

ANSI/AMCA Standard 500-L-07

Laboratory Methods of Testing Louvers for Rating

An American National Standard
Approved by ANSI on January 17, 2006



**AIR MOVEMENT AND CONTROL
ASSOCIATION INTERNATIONAL, INC.**

The International Authority on Air System Components



Documents

Document Sharing Hub

ANSI/AMCA STANDARD 500-L-07

Laboratory Methods of Testing Louvers for Rating



**Air Movement and Control Association International, Inc.
30 West University Drive
Arlington Heights, IL 60004-1893**

© 2007 by Air Movement and Control Association International, Inc.

All rights reserved. Reproduction or translation of any part of this work beyond that permitted by Sections 107 and 108 of the United States Copyright Act without the permission of the copyright owner is unlawful. Requests for permission or further information should be addressed to the Chief Staff Executive, Air Movement and Control Association International, Inc. at 30 West University Drive, Arlington Heights, IL 60004-1893 U.S.A.

Authority

AMCA Standard 500-L-07 was adopted by the membership of the Air Movement and Control Association International, Inc. on 19 October, 2006. It was approved as an American National Standard by the American National Standards Institute (ANSI) and became effective on 11 January 2007.

ANSI/AMCA 500-L Review Committee

Robert Van Becelaere, Chairman	Ruskin Manufacturing Co.
Larry Carnahan	Airline Products
Sharyn I. Blanchard	The Airolite Company
Roger Lichtenwald	American Warming & Ventilation
Vincent Kreglewicz	Arrow United Industries
Rich Niemela	Cesco Products
Bill Vincent	Construction Specialties, Inc.
Arnold Druda	Farr, Inc.
Terry Horvat	Greenheck Fan Corporation
Wendell Simmons	Hart and Cooley, Inc.
James Sterriker	Industrial Louvers, Inc.
Dane Carey	NCA Manufacturing
James Tatum	NCA Manufacturing
Mike Beaver	P.C.I. Industries, Inc.
Tim Orris	AMCA International, Inc.

Disclaimer

AMCA uses its best efforts to produce standards for the benefit of the industry and the public in light of available information and accepted industry practices. However, AMCA does not guarantee, certify or assure the safety or performance of any products, components or systems tested, designed, installed or operated in accordance with AMCA standards or that any tests conducted under its standards will be non-hazardous or free from risk.

Objections to AMCA Standards and Certifications Programs

Air Movement and Control Association International, Inc. will consider and decide all written complaints regarding its standards, certification programs, or interpretations thereof. For information on procedures for submitting and handling complaints, write to:

Air Movement and Control Association International
30 West University Drive
Arlington Heights, IL 60004-1893 U.S.A.

or

AMCA International, Incorporated
c/o Federation of Environmental Trade Associations
2 Waltham Court, Milley Lane, Hare Hatch
Reading, Berkshire
RG10 9TH United Kingdom

Related AMCA Standards and Publications

AMCA Publication 501 *Application Manual for Air Louvers*

AMCA Publication 511 *Certified Ratings Program for Air Control Devices*

TABLE OF CONTENTS

1. Purpose	1
2. Scope	1
3. Units of Measurement	1
3.1 System of units	1
3.2 Basic units	1
3.3 Airflow rate and velocity	1
3.4 Water flow rate	1
3.5 Pressure	1
3.6 Torque	1
3.7 Gas properties	1
3.8 Dimensionless groups	2
3.9 Physical constants	2
4. Symbols and Subscripts	2
4.1 Symbols and subscripted symbols	2
4.2 Additional measurements (planes of measurement)	3
5. Definitions	4
5.1 Louver	4
5.2 Air control louver	4
5.3 Free area	4
5.4 Face area and core area	4
5.5 Psychrometrics	4
5.6 Pressure	4
5.7 Performance variables	5
5.8 Miscellaneous	5
6. Instruments and Methods of Measurement	5
6.1 Accuracy	5

6.2	Pressure	.5
6.3	Airflow rate	.6
6.4	Water flow rate	.7
6.5	Torque	.7
6.6	Air density	.7
6.7	Voltage	.8
6.8	Meters	.8
6.9	Pneumatic actuator supply air pressure	.8
6.10	Pressure gauges	.8
6.11	Chronometers	.8
6.12	Rain gauge	.8
7.	Equipment and Setups	.8
7.1	Setups	.8
7.2	Ducts	.8
7.3	Chambers	.9
7.4	Variable supply and exhaust systems	.9
7.5	Wind driven rain simulation equipment	.10
8.	Objective, Observations, and Conduct of Test	.10
8.1	Air performance-pressure drop test	.10
8.2	Air leakage flow rate	.11
8.3	Water penetration	.15
9.	Calculations	.19
9.1	Calibration correction	.19
9.2	Density and viscosity of air	.19
9.3	Louver flow rate at test conditions	.19
9.4	Density correction	.21
9.5	Air leakage-system leakage correction	.21
Annex A.	Presentation of Air Performance Results for Rating Purposes	.44
Annex B.	Water Penetration Performance	.45

Annex C. References 46

Annex D. Simulated Rain Spray Nozzles 47

Annex E. Water Eliminator Performance Test 48

Annex F. Wind Driven Rain Performance 49

Laboratory Methods of Testing Louvers for Rating

1. Purpose

The purpose of this standard is to establish uniform laboratory test methods for louvers. The characteristics to be determined include air leakage, pressure drop, water penetration, wind driven rain, and operational torque.

It is not the purpose of this standard to establish minimum or maximum performance ratings.

2. Scope

This standard may be used as a basis for testing louvers with air used as the test gas.

Tests conducted in accordance with the requirements of this standard are intended to demonstrate the performance of a louver and are not intended to determine acceptability level of performance. It is not the scope of this standard to indicate actual sequences of testing, nor is it in its scope to specify minimum or maximum criteria for testing.

The parties to a test for guarantee purposes may agree to exceptions to this standard in writing, prior to the test. However, only a test which does not violate any mandatory requirement of this standard shall be designated as a test conducted in accordance with this standard.

3. Units of Measurement

3.1 System of units

SI units (The International System of Units, Le Système International d'Unités) [1] are the primary units employed in this standard, with I-P units (Inch-Pound) given as the secondary reference. SI units are based on the fundamental values of the International Bureau of Weights and Measures [1], and I-P values are based on the values of the National Institute of Standards and Technology which are, in turn, based on the values of the International Bureau. Annex A provides conversion factors and coefficients for SI and other metric systems.

3.2 Basic units

The unit of length is the meter (m) or millimeter (mm); I-P units are the foot (ft.) or the inch (in.). The unit of mass is the kilogram (kg); the I-P unit is the poundmass (lb_m). The unit of time is either the minute (min) or the second (s). The unit of temperature is either the degree Celsius (°C) or kelvin (K). I-P units are either the degree Fahrenheit (°F) or the degree Rankine (°R). The unit of force is the newton (N); the I-P unit is the pound (lb).

3.3 Airflow rate and velocity

3.3.1 Airflow rate. The unit of volumetric airflow rate is the cubic meter per second (m³/s); the I-P unit is the cubic foot per minute (cfm).

3.3.2 Airflow velocity. The unit of airflow velocity is the meter per second (m/s); the I-P unit is the foot per minute (fpm).

3.4 Water flow rate

The unit of liquid volume is the liter (L); the I-P unit is the gallon (gal). The unit of liquid flow rate is the liter per second (L/s); the I-P unit is the gallon per minute (gpm).

3.5 Pressure

The unit of pressure is the pascal (Pa) or the millimeter of mercury (mm Hg); the I-P unit is either the inch water gauge (in. wg), or the inch mercury column (in. Hg). Values in mm Hg or in. Hg shall be used only for barometric pressure measurements. The in. wg shall be based on a one inch column of distilled water at 68°F under standard gravity and a gas column balancing effect based on standard air. The in. Hg shall be based on a one inch column of mercury at 32°F under standard gravity in a vacuum. The mm Hg shall be based on a one mm column of mercury at 0°C under standard gravity in a vacuum.

3.6 Torque

The unit of torque is the newton-meter (N-m); the I-P unit is the pound-inch, (lb-in.).

3.7 Gas properties

The unit of density is the kilogram per cubic meter (kg/m³); the I-P unit is the pound mass per cubic foot.

(lb_m/ft³). The unit of viscosity is the Pascal-second, (Pa-s); the I-P unit is the pound mass per foot-second (lb_m/ft-s). The SI unit of gas constant is the joule per kilogram-kelvin (J/kg-K); the I-P unit is the foot-pound per pound mass-degree Rankine, (ft-lb_f/lb_m-°R).

3.8 Dimensionless groups

Various dimensionless quantities appear in the text. Any consistent system of units may be employed to evaluate these quantities unless a numerical factor is included, in which case units must be as specified.

3.9 Physical constants

The value of standard gravitational acceleration shall be taken as 9.80665 m/s² (32.174 ft/s²) at mean sea level at 45° latitude [2]. The density of distilled water at saturation pressure shall be taken as 998.278 kg/m³ (62.3205 lb_m/ft³) at 20°C (68°F) [3]. The density of mercury at saturation pressure shall be taken at 13595.1 kg/m³ (848.714 lb_m/ft³) at 0°C (32°F) [3]. The specific weights in kg/m³ (lb_m/ft³) of these fluids under standard gravity in a vacuum are numerically equal to their densities at corresponding temperatures.

4. Symbols and Subscripts

4.1 Symbols and subscripted symbols

SYMBOL	DESCRIPTION	SI UNIT	I-P UNIT
A	Area of Cross-Section	m ²	ft ²
A_c	Louver Core Area/Area of hole in Calibration Plate	m ²	ft ²
C	Nozzle Discharge Coefficient	dimensionless	
D	Diameter and Equivalent Diameter	m	ft
D_h	Hydraulic Diameter	m	ft
E	Energy Factor	dimensionless	
E	Effectiveness	%	
F	Beam Load	N	lb
g	Acceleration due to gravity	m/s ²	ft/s ²
G	Water Volume Flow Rate	L/s	gpm
K_p	Compressibility Coefficient	dimensionless	
l	Length of Moment Arm	m	in
L	Nozzle Throat Dimension	m	ft
L_e	Equivalent Length of Straightener	m	ft
$L_{x,xN}$	Length of Duct Between Planes x and xN	m	ft
M	Chamber Dimension	m	ft
n	Number of Readings	dimensionless	
N	Speed of Rotation	rpm	rpm
P_s	Static Pressure	Pa	in. wg
P_{sx}	Static Pressure at Plane x	Pa	in. wg
P_t	Total Pressure	Pa	in. wg
P_{tx}	Total Pressure at Plane x	Pa	in. wg
P_v	Velocity Pressure	Pa	in. wg
P_{vx}	Velocity Pressure at Plane x	Pa	in. wg
p_b	Corrected Barometric Pressure	Pa	in. Hg
p_e	Saturated Vapor Pressure at t_w	Pa	in. Hg
p_p	Partial Vapor Pressure	Pa	in. Hg
Q	Louver Airflow Rate	m ³ /s	cfm
Q_x	Airflow Rate at Plane x	m ³ /s	cfm
q_d	Water Penetration Rate Collected Downstream of the Test Louver	L/h	gpm
q_s	Water Supply Rate to Nozzles	L/h	gpm
q_u	Water Rejection Rate Collected Upstream of the Test Louver	L/h	gpm
Q_v	Volume rate of Airflow at Flow Meter	m ³ /s	cfm

Q_w/a	Rainfall rate through the calibration plate	L/h/m ²	gpm/ft ²
R	Gas Constant	J/kg-K	ft-lb/lb _m -°R
Re	Reynolds Number	dimensionless	
T	Torque	N-m	lb-in.
t_d	Dry-Bulb Temperature	°C	°F
t_s	Static Temperature	°C	°F
t_t	Total Temperature	°C	°F
t_w	Wet-Bulb Temperature	°C	°F
V	Velocity	m/s	fpm
v_w	Wind Velocity	m/s	fpm
v_c	Core Velocity	m/s	fpm
w	Weight of water	g	oz.
W	Rainfall Rate	mm/hr.	in./hr.
y	Thickness of Straightener Element	m	ft
Y	Nozzle Expansion Factor	dimensionless	
z	Function Used to Determine K_p	dimensionless	
α	Static Pressure Ratio for Nozzles	dimensionless	
β	Diameter Ratio for Nozzles	dimensionless	
γ	Ratio of Specific Heats	dimensionless	
ΔP	Pressure Differential	Pa	in. wg
ΔP_n	Pressure Differential Across Nozzle	Pa	in. wg
$\Delta p_{x,x'}$	Pressure Differential Between Planes x and x'	Pa	in. wg
μ	Air Viscosity	Pa-s	lb _m /ft-s
ρ	Air Density	kg/m ³	lb _m /ft ³
ρ_x	Air Density at Plane x	kg/m ³	lb _m /ft ³

4.2 Additional subscripts (planes of measurement)

SUBSCRIPT DESCRIPTION

c	Converted parameter
DS	Louver and system
I	Outlet of Louver under Test
m	Measuring Point at the Airflow Meter
n	Value at Selected Point of Airflow Rate/Static Pressure Curve
o	Measured value with Calibration Plate
r	Reading
s	System
x	Plane 0, 1, 2, ..., as appropriate
0	Plane 0 (general test area)
1	Plane of inlet of louver being tested
2	Plane of outlet of louver being tested
3	Plane of Pitot traverse
4	Plane of duct P_s measurement downstream of louver being tested
5	Plane of nozzle inlet P_s measurement
6	Plane of nozzle discharge station
7	Plane of P_s measurement in chamber downstream of louver being tested
8	Plane of P_s measurement in chamber upstream of louver being tested
9	Plane of duct P_s measurement of upstream louver being tested (used to show correct values against references values)

5. Definitions

5.1 Louver

A louver is a device comprised of multiple blades which, when mounted in an opening, permits the flow of air but inhibits the entrance of other elements.

5.1.1 Fixed blade louver. A louver in which the blades do not move.

5.1.2 Adjustable blade louver. A louver in which the blades may be operated either manually or by mechanical means.

5.2 Air control louver

A mechanical device which does not fit the definition of a louver and which, when placed in a duct or opening, is used to regulate airflow.

5.3 Free area

The minimum area through which air can pass. It is determined by multiplying the sum of the minimum distances between intermediate blades, top blade and head and bottom blade and sill, by the minimum distance between jambs. The percent of free area is the free area thus calculated, divided by the gross area of the air control louver $\times 100$. See louver cross-sections (Figure 1).

5.3.1 Free area velocity. Airflow through a louver divided by its free area.

5.4 Face area and core area

5.4.1 Face area. The total cross sectional area of a louver, duct or wall opening.

5.4.1.1 Face area velocity. Airflow through a louver divided by its face area.

5.4.2 Core area. The product of the minimum height H and minimum width W of the front opening in the louver assembly with the louver blades removed (see Fig. 12).

5.4.2.1 Louver calibration plate. The louver calibration plate is a plate having an opening of the same geometric shape and dimensions as the core area of the test specimen.

5.4.2.2 Core area velocity. The airflow rate through the louver divided by the core area.

5.4.2.3 Core ventilation rate. The airflow rate through the core area of the louver.

5.5 Psychrometrics

5.5.1 Dry-bulb. The air temperature measured by a dry temperature sensor.

5.5.2 Wet-bulb. The temperature measured by a temperature sensor covered by a water-moistened wick and exposed to air in motion. When properly measured, it is a close approximation of the temperature of adiabatic saturation.

5.5.3 Wet-bulb depression. The difference between dry-bulb and wet-bulb temperatures at the same location.

5.5.4 Stagnation (total) temperature. The temperature that exists by virtue of the internal and kinetic energy of the air. If the air is at rest, the stagnation (total) temperature will equal the static temperature.

5.5.5 Static temperature. The temperature which exists by virtue of the internal energy of the air only. If a portion of the internal energy is converted into kinetic energy, the static temperature will be decreased accordingly.

5.5.6 Air density. The mass per unit volume of air.

5.5.7 Standard air. Standard air is air with a density of 1.2 kg/m^3 ($0.075 \text{ lb}_m/\text{ft}^3$), a ratio of specific heats of 1.4, a viscosity of $1.8185 \times 10^{-5} \text{ Pa}\cdot\text{s}$ ($1.222 \times 10^{-5} \text{ lb}_m/\text{ft}\cdot\text{s}$). Air at 20°C (68°F) temperature, 50% relative humidity, and 101.3207 kPa (29.92 in. Hg) barometric pressure has these properties, approximately.

5.6 Pressure

5.6.1 Pressure. Force per unit area. This corresponds to energy per unit volume of fluid.

5.6.2 Absolute pressure. The value of a pressure when the datum pressure is absolute zero. It is always positive.

5.6.3 Barometric pressure. The absolute pressure exerted by the atmosphere at the location of measurement.

5.6.4 Gauge pressure. The value of a pressure when the reference pressure is the barometric pressure at the point of measurement. It may be negative or positive.

5.6.5 Velocity pressure. That portion of the air pressure which exists by virtue of the rate of motion only. It is always positive.

5.6.6 Static pressure. That portion of the air pressure which exists by virtue of the degree of compression only. If expressed as gauge pressure, it may be negative or positive.

5.6.7 Total pressure. The air pressure which exists by virtue of the degree of compression and the rate of motion. It is the algebraic sum of the velocity pressure and the static pressure at a point. Thus, if the air is at rest, the total pressure will equal the static pressure.

5.6.8 Pressure differential. The change in static pressure across a louver.

5.7 Performance variables

5.7.1 Pressure drop. The difference in pressure between two points in a flow system, usually caused by frictional resistance to fluid flow through an opening, in a duct or other flow system.

Pressure drop is a measure of the resistance to airflow across a louver. It is expressed as the difference in static pressure across the louver for a specific rate of airflow.

5.7.2 Air leakage. The amount of air passing through a louver when it is in the closed position and at a specific pressure differential. It is expressed as the volumetric rate of air passing through the louver divided by the face area.

5.7.3 Water penetration. The amount of water passing through a louver while air is flowing through it at a specific free area velocity. It is expressed as the weight of water passing through the louver divided by the free area, at a specified free area velocity.

5.7.3.1 Insertion loss. The difference in simulated rain penetration between the test specimen and the calibration plate at the same test conditions.

5.7.3.2 Louver effectiveness. The effectiveness of a louver at any core area velocity through the louver is the insertion loss of the louver assembly divided by the water penetration of the calibration plate at that velocity.

5.8 Miscellaneous

5.8.1 Shall and should. The word *shall* is to be understood as mandatory; the word *should* as advisory.

5.8.2 Determination. A determination is a complete set of measurements for a particular point of

operation of the test louver. The measurements must be sufficient to determine all appropriate performance variables as defined in Section 5.7.

5.8.3 Test. A series of determinations for various points of operation of a louver.

5.8.4 Energy factor. Energy factor is the ratio of the total kinetic energy of the airflow to the kinetic energy corresponding to the average velocity of air.

6. Instruments and Methods of Measurement

6.1 Accuracy [4]

The specifications for instruments and methods of measurement which follow include both accuracy requirements and specific examples of equipment that are capable of meeting those requirements. Equipment other than the examples cited may be used provided the accuracy requirements are met or exceeded.

6.2 Pressure

The total pressure at a point shall be measured on an indicator, such as a manometer, with one leg open to atmosphere and the other leg connected to a total pressure sensor, such as a total pressure tube or the impact tap of a Pitot-static tube. The static pressure at a point shall be measured on an indicator, such as a manometer, with one leg open to the atmosphere and the other leg connected to a static pressure sensor, such as a static pressure tap or the static tap of a Pitot-static tube. The velocity pressure at a point shall be measured on an indicator, such as a manometer, with one leg connected to a total pressure sensor, such as the impact tap of a Pitot-static tube, and the other leg connected to a static pressure sensor, such as the static tap of the same Pitot-static tube. The differential pressure between two points shall be measured on an indicator, such as a manometer, with one leg connected to the upstream sensor, such as a static pressure tap, and the other leg connected to the downstream sensor, such as a static pressure tap.

6.2.1 Manometers and other pressure indicating instruments. Pressure shall be measured on manometers of the liquid column type using inclined or vertical legs or other instruments which provide a maximum uncertainty of 1% of the maximum observed test reading during the test or 3 Pa (0.01 in. wg) whichever is larger.

6.2.1.1 Calibration. Each pressure indicating instrument shall be calibrated at both ends of the scale and at least nine equally spaced intermediate

points in accordance with the following:

- (1) When the pressure to be indicated falls in the range of 0 to 0.5 kPa (0 to 2 in. wg), calibration shall be against a water-filled hook gauge of the micrometer type or a precision micromanometer.
- (2) When the pressure to be indicated is above 0.5 kPa (2 in. wg), calibration shall be against a water-filled hook gauge of the micrometer type, a precision micromanometer, or a water-filled U-tube.

6.2.1.2 Averaging. Since the airflow and pressures through a louver in a typical system are never strictly steady, the pressure indicated on any instrument will fluctuate with time. In order to obtain a representative reading, either the instrument must be damped or the readings must be averaged in a suitable manner. Multi-point or continuous record averaging can be accomplished with instruments and analyzers designed for this purpose.

6.2.1.3 Corrections. Manometer readings shall be corrected for any difference in specific weight of gauge fluid from standard, any difference in gas column balancing effect from standard, or any change in length of the graduated scale due to temperature. However, corrections may be omitted for temperatures between 14°C and 26°C (58°F and 78°F), latitudes between 30° and 60°, and elevations up to 1500m (5000 ft.).

6.2.2 Pitot-static tubes [5] [6]. The total pressure or the static pressure at a point may be sensed with a Pitot-static tube of the proportions shown in Figure 4. Either or both of these pressure signals can then be transmitted to a manometer or other indicator. If both pressure signals are transmitted to the same indicator, the differential shall be considered the velocity pressure at the point of the impact opening.

6.2.2.1 Calibration. Pitot-static tubes having the proportions shown in Figure 4 are considered primary instruments and need not be calibrated provided they are maintained in the specified condition.

6.2.2.2 Size. The Pitot-static tube shall be of sufficient size and strength to withstand the pressure forces exerted upon it. The outside diameter of the tube shall not exceed 1/30 of the test duct diameter except that when the length of the supporting stem exceeds 24 tube diameters, the stem may be progressively increased beyond this distance. The minimum practical tube diameter is 2.5 mm (0.10 in.).

6.2.2.3 Support. Rigid support shall be provided to hold the Pitot-static tube axis parallel to the axis of the duct within 1 degree and at the head locations

specified in Figure 3 within 1.2 mm (0.05 in.) or 0.25% of the duct diameter, whichever is larger. Straighteners are specified so that flow lines will be approximately parallel to the duct axis.

6.2.3 Static pressure taps. The static pressure at a point may be sensed with a pressure tap of the proportions shown in Figure 2. The pressure signal can then be transmitted to an indicator.

6.2.3.1 Calibration. Pressure taps having the proportions shown in Figure 2 are considered primary instruments and need not be calibrated provided they are maintained in the specified condition.

6.2.3.2 Averaging. An individual pressure tap is sensitive only to the pressure in the immediate vicinity of the hole. In order to obtain an average, at least four identical taps shall be manifolded into a piezometer ring. The manifold shall have an inside area at least four times that of each tap.

6.2.3.3 Piezometer rings. Piezometer rings are specified for upstream and downstream nozzle taps and for outlet duct or chamber measurements unless Pitot traverse is specified. Measuring planes shall be located as shown in the figure for the appropriate setup.

6.2.4 Other pressure indicating instruments. Pressure measuring systems consisting of indicators and sensors other than manometers and Pitot-static tubes, or static pressure taps may be used if the combined uncertainty of the system including any transducers does not exceed the combined uncertainty for an appropriate combination of manometers and Pitot-static tubes, or static pressure taps.

6.3 Airflow rate

An airflow rate shall be calculated either from measurements of velocity pressure obtained by Pitot traverse or from measurements of pressure differential across a flow nozzle. Airflow rates less than 10 cfm may be measured directly using an airflow meter.

6.3.1 Pitot traverse [7]. Airflow rate may be calculated from the velocity pressures obtained by traverses of a duct with a Pitot-static tube for any point of operation provided the average velocity corresponding to the airflow rate is at least 6.35 m/s (1250 fpm).

6.3.1.1 Traverse point. The number and locations of the measuring stations on each diameter and the number of diameters shall be as specified in Figure 3.

6.3.1.2 Averaging. The stations shown in Figure 3 are located on each diameter according to the log-linear rule [8]. The arithmetic mean of the individual velocity measurements made at these stations will be the mean velocity through the measuring section for a wide variety of profiles [9].

6.3.2 Nozzles. Airflow rate may be calculated from the pressure differential measured across an airflow nozzle or bank of nozzles for any point of operation provided the pressure differential across the nozzle bank is at least 25 Pa (0.1 in. wg). The uncertainty of the airflow rate measurement can be reduced by changing to a smaller nozzle or combination of nozzles for low airflow rates.

6.3.2.1 Size. The nozzle or nozzles shall conform to Figure 8A. Nozzles may be of any convenient size. However, when a duct is connected to the inlet of the nozzle, the ratio of nozzle throat diameter to the diameter of the inlet duct shall not exceed 0.525.

6.3.2.2 Calibration. The standard nozzle is considered a primary instrument and need not be calibrated if maintained in the specified condition. Reliable coefficients have been established for throat dimensions $L = 0.5D$ and $L = 0.6D$, shown in Figure 8A [10]. Throat dimension $L = 0.6D$ is recommended for new construction.

6.3.2.3 Chamber nozzles. Nozzles without integral throat taps may be used for multiple nozzle chambers in which case upstream and downstream pressure taps shall be located as shown in the figure for the appropriate setup. Alternatively, nozzles with throat taps may be used in which case the throat taps located as shown in Figure 8A shall be used in place of the downstream pressure taps shown in the figure for the setup and the piezometer for each nozzle shall be connected to its own indicator.

6.3.2.4 Ducted nozzles. Nozzles with integral throat taps shall be used for ducted nozzle setups. Upstream pressure taps shall be located as shown in the figure for the appropriate setup. Downstream taps are the integral throat taps and shall be located as shown in Figure 8A.

6.3.2.5 Taps. All pressure taps shall conform to the specification in Section 6.2.3 regarding geometry, number, and manifolding into piezometer rings.

6.3.3 Airflow meter. An airflow rate may be measured directly using a calibrated airflow meter capable of measuring airflow in increments of 0.2 L/s (25 cubic feet per hour) or less. A direct-reading airflow meter may be used if the airflow is below 4.7 L/s (10 cfm).

6.3.4 Other airflow measurement methods.

Airflow measurement methods that utilize a meter or a traverse other than flow nozzles or Pitot-static tube traverse described herein may be used if the uncertainty introduced by the method does not exceed that introduced by an appropriate flow nozzle or Pitot-static tube traverse method. The contribution to the combined uncertainty in the airflow rate measurement shall not exceed that corresponding to 1.2% of the discharge coefficient for a flow nozzle [11].

6.4 Water flow rate

A calibrated flow meter capable of indicating flow in increments of 0.5 liter per minute (0.1 gallon per minute) or less, per unit of time or less shall be used. Measurement accuracy shall be within 0.5% of the indicated flow rate.

Water flow meters shall be calibrated against a known weight of water flowing for a measurement time period or factory calibrated.

6.5 Torque

A torque meter having a demonstrated accuracy of $\pm 2\%$ of observed reading may be used to determine power.

6.5.1 Calibration. A torque meter shall have a static calibration and may have a running calibration through its range of usage. The static calibration shall be made by suspending weights from a torque arm. The weights shall have certified accuracies of $\pm 0.2\%$. The length of the torque arm shall be determined to an accuracy of $\pm 0.2\%$.

6.5.2 Tare. The zero torque equilibrium (tare) and the span of the readout system shall be checked before and after each test. In each case, the difference shall be within 0.5% of the maximum value measured during the test.

6.6 Air density

Air density shall be calculated from measurements of wet-bulb temperature, dry-bulb temperature, and barometric pressure. Other parameters may be measured and used if the maximum error in the calculated density does not exceed 0.5%.

6.6.1 Thermometers. Both wet and dry-bulb temperatures shall be measured with thermometers or other instruments with demonstrated accuracies of $\pm 1^\circ\text{C}$ ($\pm 2^\circ\text{F}$) and readability of 0.5°C (1°F) or finer.

6.6.1.1 Calibration. Thermometers shall be calibrated over the range of temperatures to be encountered during test against a thermometer with a calibration that is traceable to the National Institute of Standards and Technology (NIST) or other national physical measures recognized as equivalent by NIST.

6.6.1.2 Wet-bulb. The wet-bulb thermometer shall have an air velocity over the water-moistened wick-covered bulb of 3.5 to 10 m/s (700 to 2000 fpm) [12]. The dry-bulb thermometer shall be mounted upstream of the wet-bulb thermometer so its reading will not be depressed.

6.6.2 Barometers. The barometric pressure shall be measured with a mercury column barometer or other instrument with a demonstrated accuracy of ± 170 Pa (± 0.05 in. Hg) and readable to 34 Pa (0.01 in. Hg) or finer.

6.6.2.1 Calibration. Barometers shall be calibrated against a mercury column barometer with a calibration that is traceable to the National Institute of Standards and Technology (NIST) or other national physical measures recognized as equivalent by NIST. A convenient method of doing this is to use an aneroid barometer as a transfer instrument and carry it back and forth to the Weather Bureau Station for comparison. A permanently mounted mercury column barometer should hold its calibration well enough so that comparisons every three months should be sufficient. Transducer type barometers shall be calibrated for each test. Barometers shall be maintained in good condition.

6.6.2.2 Corrections. Barometric readings shall be corrected for any difference in mercury density from standard or any change in length of the graduated scale due to temperature. Refer to manufacturer's instructions.

6.7 Voltage

Actuator input voltage during the test shall be within 1% of the voltage shown on the actuator nameplate.

6.8 Meters

Electrical meters shall have certified accuracies of $\pm 1.0\%$ of observed reading. It is preferable that the same meters shall be used for the test as for the calibration.

6.9 Pneumatic actuator supply air pressure

Pneumatic actuator supply air pressure during a test shall be within 5% of the desired test pressure.

6.10 Pressure gauges

Supply air pressure for pneumatic actuator shall be measured with a pressure gauge or other instrument with a demonstrated accuracy of ± 10 kPa (1 psi) and a readability of 10 kPa (1 psi) or less.

6.11 Chronometers

Time measurements shall be made with a watch having minimum accuracy of $\pm 0.2\%$ per day.

6.12 Rain gauge

Rain gauge shall have an accuracy of $\pm 2\%$ of reading.

7. Equipment and Setups

7.1 Setups

Six test louver setups are diagramed in Figures 5.1, 5.2, 5.4, 5.5, 5.6, and 5.11. Six airflow measurement setups are diagramed in Figures 6.1, 6.2, 6.3, 6.4, 6.5 and 6.6.

7.1.1 Installation Types. There are three categories of installation types which can be used with louvers. The installation types and the corresponding test louver setup figures are:

Figure 5.1 - Free Inlet, Ducted Outlet

Figure 5.2 - Ducted Inlet, Free Outlet

Figures 5.4, 5.5, 5.6, 5.11 - Free Inlet, Free Outlet

7.1.2 Leakage. The ducts, chambers and other equipment utilized should be designed to withstand the pressure and other forces to be encountered. All joints between the louver and the measuring plane should be designed for minimum leakage.

7.2 Duct

A duct may be incorporated in a laboratory setup to provide a measuring plane or to simulate the conditions the louver is expected to encounter in service or both. The dimension D in the test louver setup figure is the inside diameter of a circular cross-section duct or equivalent diameter of a rectangular cross-section duct with inside transverse dimensions a and b where:

$$D = \sqrt{4ab/\pi} \quad \text{Eq. 7.1}$$

7.2.1 Transformation Pieces (Figure 10)

7.2.1.1 Transformation pieces used to connect a louver being tested and a duct with a measuring plane shall not contain any converging element that

makes an angle with the duct axis greater than 7.5° or a diverging element that makes an angle with the duct greater than 3.5°.

7.2.1.2 Transformation pieces used to connect a variable exhaust system to a flow measuring nozzle shall have a maximum included angle of 7°.

7.2.1.3 Transformation pieces used to connect a duct containing a louver being tested and a flow measuring duct shall not contain any converging or diverging element that makes an angle with the duct axis greater than 30°.

7.2.1.4 Transformation pieces used to connect a duct which provides a measuring plane to a variable supply system or a chamber shall not be restricted as to size or shape.

7.2.2 Roundness. The portion of a Pitot traverse duct within one-half duct diameter of either side of the plane of measurement shall be round within 0.5% of the duct diameter. The remainder of the duct shall be round within 1% of the duct diameter. The area of the plane of measurement shall be determined from the average of four diameters measured at 45° increments. The diameter measurements shall be accurate to 0.2%.

7.2.3 Straighteners. Straighteners or star straighteners shall be used where indicated in the figures. The downstream plane of the straightener or star 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 or star straightener shall be as specified in Figure 9A or 9B [14].

7.3 Chamber

A chamber may be incorporated in a laboratory setup to provide a measuring station or to simulate the conditions the louver is expected to encounter in service or both. A chamber may have a circular or rectangular cross-sectional shape. The dimension M in the airflow measurement setup diagram is the inside diameter of a circular chamber or the equivalent diameter of dimensions a and b where

$$M = \sqrt{(4ab/\pi)} \quad \text{Eq. 7.2}$$

7.3.1 Outlet chamber. An outlet chamber (Figure 5.4) shall have a cross-sectional area at least fifteen times the free area of the louver being tested.

7.3.2 Inlet chamber. An Inlet chamber (Figure 5.5) shall have a cross-sectional area at least three times the free area of the louver being tested.

7.3.3 Airflow Settling Means. Airflow settling means shall be installed in a chamber where indicated on the test setup figure to provide proper airflow patterns.

Where a measuring plane is located downstream of the settling means, the settling means is provided to ensure a substantially uniform flow ahead of the measuring plane. In this case, the maximum local velocity at a distance 0.1M downstream of the screen shall not exceed the average velocity by more than 25% unless the maximum local velocity is less than 2 m/s (400 fpm).

Where a measuring plane is located upstream of the settling means, the purpose of the settling screen is to absorb the kinetic energy of the upstream jet, and allow its normal expansion as if in an unconfined space. This requires some backflow to supply the air to mix at the jet boundaries, but the maximum reverse velocity shall not exceed 10% of the calculated Plane 2 or Plane 6 mean jet velocity.

Where measuring planes are located on both sides of the settling means within the chamber, the requirements for each side as outlined above shall be met.

Any combination of screens or perforated plates that will meet these requirements may be used, but in general a reasonable chamber length for the settling means is necessary to meet both requirements. Screens of square mesh round wire with open areas of 50% to 60% are suggested and several will usually be needed to meet the above performance specifications. A performance check will be necessary to verify the airflow settling means are providing proper flow patterns.

7.3.4 Multiple nozzles. Multiple nozzles shall be located as symmetrically as possible. The centerline of each nozzle shall be at least 1.5 nozzle throat diameters from the chamber wall. The minimum distance between centers of any two nozzles in simultaneous use shall be three times the throat diameter of the larger nozzle.

7.4 Variable supply and exhaust systems

A means of varying the points of operation shall be provided in a laboratory setup.

7.4.1 Throttling device. A throttling device may be used to control the point of operation. The device shall be located on the end of the duct or chamber and shall be symmetrical about the duct or chamber axis.