ ________

CALCULATED DATA

$C_r$ ________ L/(s.Pa$^n$)

n ________

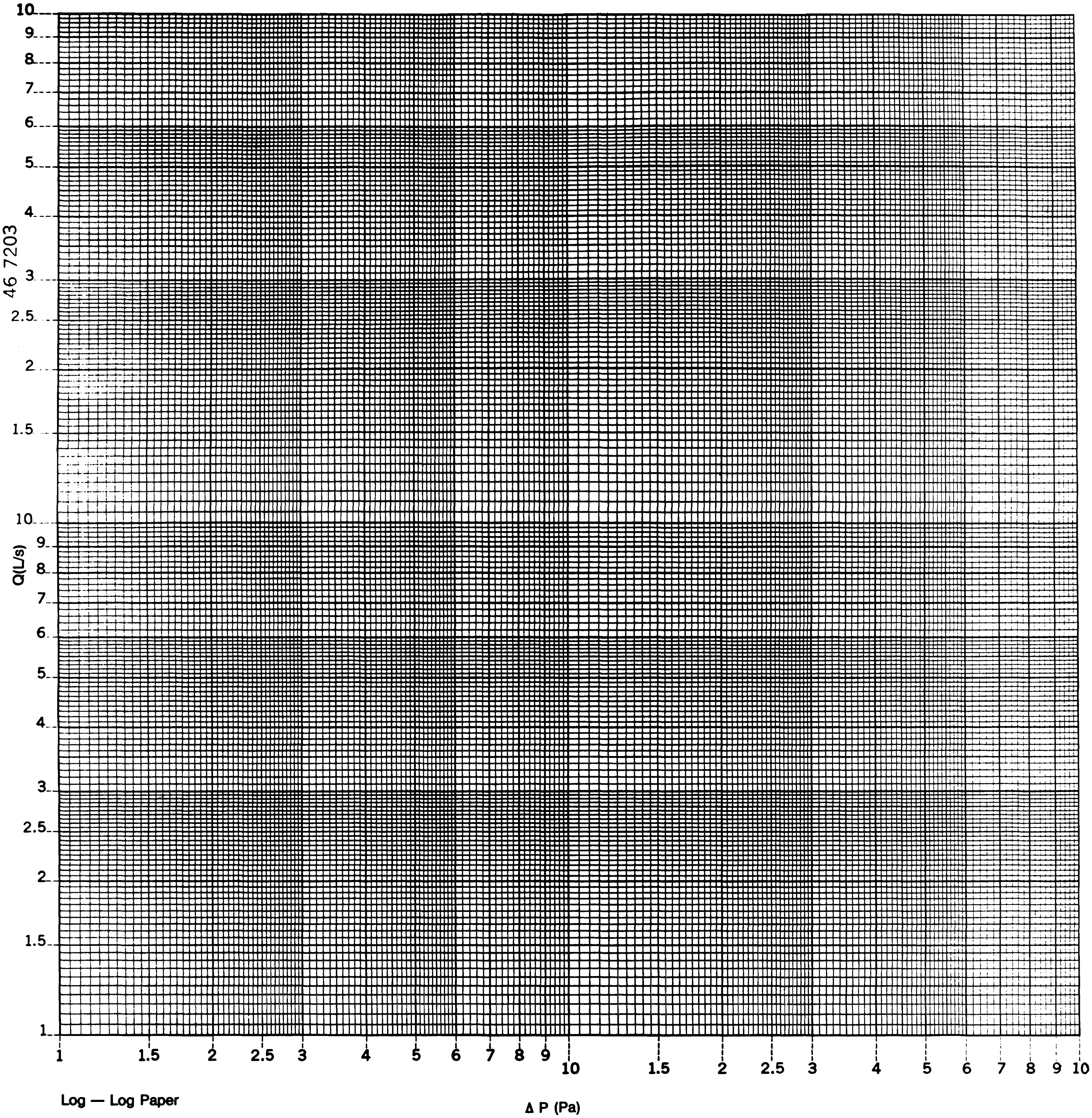
r ________

ELA ________ m$^2$

NLA ________ cm$^2$/m$^2$

RELATIVE STANDARD ERROR ________

PLOT OF MEASURED DATA

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