Proposed Code Modifications

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TAC: Mechanical

Total Mods for **Mechanical** in **Approved as Submitted: 30**

Total Mods for report: 55

Sub Code: Mechanical

M7836

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Date Submitted	12/14/2018	**Section**	202	**Proponent**	Amanda Hickman
Chapter	2	**Affects HVHZ**	No	**Attachments**	No

TAC Recommendation Approved as Submitted

Commission Action Pending Review

Comments

General Comments **No** **Alternate Language** **No**

Related Modifications

#7839 (Large-diameter ceiling fan)
#7842 (Reference standards)

Summary of Modification

Adds definition for Large-diameter ceiling fan

Rationale

This proposal brings in the definition for Large-diameter ceiling fans that is consistent with the DOE fan regulations and also approved proposals to the 2018 International Mechanical Code.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

This modification will provide clarity to code enforcement for these types of fans.

Impact to building and property owners relative to cost of compliance with code

There is no cost impact, as this proposal is only introducing a definition of these types of fans.

Impact to industry relative to the cost of compliance with code

There is no cost impact, as this proposal is only introducing a definition of these types of fans.

Impact to small business relative to the cost of compliance with code

There is no cost impact, as this proposal is only introducing a definition of these types of fans.

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

This modification brings in a definition that will help code enforcement more easily identify these types of fans so that they will follow the appropriate reference standards and code requirements. This will ensure the public's health and safety.

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

This modification will improve the code by providing code enforcement the appropriate definition for these types of fans.

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

This modification does not discriminate. It is only bringing in a definition for these types of fans.

Does not degrade the effectiveness of the code

This modification does not degrade the effectiveness of the code. It is only bringing in a definition for these types of fans.

Add new definition as follows:

Large-diameter ceiling fan. A ceiling fan that is greater than 7 feet (2134 mm) in diameter. These fans are sometimes referred to as High-Volume, Low-Speed (HVLS) fans.

M7290

Date Submitted	11/16/2018	**Section**	404.1	**Proponent**	James Bickford
Chapter	4	**Affects HVHZ**	No	**Attachments**	No
TAC Recommendation	Approved as Submitted				
Commission Action	Pending Review				

Comments

General Comments **No**

Alternate Language **No**

Related Modifications

404.2

Summary of Modification

Changes text of Section 404.1 “Enclosed parking garages.” It also deletes Section 404.2. Section 404.2 is being rolled into Section 404.1. It clarifies that the exhaust system either has to run constantly or it has to run automatically.

Rationale

This section has been misinterpreted regarding intermittent operation. No technical changes are proposed by this revision. It is simpler to state that the exhaust system either has to run constantly or it has to run automatically.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

None

Impact to building and property owners relative to cost of compliance with code

Will not increase the cost of construction

This proposal will not increase the cost of construction because no additional labor, materials, equipment, appliances or devices are mandated beyond what is currently required by the code nor are the code requirements made more stringent.

Impact to industry relative to the cost of compliance with code

Will not increase the cost of construction

This proposal will not increase the cost of construction because no additional labor, materials, equipment, appliances or devices are mandated beyond what is currently required by the code nor are the code requirements made more stringent.

Impact to small business relative to the cost of compliance with code

Will not increase the cost of construction

This proposal will not increase the cost of construction because no additional labor, materials, equipment, appliances or devices are mandated beyond what is currently required by the code nor are the code requirements made more stringent.

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

This proposal will not increase the cost of construction because no additional labor, materials, equipment, appliances or devices are mandated beyond what is currently required by the code nor are the code requirements made more stringent.

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

Will not increase the cost of construction

This proposal will not increase the cost of construction because no additional labor, materials, equipment, appliances or devices are mandated beyond what is currently required by the code nor are the code requirements made more stringent.

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

Will not increase the cost of construction

This proposal will not increase the cost of construction because no additional labor, materials, equipment, appliances or devices are mandated beyond what is currently required by the code nor are the code requirements made more stringent.

Does not degrade the effectiveness of the code

Will not increase the cost of construction

This proposal will not increase the cost of construction because no additional labor, materials, equipment, appliances or devices are mandated beyond what is currently required by the code nor are the code requirements made more stringent.

404.1 Enclosed parking garages. ~~Where mechanical~~ Mechanical ventilation systems for enclosed parking garages shall operate ~~intermittently, such operation~~ continuously or shall be ~~automatic~~ automatically operated by means of carbon monoxide detectors applied in conjunction with nitrogen dioxide detectors. Such detectors shall be installed in accordance with their manufacturers

□" recommendations. Automatic operation shall cycle the ventilation system between the following two modes of operation:

1.Full-on at an airflow rate of not less than 0.75 cfm per square foot of the floor area served.

2. Standby at an airflow rate of not less than 0.05 cfm per square foot of the floor areaserved.

Delete without substitution:

~~**404.2 Minimum ventilation.** Automatic operation of the system shall not reduce the ventilation airflow ratebelow0.05cfm persquarefoot(0.00025m^3/s•m^2)ofthefloorareaandthesystem shallbecapable of producing a ventilation airflow rate of 0.75 cfm per square foot (0.0038 m^3/s • m^2) of floorarea.~~

M8326

Date Submitted	12/15/2018	**Section**	403.3.2.1	**Proponent**	Joseph Lstiburek
Chapter	4	**Affects HVHZ**	No	**Attachments**	No
TAC Recommendation	Approved as Submitted				
Commission Action	Pending Review				

Comments

General Comments **No**

Alternate Language **No**

Related Modifications

Need to provide a definition for balanced ventilation in the Definitions section of the code.

Summary of Modification

Provides a credit for balanced mechanical ventilation.

Rationale

Balanced ventilation with distribution is a significantly more effective means of providing outdoor air. It provides improved air quality at a lower air change rate thereby reducing part load humidity problems and related mold issues.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

Reduces mold and indoor air quality problems and saves energy.

Impact to building and property owners relative to cost of compliance with code

Reduces mold and indoor air quality problems and saves energy.

Impact to industry relative to the cost of compliance with code

The cost of compliance is approximately $150 to $200. Outside air with a motorized damper is provided to the return side of the air handler. The operation of this outside air is linked to the operation of an existing exhaust fan in the home. This can also be accomplished with a ERV.

Impact to small business relative to the cost of compliance with code

The cost of compliance is approximately $150 to $200. Outside air with a motorized damper is provided to the return side of the air handler. The operation of this outside air is linked to the operation of an existing exhaust fan in the home.

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

Reduces mold problems and improves indoor air quality while reducing energy/utility bills.

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

Reduces mold problems and improves indoor air quality while reducing energy/utility bills.

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

Uses already available equipment manufactured by dozens of suppliers.

Does not degrade the effectiveness of the code

Improves the effectiveness of the code by reducing mold problems and improving indoor air quality while reducing energy/utility bills.

BALANCED VENTILATION. Any combination of concurrently operating mechanical exhaust and mechanical supply whereby the total mechanical exhaust flow rate is within 10% of the total mechanical supply airflow rate.

"No change to Section 403.3.2.1"

Exceptions:

"No change to exception #1"

2. The minimum mechanical ventilation rate determined in accordance with Equation 4-9 shall be reduced by 30% provided that both of the following conditions apply:

-

2.1. A ducted system supplies ventilation air directly to each bedroom and to one or more of the following rooms:

2.1.1. Living room

2.1.2. Dining room

2.1.3. Kitchen

-

2.2. The whole-house ventilation system is a balanced ventilation system.

M7294

Date Submitted	11/16/2018	**Section**	504.4.1	**Proponent**	James Bickford
Chapter	5	**Affects HVHZ**	No	**Attachments**	No

TAC Recommendation Approved as Submitted
Commission Action Pending Review

Comments

General Comments **No** **Alternate Language** **No**

Related Modifications

Summary of Modification

Adds new section 504.4.1 “Exhaust termination outlet and passageway size.”

Rationale

The allowable (calculated) length of the dryer exhaust duct is based on an open (non-restrictive) exhaust terminal. Some exhaust terminals increase resistance due to their inherent design characteristics (path and final opening size). Clarifies section

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

Will help enforcement

Impact to building and property owners relative to cost of compliance with code

Will increase the cost of construction The cost of the vent terminal may be higher.

Impact to industry relative to the cost of compliance with code

Will increase the cost of construction The cost of the vent terminal may be higher.

Impact to small business relative to the cost of compliance with code

Will increase the cost of construction The cost of the vent terminal may be higher.

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

Will increase the cost of construction The cost of the vent terminal may be higher.

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

Will increase the cost of construction The cost of the vent terminal may be higher.

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

Will increase the cost of construction The cost of the vent terminal may be higher.

Does not degrade the effectiveness of the code

Will increase the cost of construction The cost of the vent terminal may be higher.

504.4.1 Exhaust termination outlet and passageway size. The passageway of dryer exhaust duct terminals shall be undiminished in size and shall provide an open area of not less than 12.5 square inches (8,065 sq mm).

M7319

Date Submitted 11/20/2018
Chapter 5
Section 506.3.13.2
Affects HVHZ No
Proponent James Bickford
Attachments No

TAC Recommendation Approved as Submitted
Commission Action Pending Review

Comments

General Comments **No**
Alternate Language **No**

Related Modifications

Summary of Modification

Modifies section 506.3.13.2 “Termination through an exterior wall.” Intent of change is fire safety related. Clarification to show that Exterior openings shall be located in accordance with section 506.3.13.3.

Rationale

The current last sentence implies that outdoor air intakes and windows can be within 3 feet of the exhaust terminal, however Section 506.3.13.3 requires a 10 foot separation for outdoor intakes unless there is a 3 foot vertical separation.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

Will clarify code section and help enforcement

Impact to building and property owners relative to cost of compliance with code

Will not increase the cost of construction

This proposal will not increase the cost of construction because no additional labor, materials, equipment, appliances or devices are mandated beyond what is currently required by the code nor are the code requirements made more stringent.

Impact to industry relative to the cost of compliance with code

Will not increase the cost of construction

This proposal will not increase the cost of construction because no additional labor, materials, equipment, appliances or devices are mandated beyond what is currently required by the code nor are the code requirements made more stringent.

Impact to small business relative to the cost of compliance with code

Will not increase the cost of construction

This proposal will not increase the cost of construction because no additional labor, materials, equipment, appliances or devices are mandated beyond what is currently required by the code nor are the code requirements made more stringent.

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

Does not affect health, safety or welfare of the general public

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

Improves code by clarification

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

Improves code by clarification

Does not degrade the effectiveness of the code

Improves code by clarification

506.3.13.2. Termination through an exterior wall. Exhaust outlets shall be permitted to terminate through exterior walls where the smoke, grease, gases, vapors and odors in the discharge from such terminations do not create a public nuisance or a fire hazard. Such terminations shall not be located where protected openings are required by the *Florida Building Code*. ~~Other exterior openings~~ Such terminations shall be located in accordance with Section 506.3.13.3 and shall not be located within 3 feet ~~(914 mm)~~ of ~~such terminations~~ any opening in the exterior wall.

M7320

Date Submitted	11/19/2018	**Section**	506.3.13.2	**Proponent**	James Bickford
Chapter	5	**Affects HVHZ**	No	**Attachments**	No

TAC Recommendation Approved as Submitted
Commission Action Pending Review

Comments

General Comments **No** **Alternate Language** **No**

Related Modifications

Summary of Modification

Clarifies exhaust outlet termination location

Rationale

Reason: The current last sentence implies that outdoor air intakes and windows can be within 3 feet of the exhaust terminal, however Section 506.3.13.3 requires a 10 foot separation for outdoor intakes unless there is a 3 foot vertical separation. This section has been misinterpreted to allow grease duct terminations to be within 3 feet of an operable window. The real intent of the current last sentence is fire safety related and that intent is preserved in the proposed revision. Exterior openings include all openings in the wall such as fixed (non-openable) fenestration panels. The clearance requirement of Section 506.3.13.3 must not be overlooked.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

None, clarifies termination location requirements

Impact to building and property owners relative to cost of compliance with code

Will not increase the cost of construction

This proposal will not increase the cost of construction because no additional labor, materials, equipment, appliances or devices are mandated beyond what is currently required by the code nor are the code requirements made more stringent.

Impact to industry relative to the cost of compliance with code

Will not increase the cost of construction

This proposal will not increase the cost of construction because no additional labor, materials, equipment, appliances or devices are mandated beyond what is currently required by the code nor are the code requirements made more stringent.

Impact to small business relative to the cost of compliance with code

Will not increase the cost of construction

This proposal will not increase the cost of construction because no additional labor, materials, equipment, appliances or devices are mandated beyond what is currently required by the code nor are the code requirements made more stringent.

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

Will provide guidance on termination location of exhaust.

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

Will provide guidance on termination location of exhaust.

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

Does not discriminate against any materials

Does not degrade the effectiveness of the code

Improves code

Revise as follows:

506.3.13.2. Termination through an exterior wall. Exhaust outlets shall be permitted to terminate through exterior walls where the smoke, grease, gases, vapors and odors in the discharge from such terminations do not create a public nuisance or a fire hazard. Such terminations shall not be located where protected openings are required by the *International Building Code*. ~~Other exterior openings~~ Such terminations shall be located in accordance with Section 506.3.13.3 and shall not be located within 3 feet ~~(914 mm)~~ of ~~such terminations~~ any opening in the exterior wall.

M7321

Date Submitted	11/19/2018	**Section**	507.2.6	**Proponent**	James Bickford
Chapter	5	**Affects HVHZ**	No	**Attachments**	No

TAC Recommendation Approved as Submitted
Commission Action Pending Review

Comments

General Comments **No** **Alternate Language** **No**

Related Modifications

Summary of Modification

Modification of Section 507.2.6 "Clearances for Type I hood."

Rationale

Reason: Type I hoods can be listed to the latest edition of UL710 which now includes testing for clearances to combustibles. There are hoods that are listed for clearances of less than 18 inches, however, the code does not currently recognize this fact and would require 18 inches minimum in all cases. Adding the new exception will allow lesser clearances without having to seek alternative approval from the AHJ.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

Will not increase the cost of construction
This proposal will not increase the cost of construction because no additional labor, materials, equipment, appliances or devices are mandated beyond what is currently required by the code nor are the code requirements made more stringent.

Impact to building and property owners relative to cost of compliance with code

Will not increase the cost of construction
This proposal will not increase the cost of construction because no additional labor, materials, equipment, appliances or devices are mandated beyond what is currently required by the code nor are the code requirements made more stringent.

Impact to industry relative to the cost of compliance with code

Will not increase the cost of construction
This proposal will not increase the cost of construction because no additional labor, materials, equipment, appliances or devices are mandated beyond what is currently required by the code nor are the code requirements made more stringent.

Impact to small business relative to the cost of compliance with code

Will not increase the cost of construction
This proposal will not increase the cost of construction because no additional labor, materials, equipment, appliances or devices are mandated beyond what is currently required by the code nor are the code requirements made more stringent.

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

Will make hoods safer

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

Makes hood installations safer

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

Does not discriminate

Does not degrade the effectiveness of the code

Improves effectiveness of code

Exceptions:

1. *Clearance* shall not be required from gypsum wallboard or ½-inch (12.7 mm) or thicker cementitious wallboard attached to noncombustible structures provided that a smooth, cleanable,nonabsorbentandnoncombustiblematerialisinstalledbetweenthehoodandthe gypsum or cementitious wallboard over an area extending not less than 18 inches (457 mm) in all directions from the hood.
2. Type I hoods listed and labeled for clearances less than 18 inches in accordance withUL710 shall be installed with the clearances specified by suchlistings.

M7323

Date Submitted 11/19/2018
Chapter 5
Section 510.8.1
Affects HVHZ No
Proponent James Bickford
Attachments No
TAC Recommendation Approved as Submitted
Commission Action Pending Review

Comments

General Comments **No**

Alternate Language **No**

Related Modifications

Summary of Modification

Adds new section requiring clean outs on ducts conveying combustible dust.

Rationale

To avoid an accumulation of combustible dust and reduce potential dust deflagration from the accumulation of dusts inside ducts, cleanouts are needed to provide accessible points as part of the housekeeping and inspection. While this hazard is more commonly found in industries that produce heavy combustible dusts [e.g. metal dusts, etc.], the potential accumulation of dusts in ducts exist in all combustible dust producing facilities.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

none

Impact to building and property owners relative to cost of compliance with code

Will increase the cost of construction
The proposed code change will increase the cost of construction since previous editions did not require cleanouts

Impact to industry relative to the cost of compliance with code

Will increase the cost of construction
The proposed code change will increase the cost of construction since previous editions did not require cleanouts

Impact to small business relative to the cost of compliance with code

Will increase the cost of construction
The proposed code change will increase the cost of construction since previous editions did not require cleanouts

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

Will improve safety

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

Strengthens code by requiring cleanouts

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

Does not discriminate

Does not degrade the effectiveness of the code

Improves code

Add new text as follows:

510.8.1 Duct cleanout. Ducts conveying combustible dust as part of a dust collection system shall be equipped with cleanouts that are provided with approved access, pre-designed to be disassembled for cleaning, or engineered for automatic cleanouts. Where provided, cleanouts shall be located at the base of each vertical duct riser and at intervals not exceeding 20 foot in horizontal sections of duct.

M7344

Date Submitted	11/20/2018	**Section**	602.2.1.1	**Proponent**	James Bickford
Chapter	6	**Affects HVHZ**	No	**Attachments**	No

TAC Recommendation Approved as Submitted
Commission Action Pending Review

Comments

General Comments **No** **Alternate Language** **No**

Related Modifications

602.1.2, 602.2.1.3

Summary of Modification

Modification of text for Sections 602.2.1.1 “Wiring”, 602.2.1.2 “Fire sprinkler piping,” and 602.2.1.3 “Pneumatic tubing.” This proposal concerns consistency with the pass/fail criteria for the testing of products from in these sections, and the listing and labeling requirements.

Rationale

Modification of text for Sections 602.2.1.1 “Wiring”, 602.2.1.2 “Fire sprinkler piping,” and 602.2.1.3 “Pneumatic tubing.” This proposal concerns consistency with the pass/fail criteria for the testing of products from in these sections, and the listing and labeling requirements.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

Clarifies section and will make enforcement easier.

Impact to building and property owners relative to cost of compliance with code

Will not increase the cost of construction

Impact to industry relative to the cost of compliance with code

Will not increase the cost of construction

Impact to small business relative to the cost of compliance with code

Will not increase the cost of construction

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

Improves code by providing clarity, positive impact on safety

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

Provides better products

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

Does not discriminate

Does not degrade the effectiveness of the code

Improves code

602.2.1.1 Wiring. Combustible electrical wires and cables and optical fiber cables exposed within a plenum shall be listed and labeled as having a ~~maximum~~ peak optical density ~~of~~ not greater than 0.50 ~~or less~~, an average optical density ~~of~~ not greater than 0.15 ~~or less~~, and a ~~maximum~~ flame spread distance ~~of~~ not greater than 5 feet (1524 mm) ~~or less~~ when tested in accordance with NFPA 262 or shall be installed in metal raceways or metal sheathed cable. Combustible optical fiber and communication raceways exposed within a plenum shall be listed and labeled as having a ~~maximum~~ peak optical density ~~of~~ not greater than 0.5 ~~or less~~, an average optical density ~~of~~ not greater than 0.15 ~~or less~~, and a ~~maximum~~ flame spread distance ~~of~~ not greater than 5 feet (1524 mm) ~~or less~~ when tested in accordance with ~~ANSI/~~UL 2024. Only plenum-rated wires and cables shall be installed in plenum-rated raceways. ~~Electrical wires and cables, optical fiber cables and raceways addressed in this section shall be listed and labeled and shall be installed in accordance with NFPA70.~~

602.2.1.2 Fire sprinkler piping. Plastic fire sprinkler piping exposed within a ~~*plenum*~~ plenum shall be used only in wet pipe systems and shall ~~have~~ be listed and labeled as having a peak optical density not greater than 0.50, an average optical density not greater than 0.15, and a flame spread ~~of~~ distance not greater than 5 feet (1524 mm) when tested in accordance with UL 1887. ~~Piping shall be *listed* and *labeled*.~~

602.2.1.3 Pneumatic tubing. Combustible pneumatic tubing exposed within plenum shall ~~have~~ be listed and labeled as having a peak optical density not greater than 0.50, an average optical density not greater than 0.15, and a flame spread ~~of~~ distance not greater than 5 feet (1524 mm) when tested in accordance with UL 1820. ~~Combustible pneumatic tubing shall be *listed* and *labeled*~~

M7346

Date Submitted	11/20/2018	**Section**	602.2.1.6	**Proponent**	James Bickford
Chapter	6	**Affects HVHZ**	No	**Attachments**	No

TAC Recommendation Approved as Submitted
Commission Action Pending Review

Comments

General Comments No

Alternate Language No

Related Modifications

602.2.1.6(NEW) 602.2.1.6.1, 602.2.1.6.2, 602.2.1.6.3

Summary of Modification

Entirely replaces Section 602.2.1.6 “Foam plastic insulation in plenums as interior finish or interior trim”. Deletes sections 602.2.1.6.1, 602.2.1.6.2, 602.2.1.6.3.

Rationale

The changes bring needed clarification regarding the approved barriers and corresponding flame spread and smoke-developed requirements for foam plastic used in plenums.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

Adds clarity

Impact to building and property owners relative to cost of compliance with code

Will not increase the cost of construction

No cost increase. This code proposal revises existing requirements without technical changes.

Impact to industry relative to the cost of compliance with code

Will not increase the cost of construction

No cost increase. This code proposal revises existing requirements without technical changes.

Impact to small business relative to the cost of compliance with code

Will not increase the cost of construction

No cost increase. This code proposal revises existing requirements without technical changes.

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

Improves safety by assuring proper materials are used.

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

Strengthens code by adding clarity

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

Does not discriminate

Does not degrade the effectiveness of the code

Strengthens code

~~**602.2.1.6 Foam plastic insulation.** Foam plastic insulation used in plenums as interior wall or ceiling finish or as interior trim shall exhibit a flame spread index of 75 or less and a smoke-developed index of 450 or less when tested in accordance with ASTM E 84 or UL 723 and shall also comply with one or more of Sections 602.2.1.6.1, 602.2.1.6.2 and 602.2.1.6.3.~~

Add new text as follows:

602.2.1.6 Foam plastic in plenums as interior finish or interior trim. Foam plastic in plenums used as interior wall or ceiling finish or interior trim, shall exhibit a flame spread index of 25 or less and a smoke-developed index of 50 or less when tested in accordance with ASTM E84 or UL 723 at the maximum thickness and density intended for use, and shall be tested in accordance with NFPA286 and meet the acceptance criteria of Section 803.1.2 of the *Florida Building Code.*

Exceptions:

1. Foam plastic in plenums used as interior wall or ceiling finish or interior trim, shall exhibit a flame spread index of 75 or less and a smoke-developed index of 450 or less when tested in accordance with ASTM E84 or UL 723 at the maximum thickness and density intended for use, where it is separated from the airflow in the plenum by a thermal barrier complying with Section 2603.4 of the *Florida Building Code*.
2. Foam plastic in plenums used as interior wall or ceiling finish or interior trim, shall exhibit a flame spread index of 75 or less and a smoke-developed index of 450 or less when tested in accordance with ASTM E84 or UL 723 at the maximum thickness and density intended for use, where it is separated from the airflow in the plenum by corrosion-resistant steel having a base metal thickness of not less than 0.0160 inch (0.4mm).
3. Foam plastic in plenums used as interior wall or ceiling finish or interior trim, shall exhibit a flame spread index of 75 or less and a smoke-developed index of 450 or less when tested in accordance with ASTM E84 or UL 723 at the maximum thickness and density intended for use, where it is separated from the airflow in the plenum by not less than a 1 inch (25mm) thickness of masonry orconcrete.

Delete without substitution:

~~**602.2.1.6.1 Separation required.** The foam plastic insulation shall be separated from the plenum by a thermal barrier complying with Section 2603.4 of the *Florida Building Code* and shall exhibit a flame spread index of 75 or less and a smoke-developed index of 450 or less when tested in accordance with ASTM E 84 or UL 723 at the thickness and density intended foruse.~~

~~**602.2.1.6.2 Approval.** The foam plasticinsulationshallexhibitaflamespreadindexof25orlessanda smoke-developed index of 50 or less when tested in accordance with ASTM E 84 or UL 723 at the thickness and density intended for use and shall meet the acceptance criteria of Section 803.1.2of the *Florida Building Code* when tested in accordance with NFPA 286.~~

M7386

Date Submitted	11/21/2018	**Section**	602.2.1.7	**Proponent**	James Bickford
Chapter	6	**Affects HVHZ**	No	**Attachments**	No
TAC Recommendation	Approved as Submitted				
Commission Action	Pending Review				

Comments

General Comments **No** **Alternate Language** **No**

Related Modifications

Summary of Modification

Modification of text for Section 602.2.1.7 “Plastic plumbing piping and tubing.” Adds new standard UL 2846-14,

Rationale

1. Clarifies that this section is only applicable to plastic piping and tubing exposed within a plenum, using wording similar to Section 602.2.1.3.
2. Makes grammatical revisions for consistency.
3. Allows an option for water distribution piping and tubing to be listed to the UL 2846 criteria noted.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

Adds clarity to the code

Impact to building and property owners relative to cost of compliance with code

Will not increase the cost of construction
This proposal provides an alternative method for evaluating plastic water distribution system piping and tubing.

Impact to industry relative to the cost of compliance with code

Will not increase the cost of construction
This proposal provides an alternative method for evaluating plastic water distribution system piping and tubing.

Impact to small business relative to the cost of compliance with code

Will not increase the cost of construction
This proposal provides an alternative method for evaluating plastic water distribution system piping and tubing.

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

Improves health, safety and welfare

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

Strengthens code by adding new standard

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

Does not discriminate

Does not degrade the effectiveness of the code

Improves effectiveness of the code.

602.2.1.7 Plastic plumbing ~~pipe~~ piping and ~~tube~~ tubing

Plastic piping and tubing used in plumbing systems shall be listed and labeled as having ~~and shall exhibit~~ a flame spread index of not ~~more~~ greater than 25 and a smoke-developed index of not more than 50 when tested in accordance with ASTM E84 or UL 723.

> **Exception:** Plastic water distribution piping and tubing listed and labeled in accordance with UL2846 as having a peak optical density not greater than 0.50, an average optical density not greater than 0.15, and a flame spread distance not greater than 5 feet (1524 mm), and installed in accordance with its listing.

Add new standard(s) as follows:

UL 2846-14, Fire Test of Plastic Water Distribution Plumbing Pipe for Visible Flame and Smoke Characteristics

M7387

Date Submitted	11/21/2018	**Section**	602.2.1.8	**Proponent**	James Bickford
Chapter	6	**Affects HVHZ**	No	**Attachments**	No

TAC Recommendation Approved as Submitted
Commission Action Pending Review

Comments

General Comments **No** **Alternate Language** **No**

Related Modifications

Summary of Modification

Adds new Section 602.2.1.8 “Pipe and duct insulation within plenums.”

Rationale

Section 602 covers the contents of plenums and section 604 covers insulation of ducts. However, it is quite common to have insulated pipes and/or insulated ducts within plenums. Pipe insulation is not specifically covered by the IMC. Moreover, the potential exists that duct insulation contained within plenums falls through the cracks and is not properly regulated. Moreover, there is also the possibility that section 604 is amended and that would affect pipe or duct insulation contained within plenums.

Note that duct insulation could be applied outside buildings and the requirements may need to be different from duct insulation within plenums. However, the new section will ensure that the fire safety requirements are applied to pipe and duct insulation contained within plenums irrespective of other requirements for exterior insulation of ducts not contained within plenums.

Therefore it is proposed to add the same requirements from Section 604.3 to the new section on pipe and duct insulation within plenums, and, that way, the section addressing materials contained within plenums is independent of the section on materials associated with ducts, whether the ducts are free-standing or within plenums.

Exception 2 to section 602.2.1 does not specifically mention pipe or duct insulation within plenums

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

This is clarification only because fire safety requirements for materials contained within plenums already exist.

Impact to building and property owners relative to cost of compliance with code

Will not increase the cost of construction

Impact to industry relative to the cost of compliance with code

Will not increase the cost of construction

Impact to small business relative to the cost of compliance with code

Will not increase the cost of construction

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

Improves fire safety

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

Improves fire safety

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

Improves fire safety

Does not degrade the effectiveness of the code

Improves fire safety

602.2.1.8 Pipe and duct insulation within plenums. Pipe and duct insulation contained within plenums, including insulation adhesives, shall have a flame spread index of not more than 25 and a smoke developed index of not more than 50 when tested in accordance with ASTM E84 or UL 723, using the specimen preparation and mounting procedures of ASTME 2231. Pipe and duct insulation shall not flame, glow, smolder or smoke when tested in accordance with ASTM C411 at the temperature at which they are exposed in service. The test temperature shall not fall below 250ºF (121ºC) . Pipe and duct insulation shall be listed and labeled.

M7388

Date Submitted	11/21/2018	**Section**	603.5.2	**Proponent**	James Bickford
Chapter	6	**Affects HVHZ**	No	**Attachments**	No
TAC Recommendation	Approved as Submitted				
Commission Action	Pending Review				

Comments

General Comments No

Alternate Language No

Related Modifications

Summary of Modification

Adds new Section 603.5.2 “Phenolic ducts.” Adds new standard “SMACNA Phenolic Duct Construction Standard 1st edition 2015.” Phenolic duct is a new air distribution material.

Rationale

Phenolic duct is a new air distribution material not presently covered in the IMC for commercial systems. The inclusion of the SMACNA Phenolic Duct Construction Standards will address this issue.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

Improves enforcement by adding new standard

Impact to building and property owners relative to cost of compliance with code

Will not increase the cost of construction

The standard provides means/methods for phenolic duct construction.

Impact to industry relative to the cost of compliance with code

Will not increase the cost of construction

The standard provides means/methods for phenolic duct construction.

Impact to small business relative to the cost of compliance with code

Will not increase the cost of construction

The standard provides means/methods for phenolic duct construction.

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

The standard provides means/methods for phenolic duct construction.

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

The standard provides means/methods for phenolic duct construction.

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

The standard provides means/methods for phenolic duct construction.

Does not degrade the effectiveness of the code

The standard provides means/methods for phenolic duct construction.

603.5.2 Phenolic ducts. Nonmetallic phenolic ducts shall be constructed in accordance with the SMACNA Phenolic Duct Construction Standards.

Add new standard(s) as follows:

SMACNA Phenolic Duct Construction Standard 1st edition 2015

M7389

Date Submitted	11/21/2018	**Section**	603.8.2	**Proponent**	James Bickford
Chapter	6	**Affects HVHZ**	No	**Attachments**	No

TAC Recommendation Approved as Submitted
Commission Action Pending Review

Comments

General Comments **No** **Alternate Language** **No**

Related Modifications

Summary of Modification

Modifies Section 603.8.2 “Sealing.” Ducts shall be sealed, secured, and then tested prior to concrete encasement or direct burial.

Rationale

The modification provides the allowable leakage rate and uses existing FECC testing criteria.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

Improves enforcement by clarifying duct leakage allowances

Impact to building and property owners relative to cost of compliance with code

Will increase the cost of construction
This may have a minimal increase in initial cost, but could have potential savings in the long run for buildings utilizing underground duct systems

Impact to industry relative to the cost of compliance with code

Will increase the cost of construction
This may have a minimal increase in initial cost, but could have potential savings in the long run for buildings utilizing underground duct systems

Impact to small business relative to the cost of compliance with code

Will increase the cost of construction
This may have a minimal increase in initial cost, but could have potential savings in the long run for buildings utilizing underground duct systems

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

This change could have potential savings for buildings utilizing underground duct systems

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

Strengthens code by referencing Energy code requirements

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

This change could have potential savings for buildings utilizing underground duct systems

Does not degrade the effectiveness of the code

Strengthens code by referencing Energy code requirements

603.8.2 Sealing. Ducts shall be sealed ~~and,~~ secured and tested prior to ~~pouring the~~ to concrete encasement or direct burial. Ducts shall be leak tested as required by Section C403 of the *Florida Energy Conservation Code*

M7394

Date Submitted	11/21/2018	**Section**	604.11	**Proponent**	James Bickford
Chapter	6	**Affects HVHZ**	No	**Attachments**	No
TAC Recommendation	Approved as Submitted				
Commission Action	Pending Review				

Comments

General Comments **No** **Alternate Language** **No**

Related Modifications

Summary of Modification

Adds exception to Section 604.11 “Vapor retarders”. Proposal adds an option to the vapor retarder requirements for duct insulation of the FMC.

Rationale

The proposal adds an option to the vapor retarder requirements for duct insulation of the FMC.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

None

Impact to building and property owners relative to cost of compliance with code

Will not increase the cost of construction

The proposal adds options for the code; does not add any new mandatory requirements

Impact to industry relative to the cost of compliance with code

Will not increase the cost of construction

The proposal adds options for the code; does not add any new mandatory requirements

Impact to small business relative to the cost of compliance with code

Will not increase the cost of construction

The proposal adds options for the code; does not add any new mandatory requirements

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

Clarifies code

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

The proposal adds options for the code; does not add any new mandatory requirements

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

The proposal adds options for the code; does not add any new mandatory requirements

Does not degrade the effectiveness of the code

The proposal adds options for the code; does not add any new mandatory requirements

1st Comment Period History

M7394-G1

Proponent Jeff Sonne for FSEC **Submitted** 2/14/2019 **Attachments** No

Comment:

Is there any research that shows this will not lead to moisture problems?

604.11 Vapor retarders.

Where ducts used for cooling are externally insulated, the insulation shall be covered with a vapor retarder having a maximum permeance of 0.05 perm [2.87 ng/(Pa • s • m^2)] or aluminum foil having a minimum thickness of 2 mils (0.051 mm). Insulations having a permeance of 0.05 perm [2.87 ng/(Pa • s • m^2)] or less shall not be required to be covered. All joints and seams shall be sealed to maintain the continuity of the vapor retarder.

Exception: A vapor retarder is not required for spray polyurethane foam insulation having a water vapor permeance of not greater than of 3 perm per inch [1722 ng/(s · m2 · Pa)] at the installed thickness.

M7936

Date Submitted	12/14/2018	**Section**	607.4	**Proponent**	Amanda Hickman
Chapter	6	**Affects HVHZ**	No	**Attachments**	Yes

TAC Recommendation Approved as Submitted
Commission Action Pending Review

Comments

General Comments **No** **Alternate Language** **No**

Related Modifications

#7919 - fire damper actuation
#7928 - access, inspection and testing
#7938 - NFPA 80 and NFPA 105

Summary of Modification

This modification revises language in section 607.4

Rationale

It is understood that periodic inspection and testing is typically within the scope of the IFC. However, it is not uncommon to alert interested parties to these requirements in the IBC (for example see Chapter 9). In this instance it is important for the design professional to be aware of the inspection and testing requirements since they impact the access requirements contained in the IBC. In addition, the proposal provides design professionals with an alternative of remote testing (as permitted by NFPA 80 and NFPA 105) in situations where adequate access for inspection and testing cannot be provided.
The proposed minimum size of the opening is consistent with NFPA 90A, a mandatory reference in the Florida Fire Prevention Code. If a design professional does not check the Fire Code, without the minimum size of the opening specified in the Building Code a situation could occur in which the design potentially complies with the Building Code but not the Fire Code.
In addition, the inspection and testing of dampers in health care facilities is a regular compliance item for AHCA, CMS, and Accrediting Organizations. From the facility perspective, accessing such dampers for testing raises some concerns with regard to infection control. By providing an option for remote testing, the compliance rate for damper inspection and testing should increase in health care facilities in the State of Florida.

See attached support file.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

The proposed minimum size of the opening is consistent with NFPA 90A, a mandatory reference in the Florida Fire Prevention Code. Therefore, this modification makes code enforcement easier.

Impact to building and property owners relative to cost of compliance with code

This modification will not increase or decrease the cost of construction .
The proposed change will reduce the time for inspecting and servicing fire dampers by 50%.

Impact to industry relative to the cost of compliance with code

This modification will not increase or decrease the cost of construction .
The proposed change will reduce the time for inspecting and servicing fire dampers by 50%.

Impact to small business relative to the cost of compliance with code

This modification will not increase or decrease the cost of construction .
The proposed change will reduce the time for inspecting and servicing fire dampers by 50%.

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

This modification will ensure the safety and welfare of the general public by making it easier to access and identify dampers for proper inspection and maintenance.

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

This modification improves the code by making it easier to access and identify dampers for proper inspection and maintenance.

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

This modification does not discriminate. It provides guidance for the access and inspection of dampers.

Does not degrade the effectiveness of the code

This modification increases the effectiveness of the code by providing access and identification requirements for dampers.

607.4 Access and identification.

~~Fire~~ Access and identification of fire and smoke dampers shall ~~be provided with an *approved* means of access, large enough to permit inspection and maintenance of the damper and its operating parts. The access shall not affect the integrity of fire-resistance-rated assemblies. The access openings shall not reduce the fire-resistance rating of the assembly. Access points shall be permanently identified on the exterior by a label having letters not less than 0.5 inch (12.7 mm) in height reading: FIRE/SMOKE DAMPER, SMOKE DAMPER or FIRE DAMPER. Access doors in ducts shall be tight fitting and suitable for the required duct construction~~ comply with Sections 607.4.1 through 607.4.2.

607.4.1 Access Fires and smoke dampers shall be provided with an approved means of access that is large enough to permit inspection and maintenance of the damper and its operating parts. Dampers equipped with fusible links, internal operators, or both shall be provided with an access door that is not less than 12 inches (305 mm) square or provided with a removable duct section.

607.4.1.1 The access shall not affect the integrity of fire-resistance-rated assemblies. The access openings shall not reduce the fire-resistance-rating of the assembly. Access doors in ducts shall be tight fitting and suitable for the required duct construction.

607.4.1.2 Restricted Access Where space constraints or physical barriers restrict access to a damper for periodic inspection and testing, the damper shall be a single- or multi-blade damper and shall comply with the remote inspection requirements of NFPA 80 or NFPA 105.

607.4.2 Identification Access points shall be permanently identified on the exterior of a label having letters not less than 1/2 inch (12.7 mm) in height reading: FIRE/SMOKE DAMPER, SMOKE DAMPER or FIRE DAMPER.

Rationale for #7936

This proposal was approved by ICC for the 2021 IMC edition. The committee unanimously supported this proposal with the comment "The proposal increases ability to inspect and service dampers. Approval is consistent with recommendation for FS66-18. The proposed text is more enforceable because it states dimensions instead of "large enough."

Fire and smoke dampers are an important part of a HVAC ductwork system, in the event of a fire they are designed to close and prevent the spread of fire and smoke throughout the building duct work system, giving the building occupants enough time to evacuate and also providing the fire department sufficient time to enter the building and extinguish the fire safely. The NFPA requires all fire and smoke dampers be periodically inspected, maintained and tested per their guidelines to assure these dampers function properly in the event of a fire.
The NFPA requires that fire and smoke dampers are inspected and maintained through an access door that provides full unobstructed access to these dampers. These access doors are mounted on the ductwork as close as possible to the damper. Access doors work well for large fire and smoke dampers because the ductwork size is large enough to except an adequate sized access door, the problem is with the smaller fire and smoke dampers, the ductwork is too small to mount an adequate size access door. NFPA 80 addresses this problem by mandating the minimum size access door shall be no smaller than 12 inch square or you must supply a removable ductwork section, this removable section provides the technician performing the inspection with the unobstructed access needed to properly inspect and maintain the smaller fire and smoke dampers. Our concerns are with the smaller fire and smoke dampers, because in many cases the removable ductwork sections for these dampers are not being provided as mandated by the NFPA 80, rather inadequate small access doors are being installed in the ductwork system next to the fire and smoke damper. Small access doors don’t provide the access needed to properly inspect and maintain the fire and smoke dampers. The inadequacies of these access doors is nothing new in the HVAC industry, in many cases when it becomes time for the periodic damper inspections the maintenance technician will ignore and pass over the small fire and smoke dampers knowing that it’s virtually impossible to perform the inspection through the access doors. We are asking for your help in addressing this problem, these fire and smoke dampers are much to important to be ignored, they save lives and countless dollars in property damage, the solutions are known they are just not being implemented.

M8320

Date Submitted 12/15/2018 **Chapter** 6
Section 601.5 **Affects HVHZ** No
Proponent Joseph Lstiburek **Attachments** No
TAC Recommendation Approved as Submitted
Commission Action Pending Review

Comments

General Comments **No** **Alternate Language** **No**

Related Modifications

Summary of Modification

Allow return air from closets

Rationale

Closets are becoming too cold due to increased attic thermal resistance resulting in mold at closet ceilings. Providing air change via return air warms closets and reduces relative humidity reducing the potential for mold.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

Reduces mold and indoor air quality problems

Impact to building and property owners relative to cost of compliance with code

Less than $150 - assuming 3 closets needing returns - 4 inch flex duct to each closet.

Impact to industry relative to the cost of compliance with code

Less than $150 - assuming 3 closets needing returns - 4 inch flex duct to each closet.

Impact to small business relative to the cost of compliance with code

Less than $150 - assuming 3 closets needing returns - 4 inch flex duct to each closet.

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

Reduces mold and indoor air quality problems.

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

Reduces mold and indoor air quality problems.

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

Does not affect current products.

Does not degrade the effectiveness of the code

Improves the effectiveness of the code by addressing a code caused problem.

1st Comment Period History

M8320-G1

Proponent pete quintela **Submitted** 1/14/2019 **Attachments** No

Comment:

This mod is in conflict with FMC 2018, Section 601.5, item #7

1st Comment Period History

M8320-G2

Proponent pete quintela **Submitted** 1/16/2019 **Attachments** No

Comment:

Change original comment from FMC 2018 to FMC 2014

1st Comment Period History

M8320-G3

Proponent	pete quintela	Submitted	1/16/2019	Attachments	No

Comment:

Change reference in my previous comments from FMC 2018, 2014 to the FMC 2017

601.5
Return air openings.
Return air openings for heating, ventilation and air-conditioning systems shall comply with all of the following:

7. Return air shall not be taken from a closet, bathroom, toilet room, kitchen, garage, boiler room, furnace room or unconditioned attic.

Exceptions:

3. Taking return air from a closet is not prohibited where such return air taken from closets shall serve only the closet and may be taken from closets that have no dedicated supply duct. Where return air is taken from a closet smaller than 30 ft2 (2.8 m2) the return air shall be no more than 30 cfm (15 l/s), shall serve only the closet, and shall not require a dedicated supply duct. Where return air is taken from a closet smaller than 30 ft2 (2.8 m2) the closet door shall be undercut a minimum of 1.5 inches (38 mm) or the closet shall include a louvered door or transfer grille with a minimum net free area of 30 inch2 (194 cm2).

M7395

Date Submitted	11/21/2018	**Section**	805.8	**Proponent**	James Bickford
Chapter	8	**Affects HVHZ**	No	**Attachments**	No

TAC Recommendation Approved as Submitted
Commission Action Pending Review

Comments

General Comments **No** **Alternate Language** **No**

Related Modifications

Summary of Modification

Adds new Section 805.8 “Insulation shield.” the code should require insulation shields for factory-built and metal chimneys as they require clearance to insulation and represents a fire hazard when one is not installed.

Rationale

The code currently requires an insulation shield for vents (802.8) to ensure proper clearance to insulation so as not to cause a fire hazard, the code should also require insulation shields for factory-built and metal chimneys as they also require clearance to insulation and represents a fire hazard when one is not installed.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

Clarifies installation proceedures

Impact to building and property owners relative to cost of compliance with code

Will not increase the cost of construction

There technically is no cost impact since the insulation shield should already be installed where needed to ensure a proper and safe installation.

Impact to industry relative to the cost of compliance with code

Will not increase the cost of construction

There technically is no cost impact since the insulation shield should already be installed where needed to ensure a proper and safe installation.

Impact to small business relative to the cost of compliance with code

Will not increase the cost of construction

There technically is no cost impact since the insulation shield should already be installed where needed to ensure a proper and safe installation.

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

Provides safe installation practice

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

Clarifies need for shielding

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

Does not discriminate

Does not degrade the effectiveness of the code

Improves effectiveness of the code

805.8 Insulation shield Where factory-built chimneys pass through insulated assemblies, an insulation shield constructed of steel having a thickness of not less than 0.0187 inch (0.4712 mm) (No. 26 gage) shall be installed to provide clearance between the chimney and the insulation material. The clearance shall be not less than the clearance to combustibles specified by the chimney manufacturer's installation instructions. Where chimneys pass through attic space, the shield shall terminate not less than 2 inches (51 mm) above the insulation materials and shall be secured in place to prevent displacement. Insulation shields provided as part of a *listed* chimney system shall be installed in accordance with the manufacturer'sinstructions.

M7839

Date Submitted	12/14/2018	**Section**	929	**Proponent**	Amanda Hickman
Chapter	9	**Affects HVHZ**	No	**Attachments**	No

TAC Recommendation Approved as Submitted
Commission Action Pending Review

Comments

General Comments **No** **Alternate Language** **No**

Related Modifications

#7836 (Large-diameter ceiling fan definition)
#7842 (Reference Standards)

Summary of Modification

This proposal adds language regarding the testing and labeling of Large-diameter ceiling fans.

Rationale

This proposal includes language and reference for the appropriate testing standard for these fans when they are installed.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

This modification will help enforcement of the code because these fans will now be required to be labeled.

Impact to building and property owners relative to cost of compliance with code

This modification will not increase cost to building or property owners, as these fans are not mandatory.

Impact to industry relative to the cost of compliance with code

This modification will ensure that the appropriate standards are followed. There will be negligible cost for performing these tests, but the test is only required one time. The cost would be divided over the product line.

Impact to small business relative to the cost of compliance with code

This modification will have no impact to small business. There is only one initial test fee that is incurred by the manufacturer. This cost is so negligible, it will not be passed down to local business or consumers.

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

This modification ensures that these types of fans meet the appropriate safety standards.

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

The sole purpose of this modification is to do just that. It brings in the appropriate standards to ensure their safety and performance.

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

This modification does not discriminate against materials, products, methods, etc. It only brings in the appropriate standards for this specific fan type.

Does not degrade the effectiveness of the code

This modification does not degrade the effectiveness of the code. It improves the effectiveness as it brings in the appropriate standards for this specific fan type.

Add new text as follows:

SECTION 929

LARGE-DIAMETER CEILING FAN

929.1 General. Where provided, large-diameter ceiling fans shall be tested and labeled in accordance with AMCA 230-15, listed and labeled in accordance with UL 507-14, and installed in accordance with the manufacturer's instructions.

M7572

Date Submitted	11/29/2018	**Section**	1202.5	**Proponent**	James Bickford
Chapter	12	**Affects HVHZ**	No	**Attachments**	No

TAC Recommendation Approved as Submitted
Commission Action Pending Review

Comments

General Comments **No**   **Alternate Language** **No**

Related Modifications

Table 1202.5

Summary of Modification

ASSE 1061 Performance Requirements for Push Fit Fittings are already referenced in the FPC.

Rationale

Adds ASSE 1061 Performance Requirements for Push Fit Fittings to this table. This standard is already referenced in the Florida Plumbing Code.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

None

Impact to building and property owners relative to cost of compliance with code

Will not increase the cost of construction Proposal addresses fittings and methods already used in the industry.

Impact to industry relative to the cost of compliance with code

Will not increase the cost of construction Proposal addresses fittings and methods already used in the industry.

Impact to small business relative to the cost of compliance with code

Will not increase the cost of construction Proposal addresses fittings and methods already used in the industry.

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

Proposal addresses fittings and methods already used in the industry.

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

Proposal addresses fittings and methods already used in the industry.

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

Proposal addresses fittings and methods already used in the industry.

Does not degrade the effectiveness of the code

Proposal addresses fittings and methods already used in the industry.

Text of Mod 7572

Revise as follows:

TABLE 1202.5 (1202.5)
HYDRONIC PIPE FITTINGS

MATERIAL	STANDARD (see Chapter 15)
Copper and copper alloys	ASME B16.15; ASME B16.18; ASME B16.22; ASME B16.26; ASTM F 1974; ASTM B16.24; ASME B16.51; <u>ASSE 1061</u>
Ductile iron and gray iron	ANSI/AWWA C110/A21.10; AWWA C153/A21.53; ASTM A 395; ASTM A 536; ASTM F 1476; ASTM F 1548
Ductile iron	ANSI/AWWA C153/A21.53
Gray iron	ASTM A 126
Malleable iron	ASME B16.3
PE-RT fittings	ASTM F 1807; ASTM F 2098; ASTM F 2159; ASTM F 2735; ASTM F 2769; <u>ASSE 1061</u>
PEX fittings	ASTM F 877; ASTM F 1807; ASTM F 2159; <u>ASSE 1061</u>
Plastic	ASTM D 2466; ASTM D 2467; ASTM F 438; ASTM F 439; ASTM F 877; ASTM F 2389; ASTM F 2735
Steel	ASME B16.5; ASME B16.9; ASME B16.11; ASME B16.28; ASTM A 53; ASTM A 106; ASTM A 234; ASTM A 420; ASTM A 536; ASTM A 395; ASTM F 1476; ASTM F 1548

Add new standard(s) as follows:

<u>ASSE 1061-2015 Performance Requirements for Push Fit Fittings</u>

M8008

Date Submitted	12/12/2018	**Section**	1208.1	**Proponent**	James Bickford
Chapter	12	**Affects HVHZ**	No	**Attachments**	No
TAC Recommendation	Approved as Submitted				
Commission Action	Pending Review				

Comments

General Comments **No** **Alternate Language** **No**

Related Modifications

Summary of Modification

Adds exception to 1208.1 “General.” Adds language from PPFA which allows for limited air testing of plastic piping systems

Rationale

PPFA has a new air testing policy, which allows for some limited air testing of plastic piping systems, if a number of conditions are met.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

Will help with proper enforcement of testing requirements. This proposal simply adds another option for air testing some specific piping materials into the code and as such, the option is not requiring that this method be chosen.

Impact to building and property owners relative to cost of compliance with code

None

Impact to industry relative to the cost of compliance with code

None

Impact to small business relative to the cost of compliance with code

None

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

No impact, This proposal simply adds another option for air testing some specific piping materials into the code and as such, the option is not requiring that this method be chosen.

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

Strengthens code by providing new testing methods.

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

This proposal simply adds another option for air testing some specific piping materials into the code and as such, the option is not requiring that this method be chosen.

Does not degrade the effectiveness of the code

This proposal simply adds another option for air testing some specific piping materials into the code and as such, the option is not requiring that this method be chosen.

1208.1 General

Hydronic piping systems shall be tested hydrostatically at one and one-half times the maximum system design pressure, but not less than 100 psi (689 kPa). The duration of each test shall be not less than 15 minutes.

EXCEPTIONS:

1.) With trap seal pull testing, where a completed DWV system is vacuum tested with all of its traps filled with water, and the trap seals are tested with a vacuum typically between one and two inches of water column.

2.) For plastic piping systems specifically designed for use with compressed air or gasses;

• Manufacturers' instructions must be strictly followed for installation, visual inspection, testing and use of the systems,

(and)

• Compressed air or other gas testing is not prohibited by the authority having jurisdiction (AHJ).

3.) When compressed air or other gas pressure testing is specifically authorized by the applicable written instructions of the manufacturers of all plastic pipe and plastic pipe fittings products installed at the time the system is being tested and compressed air or other gas testing is not prohibited by the authority having jurisdiction (AHJ).

The manufacturer should be contacted if there is any doubt as to how a specific system should be tested.

M8011

Date Submitted	12/12/2018	**Section**	1209.3	**Proponent**	James Bickford
Chapter	12	**Affects HVHZ**	No	**Attachments**	No

TAC Recommendation Approved as Submitted
Commission Action Pending Review

Comments

General Comments **No**

Alternate Language **No**

Related Modifications

1209.3.5

Summary of Modification

Modifies text for Section 1209 “Embedded piping.” Adds new Section 1209.3.5 “Cross-linked polyethylene (PEX) joints.”

Rationale

Addition of the PEX joints section is necessary to be consistent with the previous sections and to be consistent with the allowances given in the PE-RT joints section, 1209.3.4.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

Will clarify installation requirements for enforcement

Impact to building and property owners relative to cost of compliance with code

None

Impact to industry relative to the cost of compliance with code

None

Impact to small business relative to the cost of compliance with code

None

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

No impact on health, safety or welfare of the general public.

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

The addition of PEX joints in this particular section of the code is really more editorial in nature as PEX is already addressed in the code but is lacking the same treatment as the other piping materials mentioned in 1209.3.

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

The addition of PEX joints in this particular section of the code is really more editorial in nature as PEX is already addressed in the code but is lacking the same treatment as the other piping materials mentioned in 1209.3.

Does not degrade the effectiveness of the code

The addition of PEX joints in this particular section of the code is really more editorial in nature as PEX is already addressed in the code but is lacking the same treatment as the other piping materials mentioned in 1209.3.

1209.3 Embedded Joints.

Joints of pipe or tubing that are embedded in a portion of the building, such as concrete or plaster, shall be in accordance with the requirements of Sections 1209.3.1 through 1209.3.4 5.

Add new section:

1209.3.5 Cross-linked polyethylene (PEX) joints.

PEX tubing shall be installed in continuous lengths or shall be joined by hydronic fittings listed in Table 1202.5.

M8034

Date Submitted	12/12/2018	**Section**	1402.4	**Proponent**	James Bickford
Chapter	14	**Affects HVHZ**	No	**Attachments**	No

TAC Recommendation Approved as Submitted
Commission Action Pending Review

Comments

General Comments **No** **Alternate Language** **No**

Related Modifications

1402.4.1

Summary of Modification

Modifies text of Section 1402.4 “Roof-mounted collectors,” and 1402.4.1 “Collectors mounted above the roof.”

Rationale

Plastic roof panels are regulated by the Florida Building Code which addresses "light transmitting plastic" roof panels. As light transmitting materials the plastics need to meet the FBC.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

Will help enforcement by clarifying requirements for panels

Impact to building and property owners relative to cost of compliance with code

Will not increase the cost of construction Clarification

Impact to industry relative to the cost of compliance with code

Will not increase the cost of construction Clarification

Impact to small business relative to the cost of compliance with code

Will not increase the cost of construction Clarification

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

Clarification only

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

Clarification only

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

Clarification only

Does not degrade the effectiveness of the code

Clarification only

1402.4Roof-mounted collectors.

Roof-mounted solar collectors that also serve as a roof covering shall conform to the requirements for roof coverings in accordance with the *Florida Building Code, Building*.

Exception: The use of plastic solar collector covers shall be limited to those *approved* light transmitting plastics meeting the requirements for plastic roof panels in the *Florida Building Code, Building*.

1402.4.1Collectors mounted above the roof.

Where mounted on or above the roof covering, the collector array and supporting construction shall be constructed of noncombustible materials or fire-retardant-treated wood conforming to the *Florida Building Code, Building* to the extent required for the type of roof construction of the building to which the collectors are accessory.

Exception: The use of plastic solar collector covers shall be limited to those *approved* light transmitting plastics meeting the requirements for plastic roof panels in the *Florida Building Code, Building*.

M7842

Date Submitted	12/14/2018	**Section**	1	**Proponent**	Amanda Hickman
Chapter	15	**Affects HVHZ**	No	**Attachments**	Yes
TAC Recommendation	Approved as Submitted				
Commission Action	Pending Review				

Comments

General Comments **No** **Alternate Language** **No**

Related Modifications

#7839 (Large-diameter ceiling fan new language)
#7836 (Large-diameter ceiling fan Fans definition)

Summary of Modification

AMCA 230-15 Reference Standard UL 507-2014 Reference Standard

Rationale

This modification adds the appropriate test and safety standards to the code for these types of fans.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

This modification adds the appropriate reference standards to the code. It also adds a label requirement, which will make code enforcement easier.

Impact to building and property owners relative to cost of compliance with code

No. Reputable manufacturers of these fans already test and install in accordance with these standards, insuring that property owners will get safe and reliable products.

Impact to industry relative to the cost of compliance with code

There is a slight cost for testing and complying with these standards to manufacturers. However, reputable. manufacturers are already doing this anyway. Also, once that product type is tested, that cost is divided over all of the fans produced.

Impact to small business relative to the cost of compliance with code

No. Any additional cost would not be passed down to small business.

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

This modification adds the appropriate safety and test standards for these types of products.

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

This modification adds the appropriate safety and test standards for these types of products.

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

No. These standards only require that safe products demonstrate their compliance.

Does not degrade the effectiveness of the code

No. This modification makes the code more effective, as it adds a label requirement in accordance with the appropriate reference standards.

Add new reference standards as follows:

ANSI/AMCA 230-15:

Laboratory Methods of Testing Air Circulating Fans for Rating and Certification

UL 507-2014:

Standard for Electric Fans

ANSI/AMCA Standard 230-15

Laboratory Methods of Testing Air Circulating Fans for Rating and Certification

An American National Standard
Approved by ANSI on October 16, 2015

AIR MOVEMENT AND CONTROL ASSOCIATION INTERNATIONAL INC.

The International Authority on Air System Components

ANSI/AMCA Standard 230-15

Laboratory Methods of Testing Air Circulating Fans for Rating and Certification

Air Movement and Control Association International
30 W. University Drive
Arlington Heights, Illinois
60004

AMCA Publications

Authority AMCA Standard 230-15 was adopted by the membership of the Air Movement and Control Association International Inc. on September 4, 2015, and approved by the American National Standards Institute on October 16, 2015.

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Related AMCA Documents

Related Publications	AMCA Publication 11, *Certified Ratings Program — Operating Manual*
	AMCA Publication 211, *Certified Ratings Program — Product Rating Manual for Fan Air Performance*
	AMCA Publication 311, *Certified Ratings Program — Product Rating Manual for Fan Sound Performance*
Related Standards	ANSI/AMCA Standard 300, *Reverberant Room Method for Sound Testing of Fans*
	ANSI/AMCA Standard 210, *Laboratory Methods of Testing Fans for Aerodynamic Performance Rating*

Contents

Laboratory Methods of Testing
Air Circulating Fans for Rating and Certification

1. Purpose

The purpose of this standard is to establish uniform methods for laboratory testing of air circulating fans to determine performance (forward or reverse flow) in terms of airflow rate for rating, certification or guarantee purposes.

2. Scope

This standard shall be used as the basis for testing air circulating fan heads, ceiling fans, box fans, table fans, portable personnel coolers or other air circulating devices when air is used as the test gas. The diameter of the fan being tested shall be limited by the minimum dimensions as shown in the applicable test figures.

Blowers, exhausters, compressors, positive displacement machines and positive pressure ventilators are not within the scope of this standard.

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

3. Units of Measurement

3.1 System of units
SI units (The International System of Units, *Le Systéme 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.

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

3.3 Velocity
The SI unit of velocity is the meter per second (m/s); the I-P unit of velocity is the foot per minute (fpm).

3.4 Thrust
The SI unit of thrust is the newton (N); the I-P unit is the pound force (lbf).

3.5 Pressure
The SI unit of pressure is the pascal (Pa). The I-P unit of pressure is either the inch water gauge (in. wg) or the inch mercury (in. Hg). Values in mm Hg or in 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-millimeter column of mercury at 0 °C under standard gravity in a vacuum.

3.6 Power
The unit of input power is the watt (W).

3.7 Speed
The unit of rotational speed is the revolution per minute (rpm).

3.8 Gas properties
The SI unit of density is the kilogram per cubic meter (kg/m^3); the I-P unit of density is the pound mass per cubic foot (lbm/ft^3). The SI unit of viscosity is the pascal-second, (Pa-s); the I-P unit of viscosity is the pound mass per foot-second (lbm/ft-s). The SI unit of gas constant is the joule per kilogram-kelvin (J/kg-K); the I-P unit of gas constant is the foot-pound force per pound-mass-degree Rankine (ft-lb/(lbm•°R)).

3.9 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.

3.10 Physical constants
The SI value of standard gravitational acceleration shall be taken as 9.80665 m/s^2, which corresponds to mean sea level at 45° latitude; the I-P value of standard gravitational

acceleration is 32.1740 ft/s^2, which corresponds to mean sea level at 45° latitude [1]. The SI density of distilled water at saturation pressure shall be taken as 998.278 kg/m^3 at 20°C; the I-P value is 62.3205 lbm/ft^3 at 68 °F [2]. The density of mercury at saturation pressure shall be taken as 13595.1 kg/m^3 at 0 °C; the I-P value is 848.714 lbm/ft^3 at 32°F [2]. The specific weights in kg/m^3 (lbm/ft^3) of these fluids in vacuum under standard gravity are numerically equal to their densities at corresponding temperatures.

4. Symbols and Subscripts

See Table 1.

5. Definitions

5.1 Air circulating fan

A non-ducted fan used for the general circulation of air within a confined space. Various types of air circulating fans are defined below.

5.1.1 Air circulating fan head
An assembly consisting of a motor, impeller and guard for mounting on a pedestal having a base and column, wall mount bracket, ceiling mount bracket, I-beam bracket or other commonly accepted mounting means.

5.1.2 Ceiling fan
A fan which is mounted to the ceiling or overhead structure of a building, usually with the fan shaft oriented vertically. The impeller may or may not be guarded.

5.1.3 Personnel cooler
A fan used in shops, factories, etc. Generally supplied with wheels or casters on the housing or frame to aid in portability, and with motor and impeller enclosed in a common guard and shroud.

5.1.4 Box fan
A fan used in an office or residential application and having the motor and impeller enclosed in an approximately square box frame having a handle.

5.1.5 Table fan
A fan intended for use on a desk, table or countertop. The fan may also be provided with the means for mounting to a wall.

5.2 Psychrometrics

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

5.2.2 Wet-bulb temperature
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.

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

5.2.4 Air density
The mass per unit volume of the air.

5.2.5 Standard air
Air with a density of 1.2 kg/m^3 (0.075 lbm/ft^3), a ratio of specific heats of 1.4, a viscosity of 1.8185 × 10^{-5} Pa•s (1.222 × 10^{-5} lbm•s). Air at 20 °C (68 °F), 50% relative humidity and 101.325 kPa (29.92 in. Hg) barometric pressure has these properties, approximately.

5.3 Pressure

5.3.1 Pressure
Pressure is force per unit area. This corresponds to energy per unit volume of fluid.

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

5.3.3 Barometric pressure
The absolute pressure exerted by the atmosphere.

5.4 Force

5.4.1 Load differential
The difference in measured force, using either standard weights or a load cell, when the fan is energized and when it is not energized.

5.5 Fan performance variables

5.5.1 Fan thrust
The reaction force due to the momentum change of the mass flow through the device.

5.5.2 Fan speed
The rotational speed of the impeller.

5.5.3 Power input
The electrical power required to drive the fan and any elements in the drive train which are considered a part of the fan.

Table 1
Symbols and Subscripts

Symbol	Description	SI Unit	I-P Unit
A	Discharge area	m^2	ft^2
D	Diameter	m	ft
E	Voltage	V	V
Eff_{circ}	Efficacy of a circulating fan	$(m^3/s)/W$	cfm/W
F_t	Force due to thrust	N	lbf
ΔF	Load differential	N	lbf
η_o	Overall efficiency	dimensionless	
I	System input current	A	A
L_1	Lever arm length	mm	in.
L_2	Lever arm length	mm	in.
N	Fan speed	rpm	rpm
p_b	Corrected barometric pressure	Pa	in. Hg
p_e	Saturated vapor pressure	Pa	in. Hg
p_p	Partial vapor pressure	Pa	in. Hg
Q_0	Airflow rate	m^3/s	cfm
R	Gas constant	J/(kg•K)	ft-lb/(lbm•°R)
ρ_0	Ambient air density	kg/m^3	lbm/ft^3
ρ_{std}	Standard air density	kg/m^3	lbm/ft^3
t_{d0}	Ambient dry-bulb temperature	°C	°F
t_{w0}	Ambient wet-bulb temperature	°C	°F
t_t	Total temperature	°C	°F
V	Air velocity	m/s	fpm
W_E	Electrical input power	W	W

5.5.4 Discharge area
Area of a circle having a diameter equal to the blade tip diameter.

5.6 Miscellaneous

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

5.6.2 Determination
A complete set of measurements for the free-air operation of an air circulator fan. A determination shall, at a minimum, include the following measurements:

Ambient dry bulb temperature in °C (°F)
Ambient wet bulb temperature in °C (°F)
Barometric pressure in mm Hg (in. Hg)
Diameter in meters (feet)
Electrical input voltage in volts
System input current in amps
Electrical input power input in watts
Fan speed in rpm
Load differential in newtons (pounds force)

5.6.3 Test
A series of determinations for one or more points of operation of a fan, e.g., various fan speeds, voltages or frequencies.

6. Instruments and Methods of Measurement

6.1 Accuracy

The specifications for instruments and methods of measurement that 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 [3].

6.1.1 Instrument accuracy
The specifications regarding accuracy correspond to two standard deviations based on an assumed normal distribution. This is frequently how instrument suppliers identify accuracy, but that should be verified. The calibration procedures, which are specified below, shall be employed to minimize errors. In any calibration process, the large systematic error of the instrument is exchanged for the

smaller combination of the systematic error of the standard instrument and the random error of the comparison. Instruments shall be set up, calibrated and read by qualified personnel trained to minimize errors.

6.1.2 Measurement uncertainty
It is axiomatic that every test measurement contains some error and that the true value cannot be known because the magnitude of the error cannot be determined exactly. However, it is possible to perform an uncertainties analysis to identify a range of values within which the true value probably lies. A probability of 95% has been chosen as acceptable for this standard.

The standard deviation of random errors can be determined by statistical analysis of repeated measurements. No statistical means are available to evaluate systematic errors, so these must be estimated. The estimated upper limit of a systematic error is called the systematic uncertainty and, if properly estimated, it will contain the true value 99% of the time. The two standard deviation limit of a random error has been selected as the random uncertainty. Two standard deviations yield 95% probability for random errors.

6.1.3 Uncertainty of a result
The results of a fan test are the various fan performance variables listed in Section 5.5. Each result is based on one or more measurements. The uncertainty in any result can be determined from the uncertainties in the measurement. It is best to determine the systematic uncertainty of the result and then the random uncertainty of the result before combining them into the total uncertainty of the result. This may provide clues on how to reduce the total uncertainty. When the systematic uncertainty is combined in quadrature with the random uncertainty, the total uncertainty will give 95% coverage. In most test situations, it is wise to perform a pre-test uncertainties analysis to identify potential problems. A pre-test uncertainties analysis is not required for each test covered by this standard because it is recognized that most laboratory tests for rating are conducted in facilities where similar tests are repeatedly run. Nevertheless, a pre-test analysis is recommended as is a post-test analysis. The simplest form of analysis is a verification that all accuracy and calibration specifications have been met. The most elaborate analysis would consider all the elemental sources of error including those due to calibration, data acquisition, data reduction, calculation assumptions, environmental effects and operational steadiness.

6.2 Airflow rate

6.2.1 Airflow rate
Airflow rate shall be calculated from the thrust, standard density and physical diameter of the fan using equations Eq. 9.6 SI or Eq. 9.6 I-P (see Section 9.4).

6.2.2 Thrust
The thrust shall be calculated from the measured load differential, ambient air density and physical dimensions of the test setup. Load differential shall be determined using either standard weights or a load cell.

6.2.2.1 Standard weights
Standard weights shall be accurate within ± 0.5%. Weights shall be added to the test apparatus to balance the apparatus (see figures) prior to energizing the fan. After the fan is energized, additional weights are added to balance the fixture. Load differential is the difference between these two weights.

6.2.2.2 Load cell
Load cell measurements shall be accurate within ± 0.5% of the measured value. Load cell measurements shall be recorded at a minimum of one-second intervals through a 120-second period of test, and the mean of the measured values reported.

6.2.3 Dimensional measurements

6.2.3.1 Lever arm lengths
Lever arm lengths, L_1 and L_2, shall be measured to within ± 0.5% of the actual value (See Test Figures 2A, 2B1 and 2B2).

6.2.3.2 Diameter
Diameter, D, is the outermost impeller blade tip diameter. It shall be measured to within ± 0.5% of the actual value (See Test Figures 1, 2A, 2B1, 2B2, 3A and 3B).

6.3 Power

Input power shall be determined from the measurement of active (real) power in all phases simultaneously by an electric meter.

6.3.1 Meters
Electrical meters shall have certified accuracies of ± 1% of observed reading.

6.3.2 Calibration
Each voltmeter, ammeter and wattmeter shall be calibrated over the range of values to be encountered during testing against a meter 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.

All electrical equipment used to measure fan performance shall be calibrated with uncertainties by an ISO 17025 accredited calibration laboratory.

6.3.3 Averaging
The power required by a fan is never strictly steady; therefore, to obtain a true reading, either the instrument must be damped or the readings must be averaged in a suitable manner. The power measurement shall be recorded at a minimum of one-second intervals through a 120-second period of test and the mean of the measured values reported. Multipoint or continuous record averaging can be accomplished with instruments and analyzers designed for this purpose.

6.4 Speed

The speed measurement shall be recorded at a minimum of one-second intervals through a 120-second period of test and the mean of the measured values reported. Speed shall be measured with a revolution counter and chronometer, a stroboscope and chronometer, a precision instantaneous tachometer, an electronic counter-timer or any other device which has a demonstrated accuracy of ± 0.5% of the value being measured.

6.4.1 Strobe
A stroboscopic device triggered by the line frequency of a public utility is considered a primary instrument and need not be calibrated if it is maintained in good condition.

6.4.2 Chronometer
A watch with a sweep second hand or digital display that keeps time within five seconds per day is considered a primary instrument.

6.4.3 Other Devices
The combination of a line frequency strobe and chronometer shall be used to calibrate all other speed measuring devices. Any speed measurement device that affects fan operating speed shall not be used.

6.5 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%.

6.5.1 Thermometers
Both wet and dry-bulb temperatures shall be measured with thermometers or other instruments with demonstrated accuracies ± 1 °C (± 2 °F) and resolution of 0.5 °C (1 °F) or finer.

6.5.1.1 Calibration
Thermometers shall be calibrated with uncertainties over the range of temperatures to be encountered during testing against a thermometer with a calibration by an ISO 17025 accredited calibration laboratory that is traceable to NIST or other national physical measures recognized as equivalent by NIST.

6.5.1.2 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) [4]. The dry-bulb thermometer shall be mounted upstream of the wet-bulb thermometer so its reading will not be depressed.

6.5.2 Barometers
The barometric pressure shall be measured with a mercury column barometer or other instrument with a demonstrated accuracy ± 1.25 mm Hg. (± 0.05 in. Hg) and readable to 0.25 mm Hg (0.01 in. Hg) or finer.

6.5.2.1 Calibration
Barometers shall be calibrated against a mercury column barometer with a calibration that is traceable to the NIST or other national physical measures recognized as equivalent by NIST. 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.

All equipment used to measure psychometric data shall be calibrated with uncertainties by an ISO 17025 accredited calibration laboratory.

6.5.2.2 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.

7. Equipment and Setups

7.1 Allowable test setups

Six setups are diagrammed in Test Figures 1, 2 and 3. The following shall be used as a guide to the selection of a proper setup.

- Test Figure 1 shall be used for ceiling fans only.
- Test Figures 2A, 2B1 and 2B2 may be used for air circulating fan heads and table fans.
- Test Figures 3A and 3B may be used for personnel coolers and box fans.

7.2 Load cell orientation

In Test Figures 1, 3A and 3B the axis of the load cell shall be parallel to the axis of the unit under test. In all other setups the axis of the load cell shall be perpendicular to the axis of the unit under test. In all cases, the test apparatus shall provide the means of isolating the load cell from torque loading.

8. Observations and Conduct of Test

8.1 General test requirements

8.1.1 Equilibrium
Equilibrium conditions shall be established before each measurement. To test for equilibrium, trial observations shall be made until steady readings are obtained.

8.1.2 Extraneous airflow
Air velocity in the test room not generated by the test circulator fan shall not exceed 0.25 m/s (50 fpm) prior to, during and after the test. Velocity measurements shall be taken immediately before and immediately after the test to ensure that this condition is met.

Location of extraneous airflow measurement shall be directly under the center of the fan at an elevation of 1701.8 mm (67 in.) above floor.

8.2 Data to be recorded

8.2.1 Test unit
The description of the test unit and its nameplate data shall be recorded.

8.2.2 Test setup
The description of the test setup including specific dimensions shall be recorded and included in the final report. Reference shall be made to the test figures in this standard. Alternatively, a drawing or annotated photograph of the setup may be attached to the data.

8.2.3 Instruments
The instruments and apparatus used in the test shall be listed. Names, model numbers, serial numbers, scale ranges and calibration information shall be recorded.

8.2.4 Test data
Test data for each determination shall be recorded. Readings shall be made simultaneously whenever possible. For all tests, ambient dry-bulb temperature (t_{d0}), ambient wet-bulb temperature (t_{w0}), ambient barometric pressure (p_b), fan diameter (D), load differential (ΔF), fan speed (N), electrical input power (W_E), voltage input (E), date, digital readout, calibration, resolution, units of force and system input current (I) shall be recorded.

For fans with variable speed, performance data shall be captured and reported in five speeds (20, 40, 60, 80 and 100 percent of maximum speed) evenly spaced throughout the speed range. If there are less than five speeds available, the performance of all speeds shall be measured.

8.2.5 Personnel
The names of test personnel shall be listed with the data for which they are responsible.

9. Calculations

9.1 Calibration correction

Calibration corrections, when required, shall be applied to individual readings before averaging or other calculations. Calibration corrections need not be made if the correction is smaller than one half the maximum allowable error as specified in Section 6.

9.2 Ambient air density

The density of ambient air (ρ_0) shall be determined from measurements, taken at the time of testing in the general test area, of dry-bulb temperature (t_{d0}), wet-bulb temperature (t_{w0}), and barometric pressure (p_b) using the following formulae [5].

$$p_e = 3.25t_{w0}^2 + 18.6t_{w0} + 692 \qquad \text{Eq. 9.1 SI}$$

$$p_e = \left(2.96\times10^{-4}\right)t_{w0}^2 - \left(1.59\times10^{-2}\right)t_{w0} + 0.41 \qquad \text{Eq. 9.1 I-P}$$

$$p_p = p_e - p_b\left(\frac{t_{d0} - t_{w0}}{1500}\right) \qquad \text{Eq. 9.2 SI}$$

$$p_p = p_e - p_b\left(\frac{t_{d0} - t_{w0}}{2700}\right) \qquad \text{Eq. 9.2 I-P}$$

$$\rho_0 = \left(\frac{p_b - 0.378p_p}{R\left(t_{d0} - 273.15\right)}\right) \qquad \text{Eq. 9.3 SI}$$

$$\rho_0 = 70.73\left(\frac{p_b - 0.378p_p}{R\left(t_{d0} + 459.67\right)}\right) \qquad \text{Eq. 9.3 I-P}$$

Equation 9.1 is approximately correct for p_e for a range of t_{w0} between 4 °C and 32 °C (40 °F and 90 °F). More precise values of p_e can be obtained from the ASHRAE Handbook of Fundamentals [6]. The gas constant (R) may be taken as 287 J/(kg•K) (53.35 ft lb/(lbm•°R) for air.

9.3 Thrust

Thrust shall be calculated according to the following:
For Test Figures 1, 3A and 3B:

$$F_t = \Delta F\left(\frac{\rho_{std}}{\rho_0}\right) \qquad \text{Eq. 9.4}$$

For Test Figures 2A, 2B1 and 2B2:

$$F_t = \Delta F \left(\frac{L_2}{L_1}\right)\left(\frac{\rho_{std}}{\rho_0}\right) \quad \text{Eq. 9.5}$$

Where:

F_t = Force due to thrust, N (lbf)
L_1 = Lever arm length, mm (in.)
L_2 = Lever arm length, mm (in.)
ΔF = Load differential, N (lbf)
ρ_0 = Ambient air density, kg/m^3 (lbm/ft^3)
ρ_{std} = Standard air density, 1.2 kg/m^3 (0.075 lbm/ft^3)

9.4 Airflow rate

The velocity distribution downstream of a circulator fan is determined by a variety of factors, including the aerodynamic design of the fan. It is beyond the scope of this standard to measure, predict or describe details of this velocity distribution. The airflow rate associated with the calculated thrust shall also be calculated as:

$$Q_0 = \sqrt{\frac{AF_t}{\rho_{std}}} \quad \text{Eq. 9.6 SI}$$

$$Q_0 = 340.3\sqrt{\frac{AF_t}{\rho_{std}}} \quad \text{Eq. 9.6 I-P}$$

Where:

Q_0 = Airflow rate, m^3/s (cfm)
F_t = Thrust, N (lb)
A = $\pi(D/2)^2$, m^2 (ft^2)
ρ_{std} = Standard air density, 1.2 kg/m^3 (0.075 lbm/ft^3)

9.5 Fan overall efficiency

9.5.1 Overall efficiency
The overall efficiency, η_o, shall be calculated from the calculated thrust, F_t, and input electrical power, W_E, using the following equations:

$$\eta_o = \frac{\frac{1}{2}\frac{\rho_0}{\rho_{std}}\sqrt{\frac{F_t^3}{A\rho_{std}}}}{W_E} \quad \text{Eq. 9.7 SI}$$

$$\eta_o = \frac{3.845\frac{\rho_0}{\rho_{std}}\sqrt{\frac{F_t^3}{A\rho_{std}}}}{W_E} \quad \text{Eq. 9.7 I-P}$$

Where:

F_t = Thrust, N (lbf)
A = Discharge area, m^2 (ft^2)
W_E = Electrical input power, watt
ρ_0 = Ambient air density, kg/m^3 (lbm/ ft^3)
ρ_{std} = Standard air density, 1.2 kg/m^3 (0.075 lbm/ft^3)

9.6 Circulator fan efficacy

9.6.1 Efficacy
The efficacy of a circulator fan shall be expressed in cubic meters per second per watt [(m^3/s)/W] or cubic feet per minute per watt (cfm/W).

$$Eff_{circ} = \frac{Q_0}{W_E} \quad \text{Eq. 9.8}$$

Where:

Q_0 = Fan airflow rate m^3/s (cfm)
W_E = Electrical input power, watt

10. Report and Results of Test

The report of a laboratory test of a fan shall include object, results, test data, and descriptions of the test fan, test instruments and personnel as outlined in Section 8. At a minimum, the report shall include the following items:

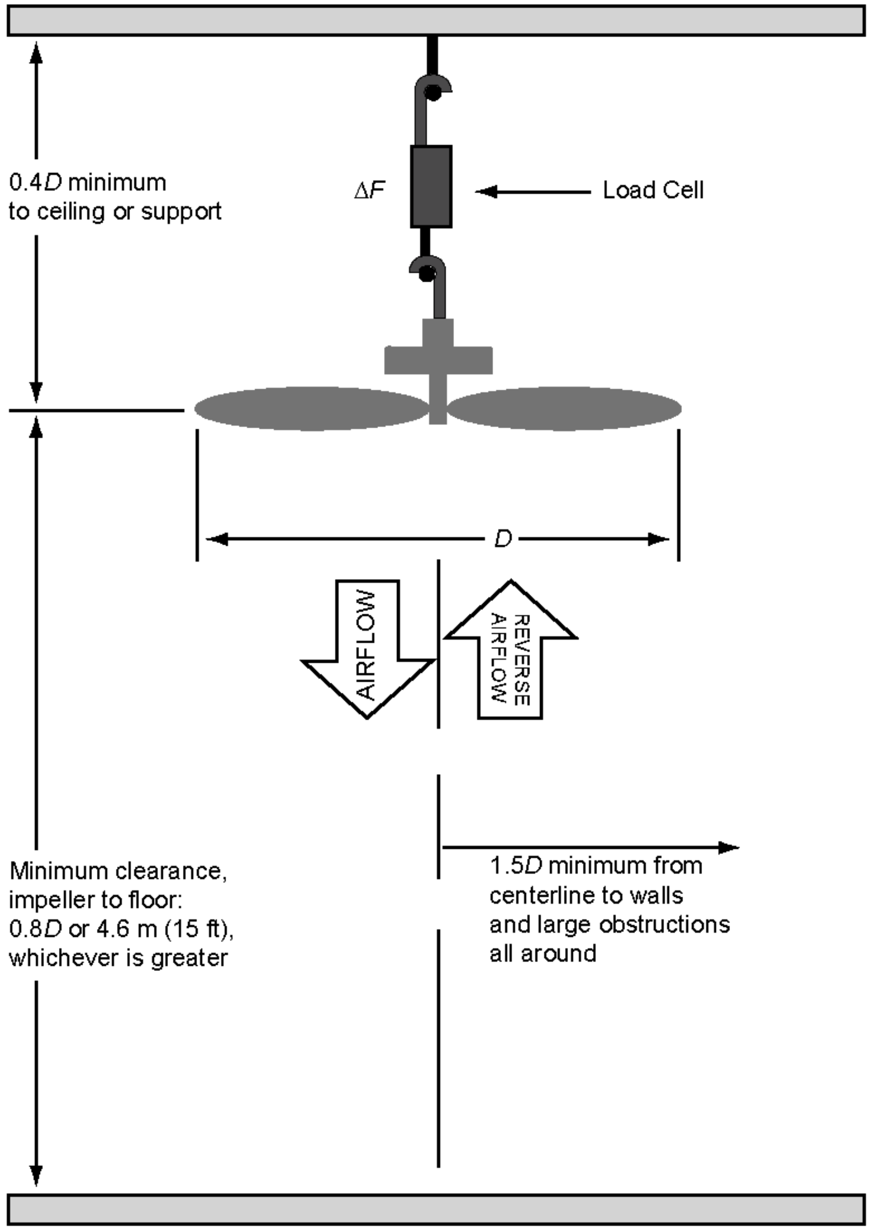
General Test Information:
Laboratory name
Laboratory address
Date of testing
Test number
Personnel performing testing
Air circulating fan type
Test setup (test figure number)
Room dimensions
Minimum clearances to walls, floor, and ceiling or support (per applicable test figure)
Lever arm length 1 (if applicable)
Lever arm length 2 (if applicable)
Fan diameter
Fan model number
Fan serial number
Motor model number
Motor serial number
Motor nameplate data
VSD model number (if applicable)
VSD serial number (if applicable)

Data at test conditions:
Ambient dry bulb temperature
Ambient wet bulb temperature
Ambient barometric pressure
Extraneous airflow before test

Extraneous airflow after test
System input voltage
System input current
System input power
Fan speed
Direction of operation (forward or reverse flow)
Load differential

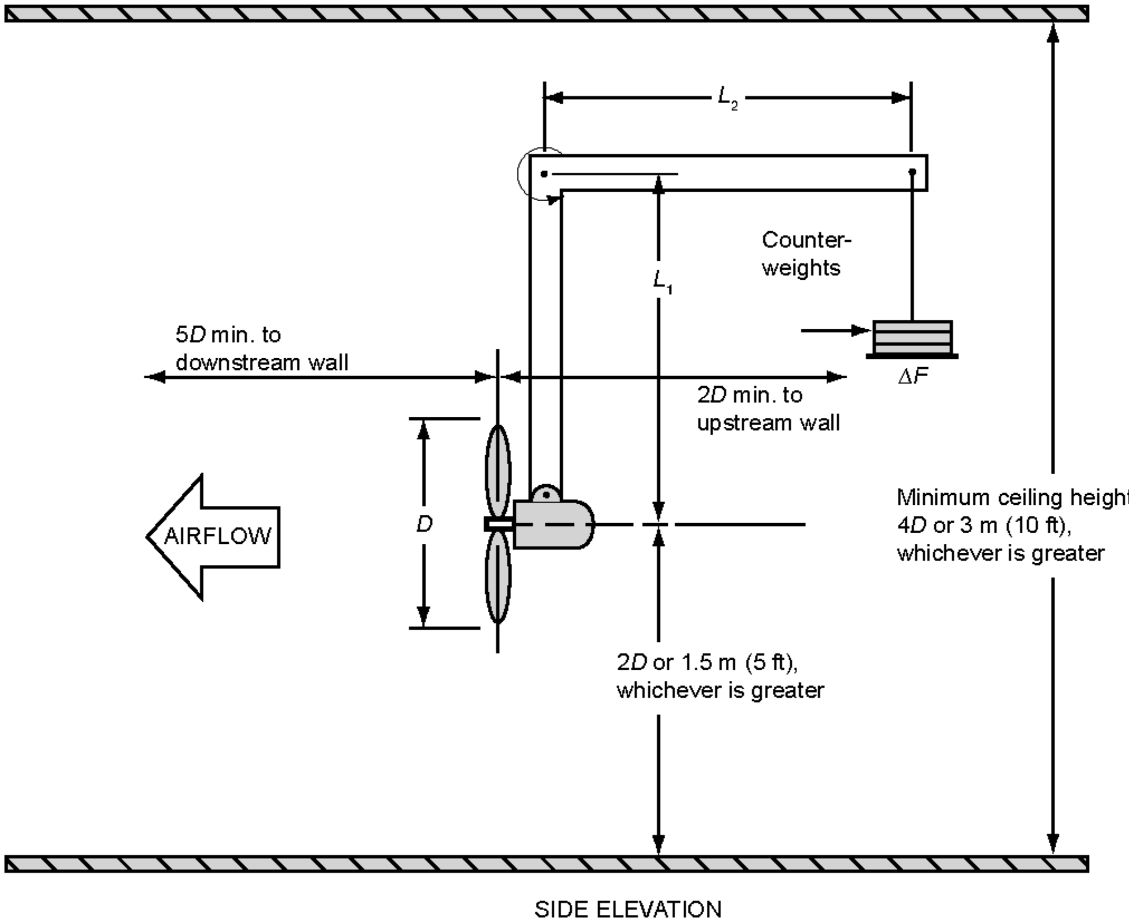
Calculated values:
Fan discharge area
Ambient air density
Percent of maximum fan speed
Thrust at standard conditions
Airflow rate
Overall efficiency at ambient conditions
Efficacy at ambient conditions

Calibration information (per instrument):
Manufacturer
Model number
Serial number
Scale range
ISO 17025 calibration laboratory
Date of last calibration
Date of next required or scheduled calibration



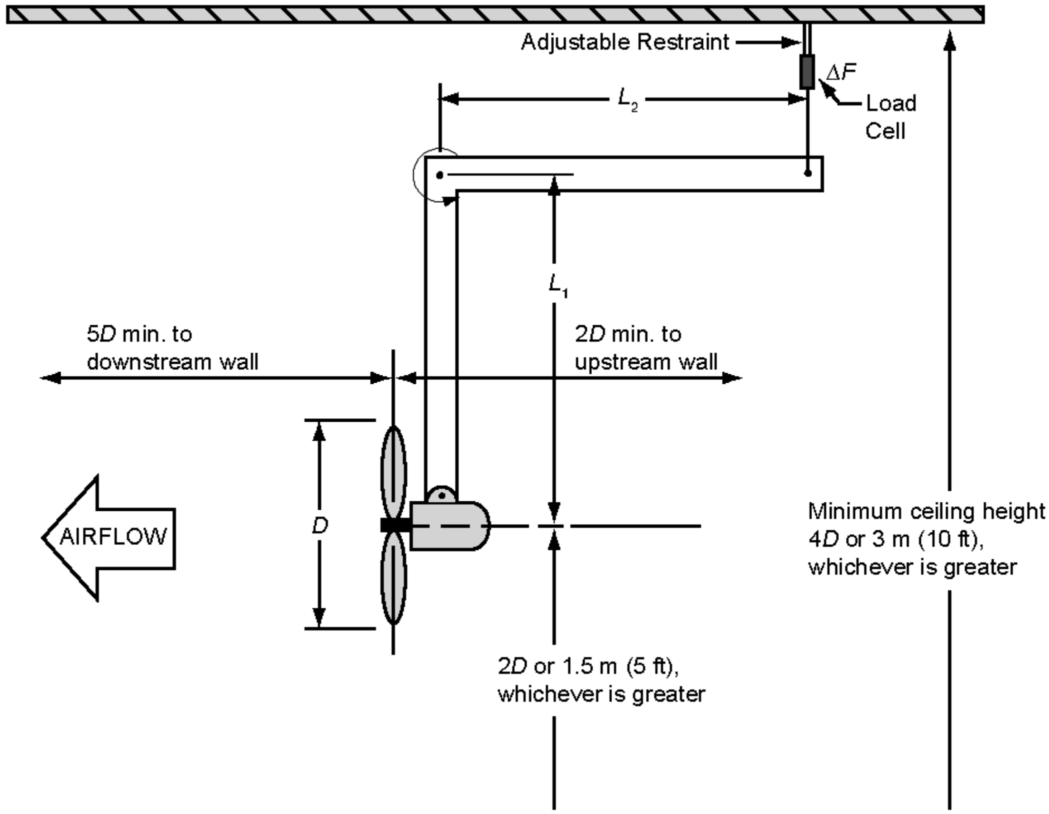
Note:
The vertical centerline through the test setup shall be kept vertical within ± 1° during testing.

Test Figure 1
Vertical Airflow Setup with Load Cell
(Ceiling Fans)



Notes:
1. The horizontal centerline through the test setup shall be kept horizontal within ± 1° during testing.
2. 2D minimum to walls and large obstructions on sides of test unit.

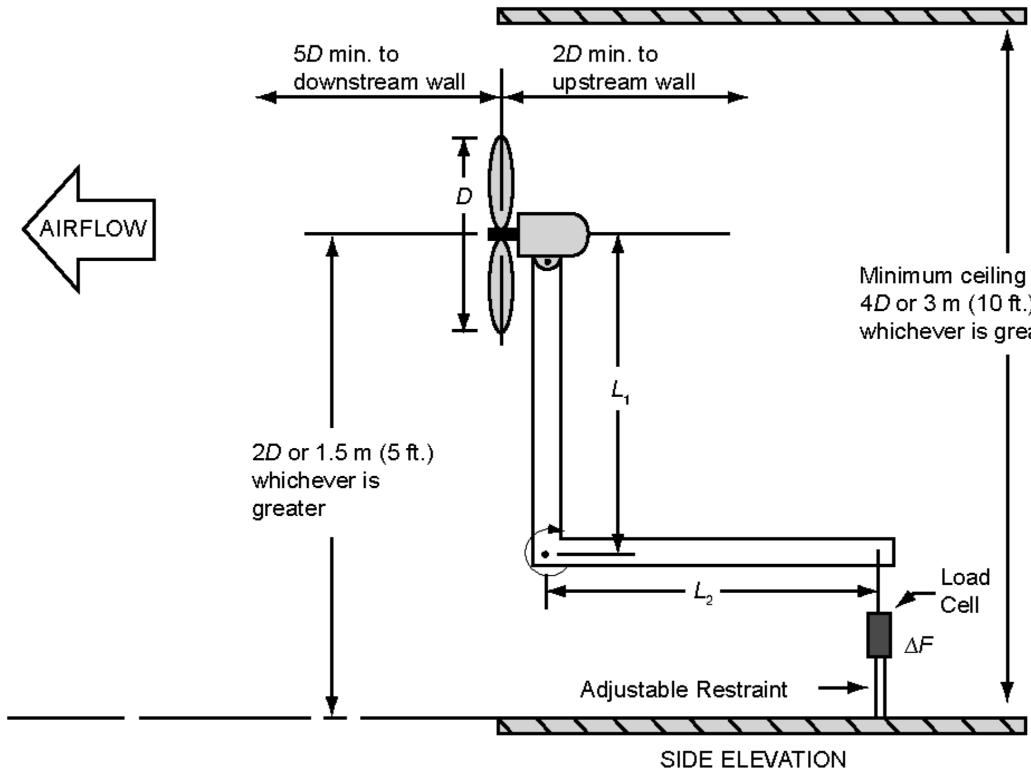
Test Figure 2A
Horizontal Airflow Setup with Counterweights Pivot Above Test Subject
(Air Circulating Fan Heads and Table Fans)



Notes:

1. The horizontal centerline through the test setup shall be kept horizontal within ± 1° during testing.
2. $2D$ minimum to walls and large obstructions on sides of test unit.

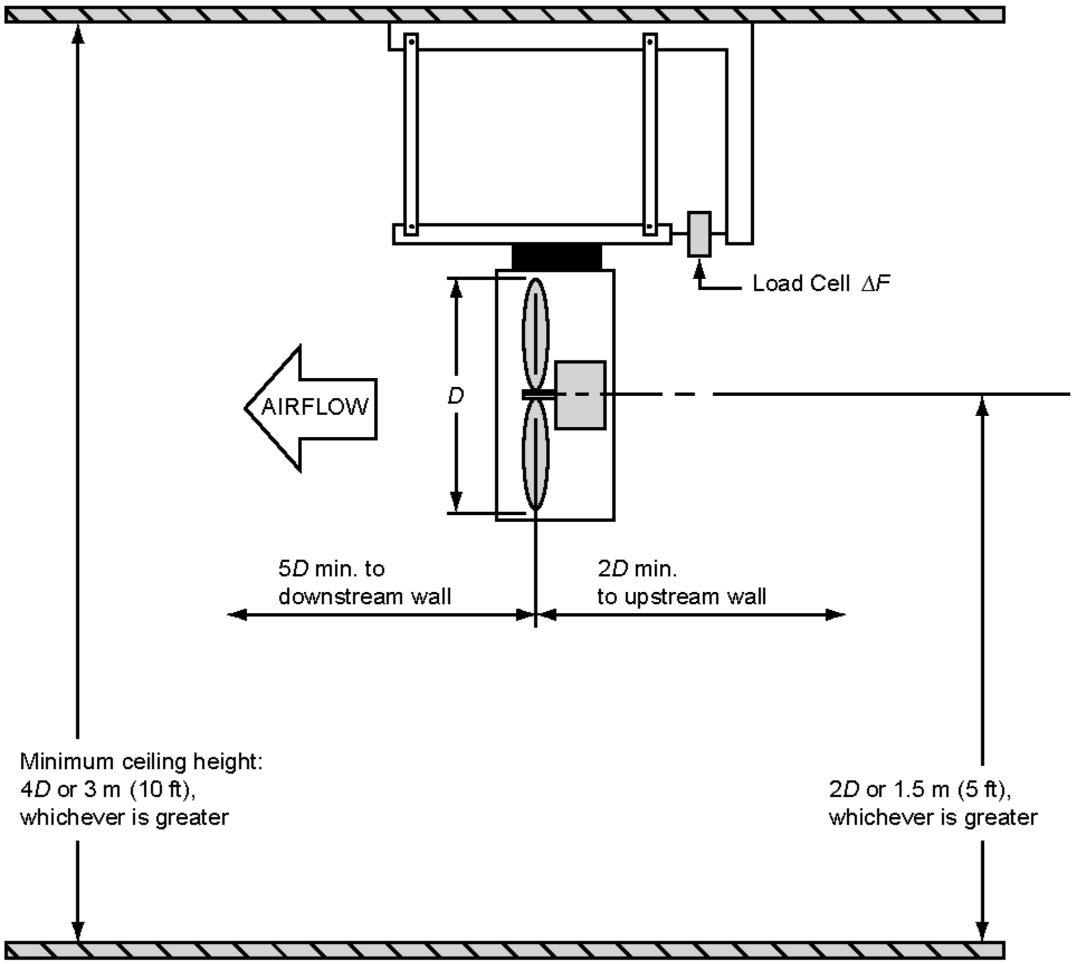
Test Figure 2B1
Horizontal Airflow Setup with Load Cell
(Air Circulating Fan Heads and Table Fans)



Notes:

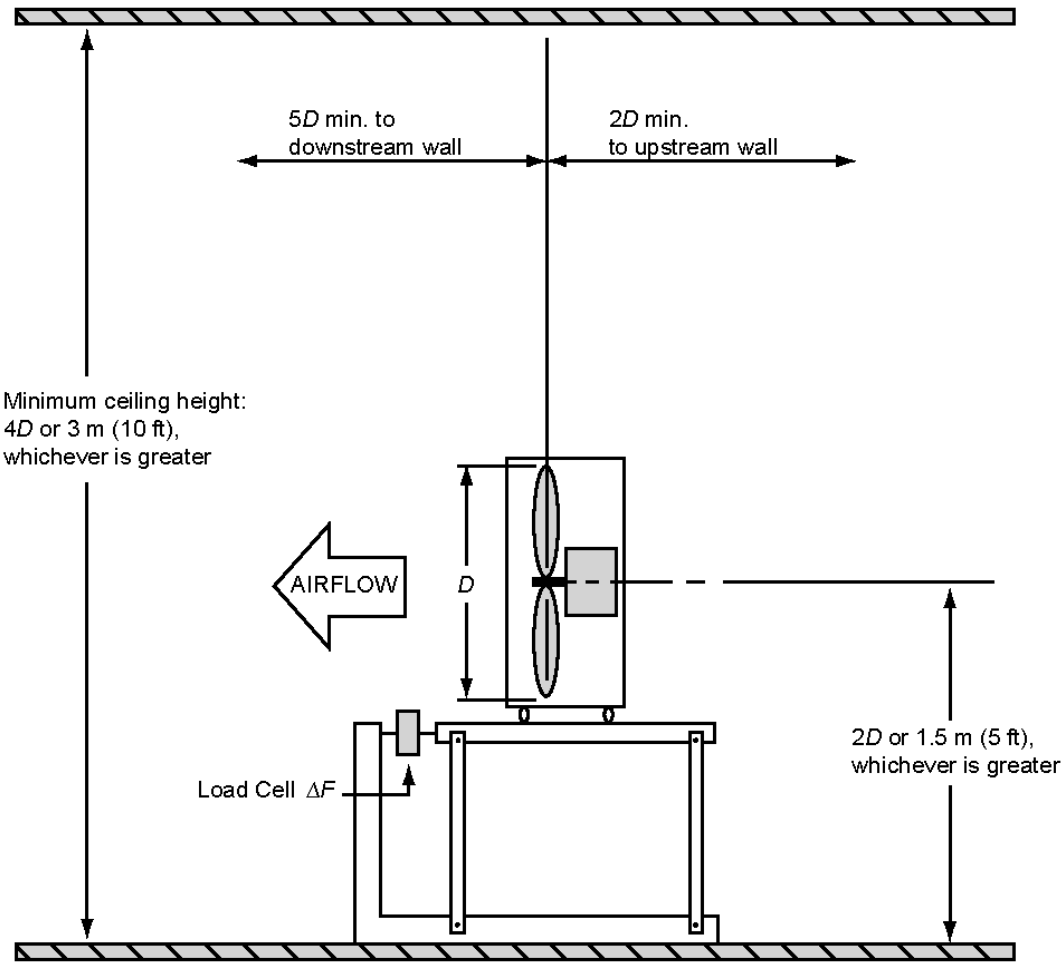
1. The horizontal centerline through the test setup shall be kept horizontal within ± 1° during testing.
2. 2*D* minimum to walls and large obstructions on sides of test unit.

Test Figure 2B2
Horizontal Airflow Setup with Load Cell Pivot Below Test Subject
(Air Circulating Fan Heads and Table Fans)



Note:
2*D* minimum to walls and large obstructions on sides of test unit.

Test Figure 3A
Horizontal Airflow Setup with Load Cell
(Box Fan or Personnel Cooler Fan)

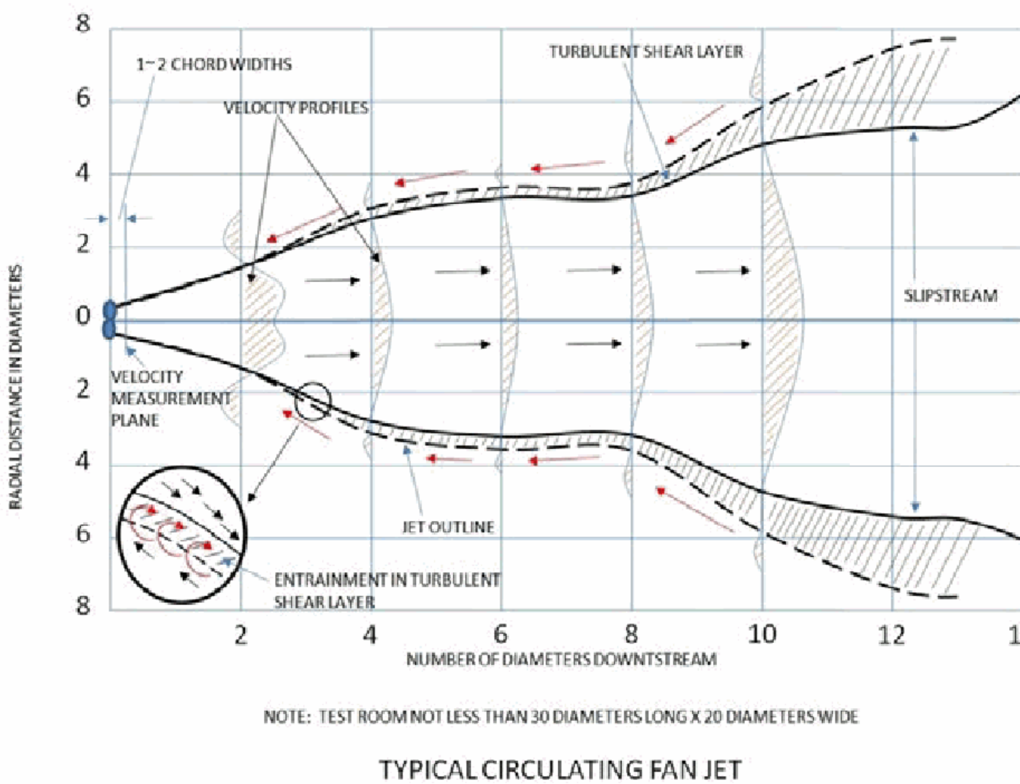


Note:
2*D* minimum to walls and large obstructions on sides of test unit.

Test Figure 3B
Horizontal Airflow Setup with Load Cell
(Box Fan or Personnel Cooler Fan)

Annex A
Circulating Fans and Their Relationship to Airflow and Velocity (Informative)

The measurement of thrust and power consumption serves as simple means to characterize and compare performance of air circulating fans. A more accurate determination of the flow through the fan requires additional measurements. Typically, this is done by measuring and integrating a velocity profile in the primary jet of the fan. Care must be taken with this type of measurement since the primary jet downstream of a circulator fan will entrain additional air from the surroundings. Consequently, the velocity profile should be obtained in a plane normal to the fan axis located about one or two chord lengths downstream in order to minimize the influence of air entrainment. In addition, the measurement must be able to accurately distinguish the axial component of the resultant velocity vector since radial and swirl components are also present. Specialized thermal or laser anemometers are the most accurate instruments capable of these measurements, but five- and seven-hole pressure probes can be used with reasonable accuracy.



Note:
Test room not less than 30*D* long x 20*D* wide.

Figure A.1
Typical Circulating Fan Jet
Adapted from *Axial Flow Fans and Ducts* [7]

Annex B
References (Informative)

[1] NBS Special Publication 330. *The International System of Units (SI)*. Taylor, Barry and Ambler Thompson, eds. Gaithersburg, MD: NIST, 2008.

[2] *Steam Tables*. New York: ASME, 1967.

[3] ASHRAE Standard 41. *Standard Measurement Guide*. Atlanta: ASHRAE, 1975. p. 5-75.

[4] ASHRAE Standard 41. p. 1-86.

[5] Helander, L. "Psychrometric Equations for the Partial Vapor Pressure and Density of Moist Air." Report to AMCA Standard 210/ASHRAE 51P Committee. Nov. 1, 1974

[6] *Handbook of Fundamentals*. Atlanta: ASHRAE, 1993

[7] Wallis, R. Allen. *Axial Flow Fans and Ducts*. New York: Wiley-Interscience, 1983.

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The Air Movement and Control Association International Inc. is a not-for-profit association of the world's manufacturers of air system equipment, such as fans, louvers, dampers, air curtains, airflow measurement stations, acoustic attenuators and other air system components for the industrial and commercial markets.

UL will be submitting a link via email to view Reference Standard UL 507-2014

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General Comments No
Alternate Language No

Related Modifications

Summary of Modification

This modification updates the reference standard AMCA 550-08 to the current version, AMCA/ANSI 550-15 (Rev. 09/18).

Rationale

This modification updates the reference standard AMCA 550-08 to the current version AMCA 550-09 Test Method for High Velocity Wind Driven Rain Resistant Louvers.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

This modification updates the reference standard to the current version, thereby improving enforcement of the code.

Impact to building and property owners relative to cost of compliance with code

There is no cost impact, as this modification is simply updating the reference standard to the current version.

Impact to industry relative to the cost of compliance with code

There is no cost impact, as this modification is simply updating the reference standard to the current version.

Impact to small business relative to the cost of compliance with code

There is no cost impact, as this modification is simply updating the reference standard to the current version.

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

This modification updates the reference standard to the current version. The updated test methods for High Velocity Wind Driven Rain Resistant Louvers will improve the overall health, safety and welfare of the general public.

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

This modification improves the code by introducing the current reference standard.

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

This modification does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities. It simply updates the reference standard to the current version.

Does not degrade the effectiveness of the code

This modification does not degrade the effectiveness of the code. It updates the reference standard to the current version, and thereby increasing the effectiveness of the code.

Updates reference standard as follows:

~~AMCA 550-08~~ AMCA/ANSI 550-15 (Rev. 09/18) Test Method for High Velocity Wind Driven Rain Resistant Louvers

STANDARD

ANSI/AMCA Standard 550-15 (Rev. 09-18)

Test Method for High Velocity Wind Driven Rain Resistant Louvers

An American National Standard
Approved by ANSI on September 20, 2018

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ANSI/AMCA Standard 550-15 (Rev. 09-18)

Test Method for High Velocity Wind Drive Rain Resistant Louvers

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AMCA Standards

Authority ANSI/AMCA Standard 550-15 (Rev. 09-18) was adopted by the membership of the Air Movement and Control

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AMCA Standard 550
Test Method for High Velocity Wind Driven Rain Resistant Louvers

1. Purpose

This standard establishes uniform laboratory test methods and minimum performance ratings for water rejection capabilities of louvers intended to be used in high velocity wind conditions.

2. Scope

Tests conducted in accordance with the requirements of this standard are intended to demonstrate the acceptability of the louver in which water infiltration must be kept to manageable amounts during a high velocity wind driven rain event. The test specimen can be approved in either an open or closed position as stated in Section 5.

3. Units of Measurement

3.1 System of units

SI units (The International System of Units, *Le Systéme International d'Unités*) 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, 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.

3.2 Basic units

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

3.3 Airflow rate and velocity

3.3.1 Airflow rate
The SI unit of volumetric airflow rate is the cubic meter per second (m^3/s); the I-P unit of volumetric flow rate is the cubic foot per minute (cfm).

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

3.4 Water flow rate

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

3.5 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.

3.6 Physical constants

The density of distilled water at saturation pressure shall be taken as 998.278 kg/m^3 (62.3205 lbm/ft^3) at 20 °C (68 °F). The density of mercury at saturation pressure shall be taken at 13595.1 kg/m^3 (848.714 lbm/ft^3) at 0 °C (32°F). The specific weights in kg/m^3 (lbm/ft^3) of these fluids under standard gravity in a vacuum are numerically equal to their densities at corresponding temperatures.

4. Definitions

4.1 Louver

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

4.2 Specimen

A representative sample of the louver model design, intended to evaluate the water rejection capability of the louver model.

4.3 Performance variables

4.3.1 Water infiltration
The amount of water passing through a louver during the test.

4.3.2 Rain fall simulation
As calculated in Section 7.2.3 and Section 7.2.5.

4.3.3 Wind stream velocity
The movement rate of air generated during the test.

5. Test Specimen

One 1000 mm x 1000 mm (39.37 in. x 39.37 in.) core area louver test specimen (as defined in ANSI/AMCA Standard 500-L) shall be submitted for this high velocity wind driven rain test. The same test specimen or an identical test specimen shall be tested in the full open position in accordance with the wind driven rain test detailed in ANSI/AMCA Standard 500-L and run at 22 m/s (50 mph) and 203.2 mm/hr (8 in./hr) of rainfall. Operable louvers intended to be shut during a high velocity wind driven rain test can be closed for that test but must be open for the ANSI/AMCA Standard 500-L wind driven rain test. Louvers such as this will need to be clearly identified on its test report, submittal and installation instructions for this qualification.

Test specimens shall be as built, unpainted, clean, degreased and without additional factory-applied coating on the specimens' surfaces that would enhance water shedding capability. All devices tested shall be without a screen across the air passages of the louver.

The test specimen is any fixed, operable, or combination (fixed and operable) blade louver. The test specimen may also have the following devices attached directly or indirectly to the louver during testing and all are considered part of the test specimen: additional louver(s), damper(s), and sleeves. Sill pan(s)/flashing(s) may be used during testing and are considered part of the test specimen. All types of seals on items, such as blades, jambs, head/sill, blade stops, and caulking, are considered part of the test specimen, excluding sealing between the test specimen and test wall.

Items such as an actuator, lever arm, manual operating lever and/or turnbuckle used to keep operable louver/damper blades in the open/closed position are allowed during testing, but these items shall not be considered as part of the test specimen.

When all blades are in the full open position, the horizontal distance between blades of any device and adjacent louver/device shall not exceed 76.2 mm (3 in.). The back of the test specimen's frame/sleeve shall be at least 610 mm (24 in.) from the back of the test chamber.

5.1 Compliance of other sizes and variations

Manufacturing of sizes other than that which was tested shall utilize the same assembly methods of construction as it pertains to fasteners (e.g., types, sizes and spacing). The distances between components/devices shall be the same as the test specimen.

Testing of the louver specimen per this standard does not guarantee an equivalent test result for other sizes.

The pass/fail compliance of a louver model only applies to the specific test specimen setup tested. Therefore, alternate designs, components, devices, etc. to a previously tested louver model will require an additional complete test to this standard. Additions to the specific test specimen setup (such as bird or insect screens, blank-offs, or security bars) do not void the compliance of a louver model.

6. Apparatus

6.1 Test frame

6.1.1
The test frame shall be constructed of CMU blocks with a minimum size of 2.45 m x 2.45 m (8 ft x 8 ft) and a hole as shown in Figure 1 to allow the insertion of the louver.

A catch basin shall be constructed behind the louver, as shown in Figure 1, to catch the water that penetrates the louver.

6.1.2
The test frame shall be painted to prevent water from penetrating the test apparatus.

6.1.3
The test frame shall be rigidly supported during the test period.

6.2 Wind generator

6.2.1
The wind generator shall provide a constant wind profile over the entire face of the louver for the specified time period to a maximum wind stream velocity of 49 m/s (110 mph).

6.2.2
If the wind generator is unable to provide the required constant profile as determined by wind stream calibration (Section 7.1), airflow from the wind generator shall be directed and smoothed by suitably shaped baffles (see Figure 2).

6.3 Water supply

6.3.1
Water shall be supplied to the wind stream using a sprinkle pipe system mounted on a movable frame capable of simulating a uniform 223.5 mm/hr (8.8 in./hr) of rainfall over the test specimen. The simulated rainfall and flow meters shall be calibrated, and the water distribution shall be checked as noted in Section 7.2 and 7.3.

7. Calibration

7.1 Wind stream calibration

7.1.1
The wind stream velocity shall be measured on a vertical plane grid having dimensions of 2.44 m wide x 1.22 m high (8 ft wide x 4 ft high) and grid dimensions of 610 mm x 610 mm (24 in. x 24 in.), located 610 mm (24 in.) in front of the test frame (without the test specimen in place), with the lower 2.44 m (8 ft) dimension in line with the bottom edge of the test frame opening. (See Figure 3.)

7.1.2
The measured wind stream velocity within each grid square shall be within ±10% of the required axial velocity for each wind speed.

7.1.3
Upon completion of the wind stream calibration, the distance from the test frame to the outlet of the wind generator and any necessary baffle configurations shall be noted and maintained while conducting the test as described in Section 8. These dimensions should be noted in the test report under calibration data and calculations.

7.2 Rainfall simulation and flow meter calibration

A maximum of six months prior to conducting the test, the flow meter(s) shall be calibrated using the method described in Section 7.2.1 through Section 7.2.6.

7.2.1
Prepare an apparatus to capture any water that would enter the wind stream during an actual test.

7.2.2
Commence water insertion for a period of one minute and capture the water. Record the flow meter reading (L/min [gal/min]) during this process.

7.2.3
Convert the flow meter reading to rainfall simulation using the following formula:

$$\left(\frac{\left(\frac{L}{min}\right)\times\left(\frac{60\ min}{1\ hour}\right)\times\left(\frac{1{,}000{,}000\ mm^3}{L}\right)}{4{,}459{,}346\ mm^2}\right) = x\left(\frac{mm}{hour}\right) \qquad \text{Eq. 7.2.3 SI}$$

$$\left(\frac{\left(\frac{gallons}{min}\right)\times\left(\frac{60\ min}{1\ hour}\right)\times\left(\frac{231\ in.^3}{1\ gallon}\right)}{6{,}912\ in.^2}\right) = x\left(\frac{in.}{hour}\right) \qquad \text{Eq. 7.2.3 I-P}$$

Note: For Equation 7.2.3 SI and Equation 7.2.3 I-P, 4,459,346 mm^2 and 6,912 $in.^2$ refer to the expected projection area of the water that hits the wall, respectively.

7.2.4
The quantity of rainfall simulation determined in Section 7.2.3 shall be within ±5% of the desired rainfall simulation of 223.5 mm/hr (8.8 in./hr).

7.2.5
Measure the volume of water (mm^3 [$in.^3$]) captured and convert this to rainfall simulation (mm/hr [in./hr]) using the following formula:

$$\left(\frac{\left(\frac{mm^3}{4{,}459{,}346\ mm^2}\right)}{1\ min}\right)\times\left(\frac{60\ min}{1\ hour}\right) = y\left(\frac{mm}{hour}\right) \qquad \text{Eq. 7.2.5 SI}$$

$$\left(\frac{\left(\frac{in^3}{6{,}912\ in.^2}\right)}{1\ min}\right)\times\left(\frac{60\ min}{1\ hour}\right) = y\left(\frac{in.}{hour}\right) \qquad \text{Eq. 7.2.5 I-P}$$

Note: For Equation 7.2.5 SI and Equation 7.2.5 I-P, 4,459,346 mm^2 and 6,912 $in.^2$ refer to the expected projection area of the water that hits the wall, respectively.

7.2.6
The rainfall simulation determined in Section 7.2.3 (x) shall be within ±5% of the rainfall simulation determined in Section 7.2.5 (y).

7.3 Water distribution check

A maximum of six months prior to conducting the test, the water distribution check over the 2.44 m wide x 1.22 m high [8 ft wide x 4 ft high]) wall surface shall be calibrated using the method outlined herein. The water distribution system must introduce water into the wind stream so that it strikes the wall area.

7.3.1
Prepare eight 610 mm (24 in.) squares of the absorptive material (e.g., roofing felt), and weigh each sample. From this data, determine the average weight of the samples. As an alternative, depending on the consistency of the weight of the absorptive material, each square used for calibration may be weighed individually.

7.3.2
Lay out the eight numbered squares of absorptive material (e.g., roofing felt) as shown in Figure 4. Put the hold-down frame over the squares of absorptive material.

7.3.3
Set the wind speed to 15.65 m/s (35 mph) and add water to the wind stream at a constant rate, as indicated on the flow meter, until the absorptive material is well wetted but not saturated, at which time the wind and water flow shall be terminated.

Table 1—Wind Stream Velocity and Water Spray Intervals for High Velocity Wind Driven Rain Resistance Testing

Interval #	Wind Speed m/s (mph)	Time (min)	Water Spray
1	15.6 (35)	15	On
2	0 (0)	5	Off
3	31.3 (70)	15	On
4	0 (0)	5	Off
5	40.2 (90)	15	On
6	0 (0)	5	Off
7	49.2 (110)	5	On
8	0 (0)	5	Off

7.3.4
Remove the hold-down frame from the wall and rapidly weigh the squares of wet absorptive material. Determine the weight of water absorbed by each square sample at the particular wind speed and flow meter setting.

7.3.5
No one particular square sample shall exhibit rainfall simulation, measured in weight, greater than or less than 25% of the average wetted weight of all eight squares.

7.3.6
Repeat the steps in Sections 7.3.1–7.3.5 at a wind speed of 31.3 m/s (70 mph).

7.4 Instruments

Instruments used in this test shall be calibrated, by means of the manufacturer's specifications, a maximum of 12 months prior to conducting the test.

8. Test Procedures

8.1
The louver to be tested shall be mounted and sealed as recommended by the manufacturer in the test frame to prevent any ingress of water other than through the louver blades.

The test specimen shall be fully open for the ANSI/AMCA Standard 500-L 50 mph, 8.0 in./hr test. The test specimen may be closed during the high velocity wind driven rain testing sequence outlined in Table 1.

8.2
The wind stream velocity intervals shall be conducted as noted in Table 1.

8.3
Water shall be added to the wind stream upon commencement of the initial wind stream velocity in an even spray at a rate equal to 223.5 mm/hr (8.8 in./hr) of rainfall over the test specimen. The flow of water shall be measured with a calibrated flow meter during the test procedure to confirm water flow. Water flow shall be stopped and started in conjunction with the airflow intervals noted in Table 1.

8.4
The water penetrating the louver at each wind stream velocity shall be collected and measured.

9. Report and Results of Test

The test report shall be submitted in its entirety and shall include, at a minimum, the following:

1. Date of test, date of report and a unique identification number, with the identification number printed on each page.
2. The name(s) of the author of the report.
3. A record of the
    a. Name and location of the facility performing the test and the name and address of the requester of the test.
    b. Names of the individuals performing the test and any witnesses.
4. Consecutive page numbers, with an indication of the total number of pages.
5. The test standard designation, including the date of issue, and an explanation detailing any derivation from the standard.
6. A signature, including titles, and date from both the professional engineer authorizing the test report and the lab technician.
7. A description of the louver, including:
    a. The model number
    b. Any drawings and photographs of the louver
    c. A detailed report of the method of installation (including fasteners and caulk)
    d. If there is a damper or operable blade louver (if so, the position of operable blades shall be listed as fully open or fully closed)
    e. Any other items, such as a sill pan/flashing, including detailed dimensions and descriptions
    f. If used, a description of the device used to keep operable blades fully closed
8. Detailed drawings of the test specimen, showing dimensioned section profiles, blade to frame connection details, frame-to-frame connection details (corners), fasteners and any other pertinent construction details.
9. Any deviation from the drawings or any modifications made to the test specimen to obtain the reported values, which shall be noted on the drawings and in the report.

    For each sample, the following items on the manufacturer-supplied drawing should be checked against the test specimen:

10. Full sample
    a. Louver overall width
    b. Louver overall height
    c. Louver depth
    d. Blade spacing
11. For head frame, jamb frame, sill, blades and other components, verify
    a. Material (aluminum components are aluminum, steel components are steel, etc., not checking chemical composition)
    b. Width of component
    c. Depth of component
    d. Thickness of component (two locations)
    e. Features and shape of component visually matches drawing
12. Unverifiable components must be documented in report

    For connection details, verify
    a. Blade to frame connections
    b. Sill to jamb connections
    c. Head to jamb connections
       (Verification shall consist of visually inspecting weld sizes and lengths)
       (Verification shall consist of inspecting fastener diameters and lengths
    d. Other connections shown on manufacturer's drawings
13. Calibration data and calculations.
14. Detailed observations of any water infiltration. Observations should include the total volume of water that infiltrated the louver at each test speed.
15. The calculated percentage of water which infiltrated the louver based on the total amount of water sprayed at the test apparatus.
16. A determination of "pass — fully open," "pass — fully closed" or "fail" based on whether or not the test specimen exhibits water infiltration in excess of 1% of the total water sprayed.
17. A statement that the laboratory is in possession of a video recording of the test intervals (see Table 1). The video recording shall be retained by the laboratory for a minimum period of five years from the test report date.
18. Photographs of the louver immediately prior to and subsequent to commencement and termination of the test.
19. All data not required herein but useful to a better understanding of the test results, conclusions or recommendations appended to the report.

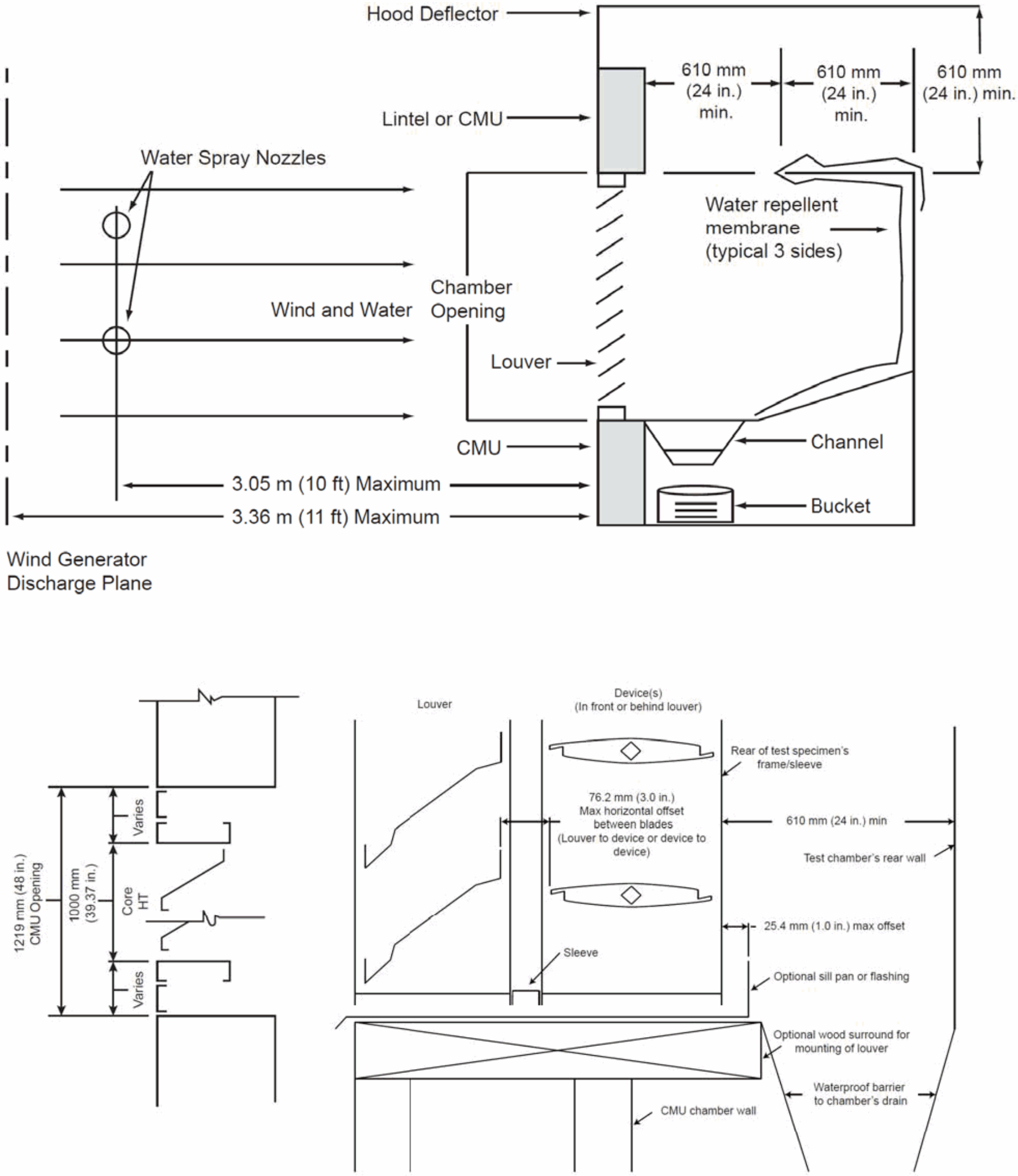
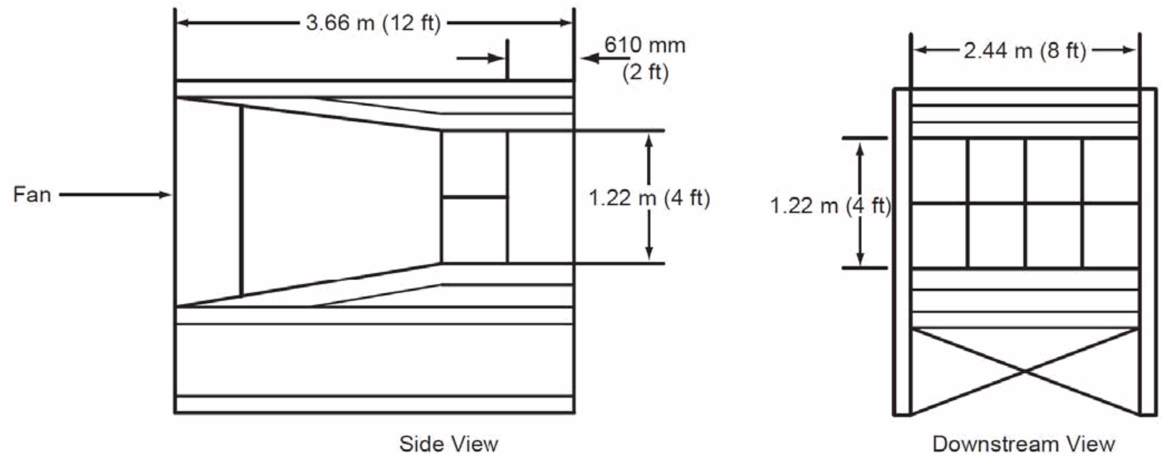


Image adapted from Miami-Dade County

Figure 1 — High Velocity Wind Driven Rain Test Setup



Florida Test Protocol TAS No. 100(A)-95

Figure 2 — Wind Tunnel with Baffles

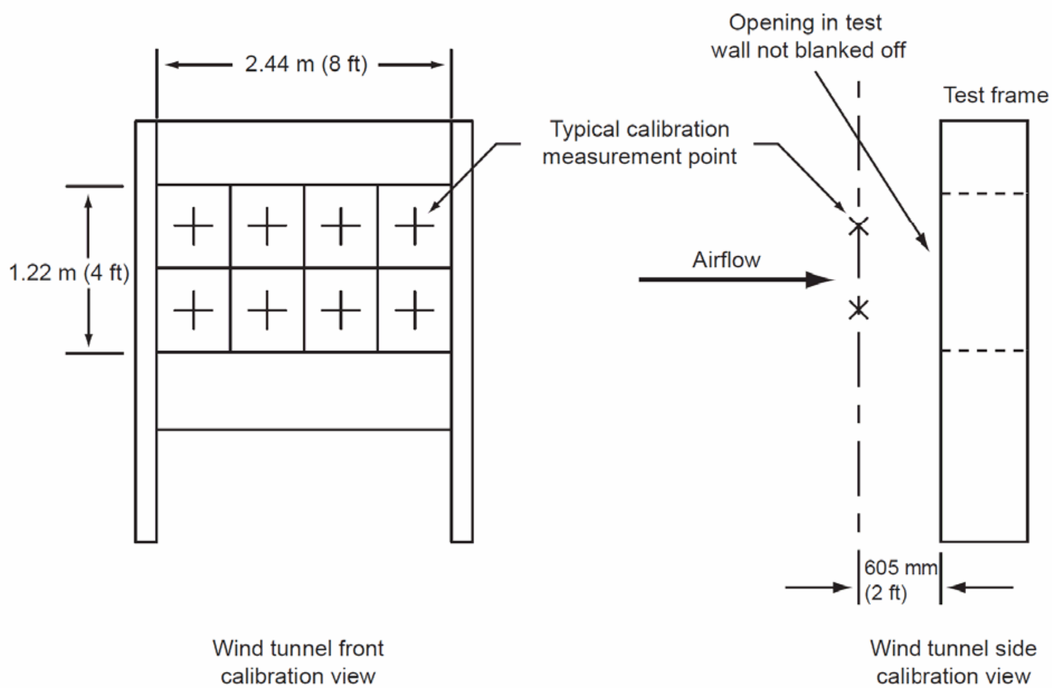


Figure 3 — Wind Stream Calibration Setup

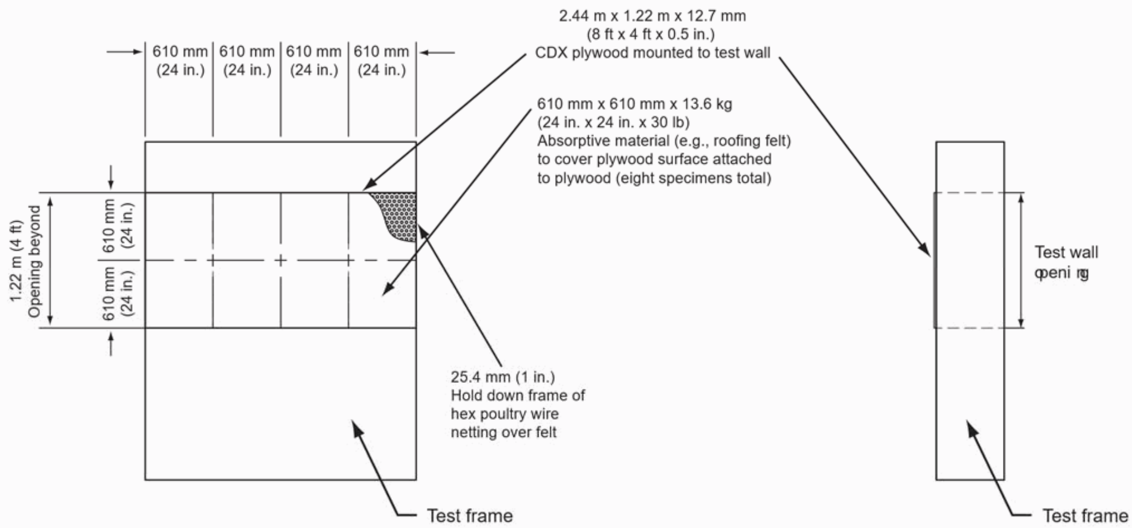


Figure 4 — Rainfall Calibration Distribution

Annex A
References (Informative)

Page, C. H. and P. Vigoureux. *The International System of Units (SI): NBS Special Publication 330*. Washington D.C.:National Bureau of Standards,1972.

"Test Procedure for Wind and Wind Driven Rain Resistance and/or Increased Windspeed Resistance of Soffit Ventilation Strip and Continuous or Intermittent Ventilation System Installed at the Ridge Area." *Florida Test Protocol TAS No. 100(A)-95*. Washington, DC: International Code Council, 1995.

ANSI/AMCA Standard 500-L-12, *Laboratory Methods of Testing Louvers for Rating*. Arlington Hts., IL: AMCA Int'l, 2012.

"Checklist #0240 for the Approval of: Louvers (Included Gable End Louvers)." Miami: Miami Dade County, 2012

Annex B
Reason for Two Louver Test Standards (Informative)

The requirement to test the louvers to two test criteria is based upon the need for the louver to perform at two conditions: during normal operation and during a hurricane.

A product could be designed for hurricane or high wind conditions but be unsuitable for normal day-to-day operation due to its high pressure-drop and energy requirements.

RESOURCES

AMCA Membership Information
http://www.amca.org/members/members.php

AMCA International Headquarters and Laboratory
www.amca.org

AMCA White Papers
www.amca.org/whitepapers

Searchable CRP Database of AMCA Certified Products
www.amca.org/certified-listed/cpsearch.php

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The Air Movement and Control Association International Inc. is a not-for-profit association of the world's manufacturers of air system equipment, such as fans, louvers, dampers, air curtains, airflow measurement stations, acoustic attenuators and other air system components for the industrial and commercial markets.

M8360

26

Date Submitted	12/15/2018	**Section**	1411.6	**Proponent**	Oscar Calleja
Chapter	14	**Affects HVHZ**	No	**Attachments**	No

TAC Recommendation Approved as Submitted
Commission Action Pending Review

Comments

General Comments **No** **Alternate Language** **No**

Related Modifications

Summary of Modification

Refrigerant piping insulation minimum R-value is shown as R-4 in this section and is in conflict with the R-3 shown on Energy Code R403.4. This change would resolve the conflict.

Rationale

This modification would resolve current conflict and allow 1/2" thick (R-3) pipe insulation to continue being used. R-4 insulation is thicker (3/4") which sometimes makes the piping hard to pass throigh openings.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

No cost impact.

Impact to building and property owners relative to cost of compliance with code

Savings in both cost of material and installation labor to owner.

Impact to industry relative to the cost of compliance with code

Savings in both cost of material and installation labor to all.

Impact to small business relative to the cost of compliance with code

Savings in both cost of material and installation labor to all.

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

Permits smaller wall penetrations and therefore reduces air leakage.

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

Provides coordination of different Codes and avoids conflicts in enforcement.

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

Does not discriminate against materials, products or methods.

Does not degrade the effectiveness of the code

Does not degrade effectiveness, rather improves the Code by eliminating conflicts.

M1411.6 Insulation of refrigerant piping.

Piping and fittings for refrigerant vapor (suction) lines shall be insulated with insulation having a thermal resistivity of not less than ~~R-4~~ **R-3**and having external surface permeance not exceeding 0.05 perm [2.87 ng/(s · m^2 · Pa)] when tested in accordance with ASTM E96.

Date Submitted	12/14/2018	**Section**	1507.3.2	**Proponent**	Mike Moore
Chapter	15	**Affects HVHZ**	No	**Attachments**	Yes

TAC Recommendation Approved as Submitted
Commission Action Pending Review

Comments

General Comments **No** **Alternate Language** **No**

Related Modifications

Summary of Modification

Requires labeling of ventilation system control.

Rationale

Tight dwelling units are being outfitted with code-mandated outdoor air/“whole-house” mechanical ventilation systems. These systems are often simply a bathroom exhaust fan expected to run continuously. The problem is that without a label indicating the system's function, occupants have no idea of the purpose of these systems and are likely to turn them off – thereby increasing the rate of accumulation of harmful indoor pollutants without their knowledge. At a minimum, these systems should be labeled to indicate that they are different than a typical bath fan. This proposed language would echo language in ASHRAE 62.2 and also within the 2018 IMC as follows: “403.3.2.4 System controls. Where provided within a dwelling unit, controls for outdoor air ventilation systems shall include text or a symbol indicating the system's function.” The language is intended to be flexible enough to allow multiple options for the text or symbol, provided it achieves the intention of conveying that the control is for a system that is not merely a standard bath fan. For example, the Home Ventilating Institute (an industry association representing over 90% of the manufacturers of residential ventilating products in the U.S.), recently developed the logo shown in the attachment for this purpose. This proposal is on the consent agenda for the 2021 IRC (RM29: http://media.iccsafe.org/codes/2018-2019/GroupA/CAH/IRC-M.pdf) , so it is very likely to be in the final language of the International Residential Code. Approval of this proposal will align the Florida Building Code - Residential with the 2021 IRC.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

Eases enforcement by identifying the fan that serves as the whole house mechanical ventilation system, where specified.

Impact to building and property owners relative to cost of compliance with code

Minimal. Labels can ship free with product or can be as simple as a hand-written identification.

Impact to industry relative to the cost of compliance with code

Minimal. Labels can ship free with product or can be as simple as a hand-written identification.

Impact to small business relative to the cost of compliance with code

Minimal. Labels can ship free with product or can be as simple as a hand-written identification.

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

Where specified, whole house mechanical ventilation systems are designed to provide minimum acceptable indoor air quality. Identifying this system as serving a different purpose than typical bath fans promotes occupant health.

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

Improves code by aligning with 2021 IRC, easing enforcement, educating home owners, and having minimal cost impact.

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

No discrimination results from this requirement. The builder has virtually infinite options for compliance.

Does not degrade the effectiveness of the code

On the contrary, supports code effectiveness by identifying the function of specified systems.

Modify as follows:

M1507.3.2 System controls. The whole-house mechanical ventilation system shall be provided with controls that enable manual override. <u>Controls shall include text or a symbol indicating their function.</u>

FRESH AIR

SYSTEM

HVI.ORG

M8362

Date Submitted	12/15/2018	**Section**	1502.4.1	**Proponent**	Oscar Calleja
Chapter	15	**Affects HVHZ**	No	**Attachments**	No

TAC Recommendation Approved as Submitted
Commission Action Pending Review

Comments

General Comments **No** **Alternate Language** **No**

Related Modifications

Summary of Modification

Adds clarification by adding the corresponding metal gauge to listed duct thickness for dryer exhaust metal ducts.

Rationale

To avoid confusion the metal gauge should be shown. Galvanized metal ducts are sold by gauge not by metal thickness.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

Improves code enforcement by establishing the common metal gauge designation which is easier to determine and avoids having to measure duct thickness.

Impact to building and property owners relative to cost of compliance with code

No cost impact.

Impact to industry relative to the cost of compliance with code

Helps manufacturers and distributors to know what material is being required and to stock.

Impact to small business relative to the cost of compliance with code

Clarifies what duct gauge is required for dryer ducts.

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

Avoids use of thinner ducts which could fail in dryer exhaust ducts.

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

Clarifies the Code requirement and thus improves it.

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

Does not discriminate against materials, products, methods or systems.

Does not degrade the effectiveness of the code

Improves Code effectiveness by clarification.

M1502.4.1Material and size.

Exhaust ducts shall have a smooth interior finish and be constructed of metal having a minimum thickness of 0.0157 inches **(28 gauge).** The duct shall be 4 inches (102 mm) nominal in diameter.

Exception: Exhaust ducts may be 4 inches nominal in diameter Schedule 40 PVC when horizontally run beneath the slab.

M8364

Date Submitted	12/15/2018	**Section**	1502.4.2	**Proponent**	Oscar Calleja
Chapter	15	**Affects HVHZ**	No	**Attachments**	No

TAC Recommendation Approved as Submitted
Commission Action Pending Review

Comments

General Comments **No** **Alternate Language** **No**

Related Modifications

Summary of Modification

Removes requirement for screws in Residential Dryer exhaust ducts. The use of screws was historically prohibited in dryer ducts due to the potential for lint accumulation and fire risk.

Rationale

Residential Dryer Exhaust ducts are mostly galvanized ducts. These come in 5 and 10 foot sections that have crimped male ends. Attachment of duct sections are made as per manufacturer's instructions and sealed with aluminum tape. Historically the use of screws has been prohibited due to the potential for lint accumulation. Ducts are secured in place with metal straps to wall studs. There is no need for screws to provide structural integrity even when ducts are cleaned using rotating brush systems.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

Makes inspection of duct attachment easier. Screws are usually covered by aluminum tape and hard to see.

Impact to building and property owners relative to cost of compliance with code

Saves labor cost and reduces installation time.

Impact to industry relative to the cost of compliance with code

Saves labor cost and reduces installation time.

Impact to small business relative to the cost of compliance with code

Saves labor cost and reduces installation time.

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

Helps to avoid lint accumulation which affects Dryer performance negatively and poses potential fire risk.

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

Strengthens Code enforcement and helps to avoid lint accumulation which affects Dryer performance negatively and poses potential fire risk.

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

Does not discriminate against materials, products or methods.

Does not degrade the effectiveness of the code

Does not degrade Code effectiveness.

M1502.4.2Duct installation.

Exhaust ducts shall be supported at intervals not to exceed 12 feet (3658 mm) and shall be secured in place. The insert end of the duct shall extend into the adjoining duct or fitting in the direction of airflow. Exhaust duct joints shall be sealed in accordance with Section M1601.4.1 ~~and shall be mechanically fastened~~. Ducts shall not be joined with screws or similar fasteners. ~~that protrude more than $^1/_8$ inch (3.2 mm) into the inside of the duct~~

M7975

Date Submitted	12/14/2018	**Section**	1	**Proponent**	Amanda Hickman
Chapter	2712	**Affects HVHZ**	No	**Attachments**	Yes
TAC Recommendation	Approved as Submitted				
Commission Action	Pending Review				

Comments

General Comments **No** **Alternate Language** **No**

Related Modifications

Summary of Modification

This modification updates the reference standard ANSI/AMCA 210-ANSI/ASHRAE 51—07 to the current version ANSI/AMCA 210-16 / ASHRAE 51-16

Rationale

This modification updates the reference standard to the most current version.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

This modification only updates the reference standard to the most current version, thereby making it easier for code enforcement.

Impact to building and property owners relative to cost of compliance with code

There is no cost impact, as this modification only updates the reference standard to the current version.

Impact to industry relative to the cost of compliance with code

There is no cost impact, as this modification only updates the reference standard to the current version.

Impact to small business relative to the cost of compliance with code

There is no cost impact, as this modification only updates the reference standard to the current version.

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

This modification updates the reference standard to the current version, thereby ensuring the health, safety and welfare of the general public.

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

This modification strengthens and improves the code by updating the reference standard to the most current version.

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

This modification does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities. It only updates the reference standard to the current version.

Does not degrade the effectiveness of the code

This modification updates the reference standard to the most current version, thereby increasing the effectiveness of the code.

Update reference standard as follows:

ANSI/AMCA 210-ANSI/ASHRAE 51—~~07~~16 Laboratory Methods for Testing Fans for Aerodynamic Performance Rating

STANDARD

ANSI/AMCA Standard 210-16/ ASHRAE Standard 51-16

Laboratory Methods of Testing Fans for Certified Aerodynamic Performance Rating

An American National Standard
Approved by ANSI on August 26, 2016

This standard in English, Chinese, European Spanish, and Latin American Spanish may be purchased at www.amca.org/store.

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ANSI/AMCA Standard 210-16
ANSI/ASHRAE Standard 51-16

Laboratory Methods of Testing
Fans for Certified Aerodynamic Performance Rating

Air Movement and Control Association International
30 W. University Drive
Arlington Heights, Illinois
60004

American Society of Heating,
Refrigerating and Air Conditioning Engineers
1791 Tullie Circle, NE
Atlanta, GA
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AMCA Publications

Authority AMCA Standard 210-16 was adopted by the membership of the Air Movement and Control Association International Inc. on July 20, 2016 and by ASHRAE on June 29, 2016. It was approved by the American National Standards Institute on August 26, 2016.

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Tim Orris	AMCA Staff

Related AMCA Documents

Related Publications	AMCA Publication 211	*Certified Ratings Program—Product Rating Manual for Fan Air Performance*

Contents

Laboratory Methods of Testing Fans for Certified Aerodynamic Performance Rating

1. Purpose and Scope

This standard establishes uniform test methods for a laboratory test of a fan or other air moving device to determine its aerodynamic performance in terms of airflow rate, pressure developed, power consumption, air density, speed of rotation and efficiency for rating or guarantee purposes.

This standard applies to a fan or other air moving device when air is used as the test gas, with the following exceptions:

(a) air circulating fans (ceiling fans, desk fans);
(b) positive pressure ventilators;
(c) compressors with interstage cooling;
(d) positive displacement machines; and
(e) test procedures to be used for design, production or field testing.

2. Normative References

The following standards contain provisions that, through specific reference in this text, constitute provisions of this American National Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this American National Standard are encouraged to investigate the possibility of applying the most recent editions of the standards listed below.

IEEE 112-96 *Standard Test Procedure for Polyphase Induction Motors and Generators*, The Institute of Electrical and Electronic Engineers, 445 Hoes Lane, Piscataway, NJ 08855-1331, U.S.A. (AMCA #1149).

3. Definitions/Units of Measure/Symbols

3.1 Definitions

3.1.1 Fan
A device that uses a power-driven rotating impeller to move air or gas (see note below). The internal energy increase imparted by a fan to air is limited to 25 kJ/kg (10.75 Btu/lbm). This limit is approximately equivalent to a pressure of 30 kPa (120 in. wg) (AMCA 99-0066).

Note: for the purpose of this standard, the term "air" is used in the sense of "gaseous fluid."

3.1.2 Fan inlet and outlet boundaries
The interfaces between a fan and the remainder of the air system; the respective planes perpendicular to an airstream entering or leaving a fan.

Various appurtenances (inlet boxes, inlet vanes, inlet cones, silencers, screens, rain hoods, dampers, discharge cones, evasés, etc.), may be included as part of a fan between the inlet and outlet boundaries.

3.1.3 Fan input power boundary
The interface between a fan and its drive.

When mechanical input power is reported, it is the interface between a fan and its drive, which in this context is either a dynamometer or calibrated motor. When electrical input power is reported, it is the interface between mains and the drive.

3.1.4 Driven fan
A fan equipped with a drive.

3.1.5 Drive
Components used to power the fan, such as a motor, motor control and transmission. Not all of these components are required to constitute a drive. A calibrated motor used to measure fan input power is generally not considered part of the drive.

3.1.6 Transmission
A system that transmits mechanical power from the motor to the fan shaft. Examples of transmissions are belts/sheaves, couplings and gears.

3.1.7 Fan outlet area
The gross inside area measured in the planes of the outlet openings.

3.1.8 Fan inlet area
The gross inside area measured in the planes of the inlet connections. For converging inlets without connection elements, the inlet area shall be considered to be that where a plane perpendicular to the airstream first meets the mouth of the inlet bell or inlet cone.

3.1.9 Dry-bulb temperature
Air temperature measured by a temperature-sensing device without modification to compensate for the effect of humidity (AMCA 99-0066).

3.1.10 Wet-bulb temperature
The air temperature measured by a temperature sensor

covered by a water-moistened wick and exposed to air in motion (AMCA 99-0066).

3.1.11 Wet-bulb depression
The difference between the dry-bulb and wet-bulb temperatures at the same location (AMCA 99-0066).

3.1.12 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 (AMCA 99-0066).

3.1.13 Static temperature
The temperature that exists by virtue of the internal energy of the air.

If a portion of the internal energy is converted into kinetic energy, the static temperature is decreased accordingly.

3.1.14 Air density
The mass per unit volume of air (AMCA 99-0066).

3.1.15 Standard air
Air with a standard density of 1.2 kg/m^3 (0.075 lbm/ft^3) at a standard barometric pressure of 101.325 kPa (29.92 in. Hg).

3.1.15.1 Standard air properties
Standard air has a ratio of specific heats of 1.4 and a viscosity of 1.8185 × 10^{-5} Pa•s (1.222 × 10^{-5} lbm/ft•s). Air at 20°C (68°F) temperature, 50% relative humidity, and standard barometric pressure has the properties of standard air, approximately.

Note: The values of the standard air density in the SI and I-P systems of units are not exactly equivalent. This may have an impact on the accuracy of the fan performance data when the data is shown in both systems of units or converted from one system to the other.

3.1.16 Pressures in the air
The pressures in the air relevant to the fan performance testing have dimension as a force per unit of area. These pressures also have a meaning of specific energy defined as energy per volume of the air or specific power defined as power per unit of the airflow. In either case, the resulting dimension is the same. The pressures in the SI system are expressed in Pa, while in the I-P system they are expressed as inches of water or mercury. The conventional conversion of 1 in. of water equals 249.089 Pa (see note below). Pressures in inches of mercury are referenced to the mercury density of 13595.08 kg/m^3 in the SI system or 848.656 lbm/ft^3 in the I-P system.

Note: This conventional conversion is based on water density of 1000 kg/m^3 in the SI system or 62.427 lbm/ft^3 in the I-P system.

3.1.17 Absolute pressure
The pressure when the datum pressure is absolute zero. It is always positive.

3.1.18 Barometric pressure
The absolute pressure exerted by the atmosphere.

3.1.19 Gauge pressure
The differential pressure when the datum pressure is the barometric pressure at the point of measurement. It may be positive or negative.

3.1.20 Total pressure
The air pressure that exists by virtue of the state of the air and the rate of motion of the air. It is the algebraic sum of velocity pressure and static pressure at a point.

If air is at rest, its total pressure will equal the static pressure.

3.1.21 Dynamic (velocity) pressure
The portion of air pressure that exists by virtue of the rate of motion of the air.

3.1.22 Static pressure
The portion of air pressure that exists by virtue of the state of the air.

If expressed as a gauge pressure, it may be positive or negative.

3.1.23 Pressure loss
A decrease in total pressure due to friction and/or turbulence.

3.1.24 Fan air density
The density of the air corresponding to the total pressure and the stagnation (total) temperature of the air at the fan inlet.

3.1.25 Fan airflow rate
The volumetric airflow rate at fan air density.

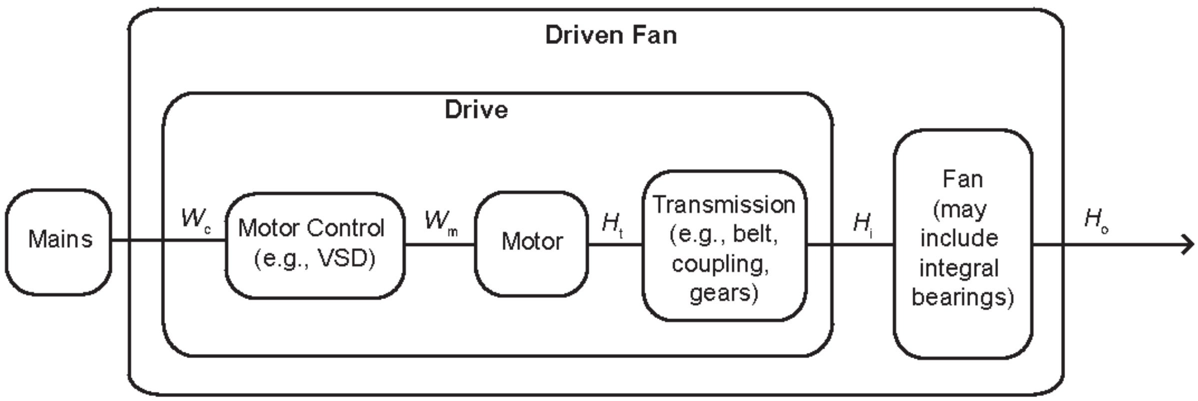
3.1.26 Fan total pressure
The difference between the total pressure at the fan outlet and the total pressure at the fan inlet.

3.1.27 Fan dynamic (velocity) pressure
A pressure calculated from the average air velocity and air density at the fan outlet.

3.1.28 Fan static pressure
The difference between the fan total pressure and the fan dynamic (velocity) pressure. Therefore, it is the difference

Table 1
Input Power Boundary

Case	Motor Control	Motor	Transmission	Fan	Boundary	Quantity Measured
1	X	X	X	X	Mains/ Motor Control	W_{cmti}
2		X	X	X	Mains/Motor	W_{mti}
3		X		X	Mains/Motor	W_{mi}
4	X	X		X	Mains/Motor Control	W_{cmi}
5			X	X	Dynamometer or Calibrated Motor/Transmission	H_{ti}
6				X	Dynamometer or Calibrated Motor/Fan	H_i



W shall designate electrical input power; the product of voltage and current; and, in the case of an AC circuit, power factor

H shall designate mechanical power, the product of torque and shaft speed when considering input power, and the product of flow and total pressure when considering output power,

Subscripts shall be used in a dynamic sense. For instance,

- W_{mti} indicates a test of an Arrangement 8 fan where motor input power is measured
- H_i indicates a test of an Arrangement 1 fan with a dynamometer
- W_{cmi} indicates a test of an Arrangement 4 fan where motor control input power is measured
-

Figure 3.1
Input Power Boundary

Table 2
Symbols and Subscripts

Symbol	Description	SI Unit		I-P Unit
A	Area of cross section	m^2		ft^2
C	Nozzle discharge coefficient		dimensionless	
D	Diameter and equivalent diameter	m		ft
D_h	Hydraulic diameter	m		ft
e	Base of natural logarithm (2.718…)		dimensionless	
E	Energy factor		dimensionless	
F	Beam load	N		lbf
f	Coefficient of friction		dimensionless	
H_i	Fan input power	W		hp
H_o	Fan output power	W		hp
K_p	Compressibility coefficient		dimensionless	
L	Nozzle throat dimension	m		ft
L_e	Equivalent length of straightener	m		ft
$L_{x,x'}$	Length of duct between planes x and x’	m		ft
l	Length of moment arm	m		in.
ln	Natural logarithm	---		---
M	Chamber diameter or equivalent diameter	m		ft
N	Rotational speed	rpm		rpm
n	Number of readings		dimensionless	
P_s	Fan static pressure	Pa		in. wg
P_{sx}	Static pressure at plane x	Pa		in. wg
P_t	Fan total pressure	Pa		in. wg
P_{tx}	Total pressure at plane x	Pa		in. wg
P_v	Fan 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	Fan airflow rate	m^3/s		cfm, ft^3/min
Q_x	Airflow rate at plane x	m^3/s		cfm, ft^3/min
R	Gas constant	J/kg•K		ft•lb/lbm•°R
Re	Reynolds number		dimensionless	
T	Torque	N•m		lbf•in.
t_d	Dry-bulb temperature	°C		°F
t_s	Stagnation (total) temperature	°C		°F
t_w	Wet-bulb temperature	°C		°F
V	Velocity	m/s		fpm, ft/min
W_x	Electrical input power, where x indicates the input power boundary	W		W
x	Function used to determine K_p		dimensionless	
Y	Nozzle expansion factor		dimensionless	
y	Thickness of airflow straightener element	m		ft
z	Function used to determine K_p		dimensionless	
α	Static pressure ratio for nozzles		dimensionless	
σ	Diameter ratio for nozzles		dimensionless	
γ	Ratio of specific heats		dimensionless	
ΔP	Pressure differential	Pa		in. wg
η_m	Motor efficiency		per unit	
η_{sx}	Fan static efficiency where x indicates the input power boundary		per unit	

Table 2 (con't)
Symbols and Subscripts

Symbol	Description	SI Unit	I-P Unit
η_{st}	Fan static efficiency where x indicates the input power boundary	per unit	
μ	Dynamic air viscosity	Pa•s	lbm/ft•s
ρ	Fan air density	Kg/m^3	lbm/ft^3
ρ_x	Air density at plane x	Kg/m^3	lbm/ft^3

Subscript	Description
c	Converted value
r	Reading
x	Plane 0,1,2 … as appropriate
0	Plane 0 (general test area)
1	Plane 1 (fan inlet)
2	Plane 2 (fan outlet)
3	Plane 3 (pitot traverse station)
4	Plane 4 (duct piezometer station)
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)

Power Subscripts

The following subscripts shall be used to designate the type of input power measured and reported during the test, and the losses present that consumed that power.

Subscript	Description
o	Fan output power
i	Fan input power
m	Electrical input power to the motor
c	Electrical input power to the motor control
t	Input power inclusive of the transmission losses
b	Input power inclusive of bearing losses

between static pressure at the fan outlet and total pressure at the fan inlet.

3.1.29 Fan rotational speed
The rotational speed of the impeller.

If the fan has more than one impeller, fan rotational speed is the rotational speed of each impeller.

3.1.30 Compressibility coefficient
The ratio of the mean airflow rate through the fan to the airflow rate at fan air density; the ratio of the fan total pressure that would be developed with an incompressible fluid to the fan total pressure that is developed with a compressible fluid, i.e., air, the test gas.

The compressibility coefficient is a thermodynamic factor that must be applied to determine fan total efficiency from fan airflow rate, fan total pressure, and fan input power. The coefficient is derived in Annex D.

3.1.31 Fan output power
The power delivered to air by the fan; it is proportional to the product of the fan airflow rate, the fan total pressure and the compressibility coefficient.

3.1.32 Fan input power
The mechanical input power to the fan.

3.1.33 Fan total efficiency
The ratio of fan output power to fan input power.

3.1.34 Fan static efficiency
The fan total efficiency multiplied by the ratio of fan static pressure to fan total pressure.

3.1.35 Fan with drive total efficiency
The ratio of fan output power to drive input power.

3.1.36 Fan with drive input power
The electric input power to the drive.

3.1.37 Fan with drive static efficiency
The fan with drive total efficiency multiplied by the ratio of fan static pressure to fan total pressure.

3.1.38 Point of operation
The relative position on a fan characteristic curve corresponding to a particular airflow rate. It is controlled during a test by adjusting the position of a throttling device, by changing flow nozzles or auxiliary fan characteristics, or by any combination of these.

3.1.39 Free delivery
The point of operation where the fan static pressure is zero.

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

3.1.41 Shut-off
The point of operation where the fan airflow rate is zero.

3.1.42 Determination
A complete set of measurements for a particular point of operation of a fan.

3.1.43 Test
A series of determinations for various points of operation of a fan.

3.1.44 Energy factor
The ratio of the total kinetic energy of the airflow to the kinetic energy corresponding to the average velocity of the airflow.

3.1.45 Demonstrated accuracy
Demonstrated accuracy is defined for the purposes of this standard as the accuracy of an instrument or the method established by testing of the instrument or the method against a primary or calibrated instrument or method in accordance with the requirements of this standard.

3.2 Units of measure

3.2.1 System of units
SI units (The International System of Units, *Le Systéme 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 [2], and I-P values are based on the values of the National Institute of Standards and Technology (NIST), which are in turn based on the values of the International Bureau.

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

3.2.3.1 Airflow rate
The SI unit of volumetric flow rate is the cubic meter per second (m^3/s); the I-P unit of volumetric flow rate is the cubic foot per minute (cfm).

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

3.2.4 Pressure
The SI unit of pressure is the pascal (Pa); the I-P unit of pressure is either the inch water gauge (in. wg) or the inch mercury (in. Hg). Values in mm Hg or in in. Hg shall be used only for barometric pressure measurements. The standard pressures in the I-P system are based on the standard density of water of 1000 kg/m^3 (62.428 lbm/ft^3) or standard density of mercury of 13595.1 kg/m^3 (848.714 lbm/ft^3) and the standard gravitational acceleration of 9.80665 m/s^2 (32.17405 ft/s^2).

3.2.5 Power, energy and torque
The SI unit of power is the watt (W); the I-P unit is horsepower (hp). The SI unit of energy is the joule (J); the I-P unit is the foot pound-force (ft•lbf). The SI unit of torque is the newton-meter (N•m); the I-P unit is the pound-force inch (lbf•in.).

3.2.6 Efficiency
Efficiency is based on a per unit basis. Percentages are obtained by multiplying by 100.

3.2.7 Rotational speed
The unit of rotational speed is the revolution per minute (rev/min or rpm).

3.2.8 Density, viscosity and gas constant
The SI unit of density is the kilogram per cubic meter (kg/m^3); the I-P unit is the pound mass per cubic foot (lbm/ft^3). The SI unit of viscosity is the pascal second (Pa•s); the I-P unit is the pound mass per foot-second (lbm/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-force per pound mass degree Rankine ([ft•lb]/[lbm•°R]).

3.2.9 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.

3.3 Symbols and subscripts

See Table 2

4. Instruments and Methods of Measurement

4.1 Accuracy [3]

The specifications for instruments and methods of measurement that follow include both instrument accuracy and measurement accuracy requirements and specific examples of equipment capable of meeting those requirements.

Equipment other than the examples cited may be used provided the accuracy requirements are met or improved upon.

4.1.1 Instrument accuracy
The specifications regarding accuracy correspond to two standard deviations based on an assumed normal distribution.

The calibration procedures given in this standard shall be employed in order to minimize errors. Instruments shall be set up, calibrated and read by qualified personnel trained to minimize errors.

4.1.2 Measurement uncertainty
Every test measurement contains some error and the true value cannot be known because the magnitude of the error cannot be determined exactly. However, it is possible to perform an uncertainty analysis to identify a range of values within which the true value probably lies. A probability of 95% has been chosen as acceptable for this standard.

The standard deviation of random errors can be determined by statistical analysis of repeated measurements. No statistical means are available to evaluate systematic errors, so these must be estimated. The estimated upper limit of a systematic error is called the systematic uncertainty, and, if properly estimated, it will contain the true value 99% of the time. The two standard deviation limit of a random error has been selected as the random uncertainty. Two standard deviations yield 95% probability for random errors.

4.1.3 Uncertainty of results
The results of a fan test are the various fan performance variables listed in Sections 3.1.21 through 3.1.31. Each result is based on one or more measurements. The uncertainty in any result can be determined from the uncertainties in the measurement. It is best to determine the systematic uncertainty and then the random uncertainty of the result before combining them into the total uncertainty of the result. This may provide clues on how to reduce the total uncertainty. When the systematic uncertainty is combined in quadrature with the random uncertainty, the total uncertainty will give 95% coverage. In most test situations, it is wise to perform a pretest uncertainties analysis to identify potential problems. A pretest uncertainties analysis is not required for each test covered by this standard because it is recognized that most laboratory tests for rating are conducted in facilities where similar tests are repeatedly run. Nevertheless, a pretest analysis is recommended, as is a post-test analysis. The simplest form of analysis is through verification that all accuracy and calibration requirements of this standard have been met. The most elaborate analysis would consider all of

the elemental sources of error, including those due to calibration, data acquisition, data reduction, calculation assumptions, environmental effects and operational steadiness.

The sample analysis given in Annex F calculates the uncertainty in each of the fan performance variables, and in addition combines certain ones into a characteristic uncertainty and others into an efficiency uncertainty.

4.2 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 the 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 connected to 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 open 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.

4.2.1 Manometers and other pressure-indicating instruments

Pressure shall be measured on manometers of the liquid column type using inclined or vertical legs or other instrument that provides a maximum uncertainty of 1% of the maximum observed reading during the test or 1 Pa (0.005 in. wg), whichever is larger.

Note: the specification permitting an uncertainty based on the maximum observed test reading during the test leads to combined relative uncertainties in both fan pressure and fan airflow rate that are higher at low values of the fan pressure or fan airflow rate than at high values of those test results. This is generally acceptable because fans are not usually rated at the low pressure or low flow portions of their characteristic curves. If there is a need to reduce the uncertainty at either low flow or low pressure, then the instruments chosen to measure the corresponding quantity must be selected with suitable accuracy (lower uncertainties) for those conditions.

4.2.1.1 Calibration

Each pressure-indicating instrument shall be calibrated at both ends of the measurement scale, plus at least nine equally spaced intermediate points in accordance with the following. The reference instrument shall be have an accuracy of +/- 0.25% of reading or 0.5 Pa, whichever is greater, and a calibration traceable to NIST or other national physical measure recognized as equivalent by NIST.

4.2.1.2 Averaging

To obtain a representative reading, an instrument must either be damped or the reading must be averaged in a suitable manner. Averaging can be accomplished mentally if the fluctuations are small and regular. Multi-point or continuous-record averaging can be accomplished with instruments or analyzers designed for this purpose. The user is cautioned that this latter type of equipment may yield unreliable readings for a fan operating in an unstable region of its performance curve.

4.2.1.3 Correction

Manometer of the liquid column type readings should be corrected for any difference in change of length of the graduated scale of the manometer if the temperature of the ambient air differs from the temperature at which it was calibrated. The manufacturer of the manometer must supply the information for correction of the graduated scale due to temperature changes.

In case of using manometric head pressure, such as inches of water or mercury, the readings should be corrected for any difference in density of gauge liquid from standard and any difference in local gravitational acceleration from standard. The standard density of water or mercury and the standard gravitational acceleration are defined in Section 3.2.4

4.2.2 Pitot-static tube [4][5]

The total pressure or static pressure at a point may be sensed with a pitot-static tube of the proportions shown in Figure 1A and 1B. 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 is considered velocity pressure at the point of the impact opening.

4.2.2.1 Calibration

A pitot-static tube having the proportions shown in Figures 1A and 1B is considered a primary instrument and need not be calibrated, provided it is maintained in a condition conforming to this standard.

4.2.2.2 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.).

4.2.2.3 Support
Rigid support shall be provided to hold the pitot-static tube axis parallel to the axis of the duct within 3 degree and at the head locations specified in Figure 3 within 1 mm (0.05 in.) or 0.25% of the duct diameter, whichever is larger.

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

4.2.3.1 Calibration
A static pressure tap meeting the requirements shown in Figure 2A is considered a primary instrument and need not be calibrated, provided it is maintained in a condition conforming to this standard. Precautions shall be taken to ensure that the air velocity does not influence the pressure measurement.

4.2.3.2 Averaging
A pressure tap is sensitive only to the pressure in the immediate vicinity of the opening. In order to obtain an average, at least four taps meeting the requirements of Figure 2A shall be manifolded into a piezometer ring. The manifold shall have an inside area at least four times that of each tap. An example is shown in Annex C.

4.2.3.3 Piezometer ring
A piezometer ring is specified for pressure measurement at upstream and downstream nozzle taps and for outlet duct or chamber measurement, unless a pitot traverse is specified. Measurement planes shall be located as shown in setup Figures 8A, 8B, 9A, 9B, 9C, 10A, 10B, 10C, 11, 12, 13, 14 or 15. See Annex C.

4.2.4 Total pressure tube
The total pressure in an inlet chamber may be sensed with a stationary tube of the proportions and requirements shown in Figure 2B. The tube shall face directly into the airflow.

4.2.4.1 Calibration
A total pressure tube is considered a primary instrument and need not be calibrated provided if it is maintained in a condition conforming to this standard.

4.2.4.2 Total pressure tubes used with setup Figures 13, 14 and 15
A total pressure tube is sensitive only to the pressure in the immediate vicinity of the open end. Locate the tube as shown in the setup figure. Since the air velocity in an inlet chamber is considered uniform due to the settling means employed, a single measurement is representative of the average chamber pressure.

4.2.5 Other pressure measurement systems
A pressure measurement system consisting of indicators and sensors other than manometers and pitot-static tubes, pressure taps or total pressure tubes 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, pressure taps or total pressure tubes. For a system used to determine fan pressure, the contribution to combined uncertainty in the pressure measurement shall not exceed that corresponding to 1% of the maximum observed static or total pressure reading during a test (indicator accuracy), plus 1% of the actual reading (averaging accuracy). For a system used to determine fan airflow rate, the combined uncertainty shall not exceed that corresponding to 1% of the maximum observed velocity pressure or differential pressure reading during a test (indicator accuracy), plus 1% of the actual reading (averaging accuracy). See the note in Section 4.2.1.

4.3 Airflow rate

Airflow rate shall be calculated as required by Section 7.3, either from measurements of pressure differential across a flow nozzle or from measurements of velocity pressure obtained by pitot traverse.

4.3.1 Pitot traverse
Airflow rate may be calculated from velocity pressure measurements obtained by traverses of a duct with a pitot-static tube for any point of operation from free delivery to shut-off, provided that average velocity corresponding to the airflow rate at free delivery at the test speed is at least 12 m/s (2400 fpm) [6]. See the note in Section 4.2.1.

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

4.3.1.2 Averaging
The stations shown in Figure 3 are located on each diameter according to the log-linear rule [7]. The arithmetic mean of the individual velocity pressure measurements made at these stations will be the mean air velocity through the measurement section for a wide variety of profiles [8].

4.3.2 Flow nozzle
Airflow rate may be calculated from the pressure differential measured across a flow nozzle or bank of flow nozzles for any point of operation from free delivery to shut-off, provided that the average velocity at the flow nozzle discharge corresponding to the airflow rate at free delivery at the test speed is at least 14 m/s (2800 fpm) [6].

4.3.2.1 Size
The flow nozzle or flow nozzles shall conform to Figure 4. A flow nozzle may be any convenient size except when a duct

is connected to the inlet of a flow nozzle, in which case the ratio of flow nozzle throat diameter to the diameter of the inlet duct shall not exceed 0.5.

4.3.2.2 Calibration

A flow nozzle meeting the requirements of this standard is considered a primary instrument and need not be calibrated if maintained in a condition conforming to this standard. Coefficients have been established for flow nozzle throat proportions $L = 0.5D$ and $L = 0.6D$, shown in Figure 4 [9]. Flow nozzle proportion $L = 0.6D$ is recommended for new construction.

4.3.2.3 Chamber flow nozzle

A flow nozzle without an integral throat tap may be used in a multiple nozzle chamber, in which case, upstream and downstream pressure taps shall be located as shown in the figure for the appropriate setup. An acceptable alternative is the use of a nozzle with a throat tap in which case the throat tap located as shown in Figure 4 shall be used in place of the downstream pressure tap shown in the figure for the setup and the piezometer for each flow nozzle shall be connected to its own indicator.

4.3.2.4 Ducted flow nozzle

A flow nozzle with an integral throat tap shall be used for a ducted flow nozzle setup. An upstream pressure tap shall be located as shown in the figure for the appropriate setup. The downstream tap is the integral throat tap and shall be located as shown in Figure 4.

4.3.2.5 Pressure tap

Each pressure tap shall conform to the requirements in Section 4.2.3.

4.3.3 Other airflow measurement methods

An airflow measurement method that utilizes a meter or traverse other than an airflow nozzle or pitot traverse shall be acceptable under this standard if the uncertainty introduced by the method does not exceed that introduced by an appropriate flow nozzle or pitot-static traverse method. The contribution to the combined uncertainty in the airflow measurement shall not exceed that corresponding to 1.2% of the discharge coefficient for a flow nozzle [10].

4.4 Fan input power

When reporting mechanical input power, power shall be determined from the rotational speed and beam load measured on a reaction dynamometer, from the rotational speed and torque measured on a torsion element, or the electrical input power measured on a calibrated motor.

When reporting electrical input power, power shall be determined from the measurement of active or real power by an electric meter.

4.4.1 Reaction dynamometers

A cradle or torque-table type reaction dynamometer having a demonstrated accuracy of ± 2% of observed reading may be used to determine fan input power.

4.4.1.1 Calibration

A reaction dynamometer shall be calibrated through its range of usage by suspending weights from a torque arm. The weights shall have certified accuracies of ± 0.2%. The length of the torque arm from rotational center to any given point of weight suspension shall be determined to an accuracy of ± 0.2%.

4.4.1.2 Tare

The zero torque equilibrium (tare) shall be checked before and after each test. The difference between the two tare values shall be within 0.5% of the maximum value measured during the test.

4.4.2 Torque

A torque meter having a demonstrated accuracy of ± 2% of observed reading may be used to determine fan input power.

4.4.2.1 Calibration

A torque measurement device shall have a static calibration and may have a running calibration through its range of use. The static calibration shall be accomplished by suspending weights from a torque arm. The weights shall have certified accuracies of ± 0.2%. The length of the torque arm from its rotational center to any given point of weight suspension shall be determined to an accuracy of ± 0.2%.

4.4.2.2 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 between the two readings shall be within 0.5% of the maximum respective value measured during the test.

4.4.3 Calibrated motor

Fan input power can be determined by measuring the electrical power input to the fan's motor only if the motor is calibrated. Calibrated motors shall have a demonstrated accuracy of ± 2%.

4.4.3.1 Motor calibration

A motor shall be calibrated throughout its range of use against an absorption dynamometer except as provided in Section 4.4.3.4. The absorption dynamometer shall be calibrated by suspending weights from a torque arm. The weights shall have accuracies of ± 0.2%. The length of the torque arm from rotational center to any given point of weight suspension shall be determined to an accuracy of ± 0.2%.

4.4.3.2 Calibrated motors controlled by a variable frequency drive (VFD)
Instead of calibrating the motor alone, as would be done if the motor was fed directly from the mains, the motor and variable frequency drive shall be calibrated as an assembly, using the same VFD and settings during the fan test as during the motor calibration, with input power measured upstream of the VFD. However, if the same VFD cannot be used during the fan test as during the motor calibration, the output of the VFD shall be filtered by a sinusoidal filter and the electric meter shall be placed between the sinusoidal filter and the motor.

4.4.3.3 Voltage and frequency
When using a calibrated motor, the motor input voltages(s) during the test shall be within 1% of the voltage(s) observed during calibration. The motor input frequency during the fan test shall be the same frequency supplied during the motor calibration.

4.4.3.4 IEEE Calibration
A polyphase induction motor may be calibrated by using the IEEE segregated loss method [11].

4.4.4 Electrical meter
An electrical meter shall have a certified accuracy of ± 1.0% of observed reading.

Electrical meters shall have a calibration traceable to NIST or other national physical measure recognized as equivalent by NIST.

4.4.5 Averaging
The torque measured 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. Averaging can be accomplished mentally if the fluctuations are small and regular. Multi-point or continuous-record averaging can be accomplished with instruments or analyzers designed for this purpose. The user is cautioned that this latter type of equipment may yield unreliable readings for a fan operating in an unstable region of its performance curve, and care must be taken to ensure that the fan operates without pressure/airflow instability.

4.5 Rotational speed

The fan shaft speed shall be measured at regular intervals throughout the period of test for each point of operation, so as to ensure the determination of average rotational speed during each such period with an uncertainty not exceeding ± 0.5%. No device used shall significantly affect the rotational speed of the fan under test or its performance.

4.5.1 Calibration
Speed measurement devices shall have a calibration traceable to NIST or other national physical measure recognized as equivalent by NIST.

4.6 Air density

Air density shall be determined 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%.

4.6.1 Thermometer
Wet-bulb and dry-bulb temperatures shall be measured with thermometer or other instruments with a demonstrated accuracy of ± 1 °C (± 2 °F) and a readability of 0.5 °C (1 °F) or finer.

4.6.1.1 Calibration
A thermometer shall be calibrated over the range of temperatures to be encountered during test against a thermometer with a calibration traceable to NIST or other national physical measure recognized as equivalent by NIST.

4.6.1.2 Measurement conditions
A 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]. A dry-bulb thermometer shall be mounted upstream of the wet-bulb thermometer. Wet-bulb and dry-bulb thermometers shall be of the same type.

4.6.2 Barometer
Ambient barometric pressure shall be measured with an instrument having a demonstrated accuracy of ± 170 Pa (± 0.05 in. Hg) and readable to 34 Pa (0.01 in. Hg) or finer.

4.6.2.1 Calibration
Barometers shall have a calibration traceable to NIST or other national physical measure recognized as equivalent by NIST

4.6.2.2 Corrections
A mercury column barometer reading shall be corrected for any difference in mercury density from standard or for any change in the length of the graduated scale due to temperature. Refer to barometer manufacturer's instructions and ASHRAE 41.3, Annex B.

5. Test Setups and Equipment

5.1 Setup

Sixteen test setups are diagrammed in Figures 7A, 7B, 8A, 8B, 9A, 9B, 9C, 10A, 10B, 10C, 11, 12, 13, 14, 15 and 16.

5.1.1 Installation types
A fan shall be tested under this standard according to one of

the four general installation types that exist in actual applications [13]. These types are

A: Free inlet, free outlet
B: Free inlet, ducted outlet
C: Ducted inlet, free outlet
D: Ducted inlet, ducted outlet

5.1.2 Selection guide
Table 3 may be used as a guide to the selection of an appropriate setup.

Table 3
Selection Guide

	Installation Type			
Setup Figure	A	B	C	D
7A, 7B, 8A, 8B, 9A, 9B, 9C, 10A, 10B, 10C		NS		NS[1]
11,12,13,14, or 15	Y[2]	Y[3]	Y[1,4]	Y[1,3]
16			Y	Y[3]

NS = Not suitable for fans with significant swirl
Y = Suitable for all fan types

Notes:
1. A simulated inlet duct may be used
2. An auxiliary inlet bell or outlet duct may not be used
3. An outlet duct or a short outlet duct, per Section 5.2.3, may be used
4. No outlet duct may be used

5.1.3 Leakage
All joints in the chamber, ducts and other equipment between the fan and the flow measuring plane, including the nozzle wall, if applicable, shall be designed and maintained to minimize leakage.

Leakage through the chamber and the duct walls between the flow measurement plane and the fan under the test shall be minimize for the pressure range in the chamber during the test.

A leakage test shall be performed prior to initial use and periodically thereafter, with corrective action taken if necessary. See Annex B for two recommended leakage test methods.

5.2 Duct

A duct may be incorporated in a laboratory test setup to provide a measurement plane or to simulate the conditions the fan is expected to encounter in service or both. Dimension D_3 or D_4 in the test setup figures are the inside diameter of a circular cross section duct or equivalent diameter of a rectangular cross section duct with inside traverse dimensions *a* and *b*, where:

$$D = \sqrt{4ab/\pi} \qquad \text{Eq. 5.2}$$

5.2.1 Long Ducts

5.2.1.1 Airflow measurement duct
A duct with a measurement plane for airflow determination shall be straight and have a uniform circular cross section. A pitot traverse duct shall be at least 10 diameters long with the traverse plane located between 8.5 and 8.75 diameters from the upstream end. Such a duct may serve as an inlet duct or an outlet duct as well as to provide a measurement plane. A duct connected to the upstream side of a flow nozzle shall be between 6.5 and 6.75 diameters long when used only to provide a measurement plane or between 9.5 and 9.75 diameters long when used as an outlet duct as well.

5.2.1.2 Pressure measurement duct
A duct with a plane for pressure measurement shall be straight and may have either a uniform circular or rectangular cross section. An outlet duct with a piezometer ring shall be at least 10 diameters long with the piezometer plane located between 8.5 and 8.75 diameters from the upstream end.

5.2.1.3 Transition pieces
Transition pieces shall be used when a duct with a measuring plane is to be connected to the fan and it is of a size or shape that differs from the fan connection. Such pieces 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 axis of greater than 3.5°. The axes of the fan opening and duct shall coincide. See Figure 5. Connecting ducts and elbows of any size and shape may be used between a duct that provides a measurement plane and a chamber. This will lead to non-reproducible results unless actual duct configuration is identified.

5.2.1.4 Duct area
An outlet duct used to provide a measurement station shall not have an area more than 5% larger or smaller than the fan outlet area. An inlet duct used to provide a measurement station shall not be more than 12.5% larger, nor 7.5% smaller than the fan inlet area.

5.2.1.5 Roundness
The portion of a pitot traverse duct within 0.5*D* 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 4 diameters measured at 45° increments. The diameter measurements shall be accurate to within 0.2%.

5.2.1.6 Airflow straightener

An airflow straightener is specified so that flow lines will be approximately parallel to the duct axis. An airflow straightener shall be used in any duct that provides a measurement plane. The form of the airflow straightener shall be as specified in Figure 6A or 6B. To avoid excessive pressure drop through the airflow straightener, careful attention to construction tolerances and details is important [14].

5.2.2 Common segment

A standardized air path of a controlled geometry used to provide consistent test results between different test configurations. The geometry of the common segment is adapted from ISO 5801.

5.2.2.1 Common segment on the fan outlet

The geometry of the common segments used for testing on the outlet side of the fan is defined in Figures 18, 19 and 20. It incorporates a flow straightener per Figure 6B and a pressure measurement station one diameter from the exit end. Figures 19 and 20 also define the geometry of transition pieces from the fan outlet to the duct, and the limits of the duct area's deviation from the fan outlet area.

5.2.3 Simulated ducts

5.2.3.1 Short outlet duct

A short outlet duct that is used to simulate installation types B and D but in which no measurements are taken shall be between 2 and 3 equivalent diameters long, have an area within 1% of the fan outlet area and be of a uniform shape to fit the fan outlet [15].

5.2.3.2 Short inlet duct

An inlet bell or an inlet bell and one equivalent duct diameter of inlet duct may be mounted on the fan inlet to simulate an inlet duct. The bell and duct shall be of the same size and shape as the fan inlet boundary connection.

5.3 Chamber

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

$$M = \sqrt{(4ab/\pi)} \qquad \text{Eq. 5.3}$$

5.3.1 Outlet chamber

An outlet chamber (Figure 11 or 12) shall have a cross-sectional area at least nine times the area of the fan outlet or outlet duct for a fan with axis of rotation perpendicular to the discharge airflow and a cross-sectional area at least sixteen times the area of the fan outlet or outlet duct for a fan with axis of rotation parallel to the discharge airflow [16].

5.3.2 Inlet chamber

An inlet chamber (Figure 13, 14 or 15) shall have a cross-sectional area at least five times the fan inlet area.

5.3.3 Airflow settling means

Airflow settling means shall be installed in chambers where indicated on the test setup figures. When the tested fan or a pressure measurement plane is located downstream of the settling means, the purpose of the settling means is to provide a substantially uniform flow ahead of the tested fan or pressure measurement plane. When the test fan or airflow measurement nozzles are located upstream of the settling means, the purpose of the settling means is to absorb the kinetic (velocity) energy of the upstream jet velocity and allow its expansion as if in an unconfined space.

Generally, several screens in each airflow-settling means will be required. Any combination of screens or perforated sheets may be used. However, three or four screens with decreasing percent of open area in the direction of airflow are suggested. It is also suggested that, within each settling means, screens of square mesh round wire be used upstream with perforated sheet used downstream. An open area of 50% to 60% is suggested for the initial screen.

All chambers must meet the requirements described in Annex A for the purposes of this standard.

5.3.4 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 the centers of any two nozzles in simultaneous use shall be three times the throat diameter of the larger nozzle.

The uncertainty of the airflow rate measurement can be reduced by changing to a smaller nozzle or combination of nozzles for the lower airflow rate range of the fan.

Unused nozzles may be sealed on any test.

5.4 Variable air supply and exhaust systems

A means of varying the fan point of operation shall be provided in a laboratory test setup.

5.4.1 Throttling device

A throttling device may be used to control the fan point of operation. Such a device shall be located on the end of the test duct or test chamber and shall be symmetrical about the duct or chamber axis.

5.4.2 Auxiliary fan

Auxiliary fans may be used to control the point of test fan operation. They shall provide sufficient pressure at the desired airflow to overcome losses through the test setup. Airflow adjustment means, such as dampers, auxiliary fan blade or auxiliary fan inlet vane pitch control, or speed control may be required. An auxiliary fan shall not surge or pulsate during a test.

6. Observations and Conduct of Test

6.1 General test requirements

6.1.1 Determinations

The number of determinations must be adequate to define the shape of the performance curve. If the full curve (i.e., free delivery to blocked tight) is desired, the number of determinations shall be no less than eight. If only a portion of the curve is desired, the number of determinations shall be no less than three. If only a single point is required, it must fall within the range of these determinations.

6.1.2 Stable operating conditions

Statistically stable conditions shall be established before each determination. To test for stable condition, trial observations shall be made until steady readings are obtained. The range of airflow over which stable condition cannot be established shall be recorded and reported.

6.1.3 Stability

Any bi-stable performance points (airflow rates at which two different pressure values can be measured) shall be reported. When a result of hysteresis, the points shall be identified as that for decreasing airflow rate and that for increasing airflow rate.

6.2 Data to be recorded

6.2.1 Test fan

The description of the test fan, including specific dimensions, shall be recorded. The nameplate data shall be copied.

6.2.2 Test setup

The description of the test setup, including specific dimensions, shall be recorded. Reference may be made to the figures in this standard. Alternatively, a drawing or annotated photograph of the setup may be attached to the recorded data.

For setups using nozzles, the nozzle diameters shall be recorded.

Table 4
Test Data to be Recorded

		Setup Figure															
Item Description	**Parameter**	7A	7B	8A	8B	9A	9B	9C	10A	10B	10C	11	12	13	14	15	16
Barometric Pressure	p_b	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Rotational Speed	N	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Beam Load or Torque or Input Power	F or T or W	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Velocity Pressure	P_{v3r}	x	x	x										x			x
Static Pressure	P_{s3r}	x	x	x										x			x
	P_{s4}			x	x	x	x	x	x	x	x				x		
	P_{s5}					x	x	x	x	x	x	x	x			x	
	P_{s7}											x	x				
Total Pressure	P_{t8}													x	x	x	
Temperature	t_{d0}	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	t_{w0}	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	t_{d2}	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	t_{d3}	x	x											x			x
	t_{d4}			x	x	x	x	x	x	x	x				x		
	t_{d5}					x	x	x	x	x	x	x	x			x	
	t_{d8}													x	x	x	
Nozzle Pressure Drop	ΔP			x	x	x	x	x	x	x	x	x	x		x	x	

6.2.3 Instruments

The instruments and apparatus used in the test shall be listed and recorded, and the manufacturer names, model numbers, serial numbers and calibration information shall be provided if requested.

6.2.4 Test data

The test data which must be recorded varies by setup figure and is shown in Table 4. One reading for each checked parameter is required for each test point with the following exceptions:

1. When environmental conditions are varying, a minimum of three readings shall be taken for t_{d0}, t_{w0}, t_{d2}, and p_b.
2. One reading for each pitot station shall be recorded for P_{v3r} and P_{s3r}.
3. For a test where P_s is less than 1 kPa (4 in. wg), the temperatures t_{d3}, t_{d4}, t_{d5}, t_{d7}, and t_{d8} need not be measured. The value t_{d0} may be used.
4. For setups Figure 11 and 12, t_{d2} may be considered equal to t_{d5} and P_{s5} may be considered equal to P_{s7}.
5. A piezometer can be used to measure P_{s8} instead of P_{t8}. See Figures 13 or 14, Note 5, or Figure 15, Note 6, for requirements.
6. For setup Figure 15, P_{s5} may be calculated. See Figure 15, Note 5.

6.2.5 Personnel

The names of test personnel shall be listed with the data for which they are responsible.

7. Calculations

7.1 Calibration correction

Calibration correction, when required, shall be applied to individual readings before averaging or other calculations. Calibration correction need not be made if the correction is smaller than one-half the maximum allowable uncertainty, as specified in Section 4.

7.2 Density and viscosity of air

7.2.1 Atmospheric air density

The atmospheric air density (ρ_0) shall be determined from measurements taken in the general test area, and of ambient dry-bulb temperature (t_{d0}) ambient wet-bulb temperature (t_{w0}), and ambient barometric pressure (p_b) using the following formulae [17]:

$$p_e = 3.25 t_{w0}^2 + 18.6 t_{w0} + 692 \qquad \text{Eq. 7.1 SI}$$

$$p_e = (2.96 \times 10^{-4}) t_{w0}^2 - (1.59 \times 10^{-2}) t_{w0} + 0.41 \qquad \text{Eq. 7.1 I-P}$$

$$p_p = p_e - p_b \left(\frac{t_{d0} - t_{w0}}{1500} \right) \qquad \text{Eq. 7.2 SI}$$

$$p_p = p_e - p_b \left(\frac{t_{d0} - t_{w0}}{2700} \right) \qquad \text{Eq. 7.2 I-P}$$

$$\rho_0 = \frac{p_b - 0.378 p_p}{R(t_{d0} + 273.15)} \qquad \text{Eq. 7.3 SI}$$

$$\rho_0 = \frac{70.73(p_b - 0.378 p_p)}{R(t_{d0} + 459.67)} \qquad \text{Eq. 7.3 I-P}$$

Equation 7.1 is approximately correct for p_e for a range of t_{w0} between 4 °C and 32 °C (40 °F and 90 °F). The gas constant (R), for air, may be taken as 287.1J/kg•K (53.35 ft•lbf/lbm•°R).

7.2.2 Duct or chamber air density

The air density in a duct or chamber at Plane x, (ρ_x), may be calculated by correcting the density of atmospheric air (ρ_0) for the static pressure (P_{sx}) and dry-bulb temperature (t_{dx}) at Plane x using:

$$\rho_x = \rho_0 \left(\frac{t_{d0} + 273.15}{t_{dx} + 273.15} \right) \left(\frac{P_{sx} + p_b}{p_b} \right) \qquad \text{Eq. 7.4 SI}$$

$$\rho_x = \rho_0 \left(\frac{t_{d0} + 459.67}{t_{dx} + 459.67} \right) \left(\frac{P_{sx} + 13.595 p_b}{13.595 p_b} \right) \qquad \text{Eq. 7.4 I-P}$$

7.2.3 Fan air density

The fan air density (ρ) shall be calculated from the atmospheric air density (ρ_0), the total pressure at the fan inlet (P_{t1}), and the stagnation (total) temperature at the fan inlet (t_{s1}) using:

$$\rho = \rho_0 \left(\frac{P_{t1} + p_b}{p_b} \right) \left(\frac{t_{d0} + 273.15}{t_{s1} + 273.15} \right) \qquad \text{Eq. 7.5 SI}$$

$$\rho = \rho_0 \left(\frac{P_{t1} + 13.595 p_b}{13.595 p_b} \right) \left(\frac{t_{d0} + 459.67}{t_{s1} + 459.67} \right) \qquad \text{Eq. 7.5 I-P}$$

On all outlet duct and outlet chamber setups, P_{t1} is equal to zero and t_{s1} is equal to t_{d0}. On all inlet chamber setups, P_{t1} is equal to P_{t8} and t_{s1} is equal to t_{d8}. On the inlet duct setup,

t_{s1} is equal to t_{d3} and P_{t1} may be considered equal to P_{t3} for fan air density calculations.

7.2.4 Dynamic air viscosity
The viscosity (μ) shall be calculated from:

$$\mu = (17.23 + 0.048t_d) \times 10^{-6} \qquad \text{Eq. 7.6 SI}$$

$$\mu = (11.00 + 0.018t_d) \times 10^{-6} \qquad \text{Eq. 7.6 I-P}$$

The value for 20 °C (68 °F) air, which is 1.819×10^{-5} Pa•s (1.222×10^{-5} lbm/ft•s), may be used between 4 °C (40 °F) and 40 °C (100 °F) [9].

7.3 Fan airflow rate at test conditions

7.3.1 Nozzle
The fan airflow rate may be calculated from the pressure differential (ΔP) measured across a single nozzle or a bank of multiple nozzles [16].

7.3.1.1 Alpha ratio
The ratio of absolute nozzle exit pressure to absolute approach pressure shall be calculated from:

$$\alpha = \frac{P_{s6} + p_b}{P_{sx} + p_b} \qquad \text{Eq. 7.11 SI}$$

$$\alpha = \frac{P_{s6} + 13.595p_b}{P_{sx} + 13.595p_b} \qquad \text{Eq. 7.11 I-P}$$

Or:

$$\alpha = 1 - \left(\frac{\Delta P}{\rho_x R (t_{dx} + 273.15)} \right) \qquad \text{Eq. 7.12 SI}$$

$$\alpha = 1 - \left(\frac{5.2014 \Delta P}{\rho_x \mathrm{R} (t_{dx} + 459.67)} \right) \qquad \text{Eq. 7.12 I-P}$$

The gas constant (R) may be taken as 287.1J/kg•K (53.35 ft•lb/lbm•°R) for air. Plane x is Plane 4 for duct approach or Plane 5 for chamber approach.

7.3.1.2 Beta ratio
The ratio (β) of nozzle exit diameter (D_6) to approach duct diameter (D_x) shall be calculated from:

$$\beta = \frac{D_6}{D_x} \qquad \text{Eq. 7.13}$$

For a duct approach, $D_x = D_4$. For a chamber approach, $D_x = D_5$, and β may be taken as zero.

7.3.1.3 Expansion factor
The expansion factor (Y) may be obtained from:

$$Y = \sqrt{\left(\frac{\gamma}{\gamma - 1}\right)\left(\alpha^{2/\gamma}\right)\left(\frac{1 - \alpha^{(\gamma-1)/\gamma}}{1 - \alpha}\right)\left(\frac{1 - \beta^4}{1 - \beta^4 \alpha^{2/\gamma}}\right)} \qquad \text{Eq. 7.14}$$

The ratio of specific heats (γ) may be taken as 1.4 for air. Alternatively, the expansion factor for air may be approximated with sufficient accuracy by:

$$Y = 1 - (0.548 + 0.71\beta^4)(1 - \alpha) \qquad \text{Eq. 7.15}$$

7.3.1.4 Energy factor
The energy factor (E) may be determined by measuring velocity pressures (P_{vr}) upstream of the nozzle at standard traverse stations and calculating:

$$E = \frac{\left[\frac{\sum (P_{vr}^{1.5})}{n}\right]}{\left[\frac{\sum (P_{vr}^{0.5})}{n}\right]^3} \qquad \text{Eq. 7.16}$$

Sufficient accuracy can be obtained for setups qualifying under this standard by setting $E = 1.0$ for chamber approach or $E = 1.043$ for duct approach [8].

7.3.1.5 Reynolds number
The Reynolds number (Re) based on nozzle exit diameter (D_6) in meters (feet), shall be calculated from:

$$\mathrm{Re} = \frac{D_6 V_6 \rho_6}{\propto} \qquad \text{Eq. 7.17 SI}$$

$$\mathrm{Re} = \frac{D_6 V_6 \rho_6}{60\propto} \qquad \text{Eq. 7.17 I-P}$$

Using properties of air as determined in Section 7.2 and the appropriate velocity (V_6) in m/s (fpm). Since the velocity determination depends on Reynolds number, an approximation must be employed. It can be shown that:

$$\mathrm{Re} = \frac{\sqrt{2}}{\propto} C D_6 Y \sqrt{\frac{\Delta P \rho_x}{1 - E\beta^4}} \qquad \text{Eq. 7.18 SI}$$

$$\mathrm{Re} = \frac{1097}{60\propto} C D_6 Y \sqrt{\frac{\Delta P \rho_x}{1 - E\beta^4}} \qquad \text{Eq. 7.18 I-P}$$

For duct approach, $\rho_x = \rho_4$. For chamber approach, $\rho_x = \rho_5$, and β may be taken as zero.

Refer to Annex G for an example of an iterative process to determine Re and C.

7.3.1.6 Discharge coefficient

The nozzle discharge coefficient (C) shall be calculated from:

$$C = 0.9986 - \left(\frac{7.006}{\sqrt{\mathrm{Re}}}\right) + \left(\frac{134.6}{\mathrm{Re}}\right) \qquad \text{Eq. 7.19}$$

For : $L/D = 0.6$

$$C = 0.9986 - \left(\frac{6.688}{\sqrt{\mathrm{Re}}}\right) + \left(\frac{131.5}{\mathrm{Re}}\right) \qquad \text{Eq. 7.20}$$

For : $L/D = 0.5$

For Re of 12,000 and above [9].

Refer to Annex G for an example of an iterative process to determine Re and C.

7.3.1.7 Airflow rate for ducted nozzle

The airflow rate (Q_4) at the entrance to a ducted nozzle shall be calculated from:

$$Q_4 = \frac{\left(CA_6Y\sqrt{\frac{2\Delta P}{\rho_4}}\right)}{\sqrt{1-E\beta^4}} \qquad \text{Eq. 7.21 SI}$$

$$Q_4 = \frac{\left(1097.8CA_6Y\sqrt{\frac{\Delta P}{\rho_4}}\right)}{\sqrt{1-E\beta^4}} \qquad \text{Eq. 7.21 I-P}$$

The area (A_6) is measured at the plane of the throat taps.

7.3.1.8 Airflow rate for chamber nozzles

The airflow rate (Q_5) at the entrance to a nozzle or multiple nozzles with chamber approach shall be calculated from:

$$Q_5 = Y\sqrt{\frac{2\Delta P}{\rho_5}}\sum(CA_6) \qquad \text{Eq. 7.22 SI}$$

$$Q_5 = 1097.8Y\sqrt{\frac{\Delta P}{\rho_5}}\sum(CA_6) \qquad \text{Eq. 7.22 I-P}$$

The coefficient (C) and the area (A_6) must be determined for each nozzle, and their products must be summed as indicated. The area (A_6) is measured at the plane of the throat taps, or the nozzle exit for nozzles without throat taps.

7.3.1.9 Fan airflow rate

The fan airflow rate (Q) at test conditions shall be obtained from the equation of continuity:

$$Q = Q_x\left(\frac{\rho_x}{\rho}\right) \qquad \text{Eq. 7.23}$$

Where Plane x is either Plane 4 or Plane 5, as appropriate.

7.3.2 Velocity traverse

The fan airflow rate may be calculated from velocity pressure measurements (P_{v3}) taken by pitot traverse.

7.3.2.1 Velocity pressure

The velocity pressure (P_{v3}) corresponding to the average velocity shall be obtained by taking the square roots of the individual measurements (P_{v3r}), summing the roots, dividing by the number of measurements (n), and squaring the quotient as indicated by:

$$P_{v3} = \left(\frac{\sum\sqrt{P_{v3r}}}{n}\right)^2 \qquad \text{Eq. 7.7}$$

7.3.2.2 Velocity

The average velocity (V_3) shall be calculated from the air density at the plane of traverse (ρ_3) and the corresponding velocity pressure (P_{v3}) using:

$$V_3 = \sqrt{\frac{2P_{v3}}{\rho_3}} \qquad \text{Eq. 7.8 SI}$$

$$V_3 = 1097.8\sqrt{\frac{P_{v3}}{\rho_3}} \qquad \text{Eq. 7.8 I-P}$$

7.3.2.3 Airflow rate

The airflow rate (Q_3) at the pitot traverse plane shall be calculated from the velocity (V_3) and the area (A_3) using:

$$Q_3 = V_3A_3 \qquad \text{Eq. 7.9}$$

7.3.2.4 Fan airflow rate

The fan airflow rate at test conditions (Q) shall be obtained from the equation of continuity:

$$Q = Q_3\left(\frac{\rho_3}{\rho}\right) \qquad \text{Eq. 7.10}$$

7.4 Fan velocity pressure at test conditions

7.4.1 Pitot traverse

When pitot traverse measurements are made, the fan velocity pressure (P_v) shall be determined from the velocity pressure (P_{v3}) using:

$$P_v = P_{v3}\left(\frac{\rho_3}{\rho_2}\right)\left(\frac{A_3}{A_2}\right)^2 \quad \text{Eq. 7.24}$$

Whenever P_{s3} and P_{s2} differ by less than 1 kPa (4 in. wg), ρ_2 may be considered equal to ρ_3.

7.4.2 Nozzle

When airflow rate (Q) is determined from nozzle measurements, the fan velocity pressure (P_v) shall be calculated from the velocity (V_2) and air density (ρ_2) at the fan outlet using:

$$Q_2 = Q\left(\frac{\rho}{\rho_2}\right) \quad \text{Eq. 7.25}$$

$$V_2 = \frac{Q_2}{A_2} \quad \text{Eq. 7.26}$$

And:

$$P_v = \frac{\rho_2 V_2^2}{2} \quad \text{Eq. 7.27 SI}$$

$$P_v = \rho_2\left(\frac{V_2}{1097.8}\right)^2 \quad \text{Eq. 7.27 I-P}$$

Or:

$$P_v = \left(\frac{Q\rho}{A_2}\right)^2\left(\frac{1}{2\rho_2}\right) \quad \text{Eq. 7.28 SI}$$

$$P_v = \left(\frac{Q\rho}{1097.8A_2}\right)^2\left(\frac{1}{\rho_2}\right) \quad \text{Eq. 7.28 I-P}$$

For outlet duct setups, whenever P_{s4} and P_{s2} differ by less than 1 kPa (4 in. wg), ρ_2 may be considered equal to ρ_4.

7.5 Fan total pressure at test conditions

The fan total pressure shall be calculated from measurements of the pressures in ducts or chambers, corrected for pressure losses that occur in the measuring duct between the fan and the plane of measurement.

7.5.1 Averages

Certain averages shall be calculated from measurements, as follows:

7.5.1.1 Pitot traverse

When a pitot traverse is used for pressure measurement: the average velocity pressure (P_{v3}) shall be as determined in Section 7.3.1.1. The average velocity (V_3) shall be as determined in Section 7.3.1.2, and the average static pressure (P_{s3}) shall be calculated from:

$$P_{s3} = \frac{\Sigma P_{s3r}}{n} \quad \text{Eq. 7.29}$$

7.5.1.2 Duct piezometer

When a duct piezometer is used for pressure measurement, the average static pressure (P_{s4}) shall be the measured value (P_{s4r}). The average velocity (V_4) shall be calculated from the airflow rate (Q) as determined in Section 7.3.1.9, and:

$$V_4 = \left(\frac{Q}{A_4}\right)\left(\frac{\rho}{\rho_4}\right) \quad \text{Eq. 7.30}$$

And the average velocity pressure P_{v4} shall be calculated from:

$$P_{v4} = \frac{\rho_4 V_4^2}{2} \quad \text{Eq. 7.31 SI}$$

$$P_{v4} = \rho_4\left(\frac{V_4}{1097.8}\right)^2 \quad \text{Eq. 7.31 I-P}$$

7.5.1.3 Chamber

When a chamber piezometer or total pressure tube is used for pressure measurement, the average static pressure (P_{s7}) shall be the measured value (P_{s7r}) and the average total pressure (P_{t8}) shall be the measured value (P_{t8r}).

7.5.2 Pressure losses

Pressure losses shall be calculated for measuring ducts and straighteners that are located between the fan and the plane of measurement.

7.5.2.1 Hydraulic diameter

The hydraulic diameter for round ducts is the actual diameter (D). The hydraulic diameter for rectangular ducts shall be calculated from the duct inside dimensions a and b at the traverse using:

$$D_h = \frac{2ab}{a+b} \quad \text{Eq. 7.32}$$

7.5.2.2 Reynolds Number

The Reynolds number (Re) based on the hydraulic diameter (D_h) in meters (feet) shall be calculated from:

$$\mathrm{Re} = \frac{D_h V \rho}{\propto} \quad \text{Eq. 7.33 SI}$$

$$\mathrm{Re} = \frac{D_h V \rho}{60 \propto} \quad \text{Eq. 7.33 I-P}$$

Using properties of air as determined in Section 7.2 and the appropriate velocity (V) in m/s (fpm).

7.5.2.3 Coefficient of friction

The coefficient of friction (f) shall be determined from [19]:

$$f = \frac{0.14}{\mathrm{Re}^{0.17}} \quad \text{Eq. 7.34}$$

7.5.2.4 Cell straightener equivalent length

The ratio of equivalent length (L_e) of a straightener to hydraulic diameter (D_h) shall be determined from the elemental thickness (y) and the equivalent diameter (D) using:

$$\frac{L_e}{D_h} = \frac{15.04}{\left[1 - 26.65\left(\frac{y}{D}\right) + 184.6\left(\frac{y}{D}\right)^2\right]^{1.83}} \quad \text{Eq. 7.35}$$

This expression is exact for round duct straighteners and sufficiently accurate for rectangular duct straighteners.

7.5.2.5 Star straightener friction loss

The conventional loss coefficient of the star straightener, including the external duct, is given by:

$$\zeta_s = 0.95\mathrm{Re}^{-0.12} \quad \text{Eq. 7.36}$$

7.5.2.6 Common part friction loss

$$\zeta_{cp} = 0.015 + 1.26(\mathrm{Re}_{Dh4}{}^{-0.3}) + 0.95(\mathrm{Re}_{Dh4}{}^{-0.12}) \quad \text{Eq. 7.37}$$

7.5.3 Inlet total pressure

The total pressure at the fan inlet (P_{t1}) shall be calculated as follows:

7.5.3.1 Open inlet

When the fan draws directly from atmosphere, P_{t1} shall be considered equal to atmospheric pressure, which is zero gauge, so that:

$$P_{t1} = 0 \quad \text{Eq. 7.38}$$

7.5.3.2 Inlet chamber

When the fan is connected to an inlet chamber, P_{t1} shall be considered equal to the chamber pressure (P_{t8}) so that:

$$P_{t1} = P_{t8} \quad \text{Eq. 7.39}$$

7.5.3.3 Inlet duct

When the fan is connected to an inlet duct, P_{t1} shall be considered equal to the algebraic sum of the average static pressure (P_{s3}) and the average velocity pressure (P_{v3}), corrected for the friction due to the length of duct ($L_{1,3}$) between the measurement plane and the fan, so that:

$$P_{t1} = P_{s3} + P_{v3} - f\left(\frac{L_{1,3}}{D_{h3}}\right)P_{v3} \quad \text{Eq. 7.40}$$

Pressure P_{s3} will be less than atmospheric and its value will be negative.

7.5.4 Outlet total pressure

The total pressure at the fan outlet (P_{t2}) shall be calculated as follows:

7.5.4.1 Open outlet

When the fan discharges directly to atmosphere, the static pressure at the fan outlet (P_{s2}) shall be considered equal to atmospheric pressure, which is zero, so that:

$$P_{t2} = P_{v2} = P_v \quad \text{Eq. 7.41}$$

The value of P_v shall be as determined in Section 7.4.

7.5.4.2 Outlet chamber

When the fan discharges directly into an outlet chamber, the static pressure (P_{s2}) at the fan outlet shall be considered equal to the average chamber pressure (P_{s7}), so that:

$$P_{t2} = P_{s7} + P_{v2} = P_{s7} + P_v \quad \text{Eq. 7.42}$$

The value of P_v shall be as determined in Section 7.4.

7.5.4.3 Short duct

When the fan discharges through an outlet duct without a measurement plane either to the atmosphere or into an outlet chamber, the pressure loss of the duct shall be considered zero and calculations shall be made according to either Section 7.5.4.1 or Section 7.5.4.2.

7.5.4.4 Piezometer outlet duct

When the fan discharges into a duct with a piezometer ring, total pressure (P_{t2}) shall be considered equal to the sum of the average static pressure (P_{s4}) and the velocity pressure (P_{v4}) corrected for the friction loss due to both the straightener and the length ($L_{2,4}$) of the duct between the fan outlet and the measurement plane.

When a cell straightener is used:

$$P_{t2} = P_{s4} + P_{v4} + f\left(\frac{L_{2,4}}{D_{h4}} + \frac{L_e}{D_{h4}}\right)P_{v4} \quad \text{Eq. 7.43}$$

When a star straightener is used:

$$P_{t2} = P_{s4} + P_{v4} + f\left(\frac{L_{2,4}}{D_{h4}} - 2\right)P_{v4} + 0.95\left(\mathrm{Re}_4{}^{-0.12}\right)P_{v4}$$

Eq. 7.44

When a common part is used:

$$P_{t2} = P_{s4} + P_{v4} + (0.015 + 1.26(\mathrm{Re}^{-0.3}) + 0.95(\mathrm{Re}^{-0.12})P_{v4}$$

Eq. 7.45

7.5.4.5 Pitot outlet duct

When the fan discharges into a duct with a pitot traverse, total pressure (P_{t2}) shall be considered equal to the sum of the average static pressure (P_{s3}) and the velocity pressure (P_{v3}) corrected for the friction loss due to both the equivalent length (L_e) of the straightener and the length ($L_{2,3}$) of the duct between the fan outlet and the measurement plane.

When a cell straightener is used:

$$P_{t2} = P_{s3} + P_{v3} + f\left(\frac{L_{2,3}}{D_{h3}} + \frac{L_e}{D_{h3}}\right)P_{v3} \qquad \text{Eq. 7.46}$$

When a star straightener is used:

$$P_{t2} = P_{s3} + P_{v3} + f\left(\frac{L_{2,3}}{D_{h3}} - 2\right)P_{v3} + 0.95(\mathrm{Re}_3)^{-0.12}P_{v3}$$

Eq. 7.47

7.5.5 Fan total pressure

The fan total pressure (P_t) at test conditions for incompressible flow shall be calculated from:

$$P_t = P_{t2} - P_{t1} \qquad \text{Eq. 7.48}$$

This is an algebraic expression so that if P_{t1} is negative, P_t will be numerically greater than P_{t2}.

7.6 Fan static pressure at test conditions

The fan static pressure (P_s) at test conditions for incompressible flow shall be calculated from:

$$P_s = P_t - P_v \qquad \text{Eq. 7.49}$$

7.7 Fan input power at test conditions

7.7.1 Reaction dynamometer

When a reaction dynamometer is used to measure torque, the fan input power (H_i) shall be calculated from the beam load (F), using the moment arm (l) and the fan rotational speed (N) using:

$$H_i = \frac{2\pi FlN}{60} \qquad \text{Eq. 7.50 SI}$$

$$H_i = \frac{2\pi FlN}{33{,}000 \times 12} \qquad \text{Eq. 7.50 I-P}$$

7.7.2 Torsion element

When a torsion element is used to measure torque, the fan input power (H_i) shall be calculated from the torque (T) and the fan rotational speed (N) using:

$$H_i = \frac{2\pi TN}{60} \qquad \text{Eq. 7.51 SI}$$

$$H_i = \frac{2\pi TN}{33{,}000 \times 12} \qquad \text{Eq. 7.51 I-P}$$

7.7.3 Calibrated motor

When a calibrated electric motor is used to measure input power, the fan input power (H_i) may be calculated from the power input (W_{em}) to the motor and the motor efficiency (η_m) using:

$$H_i = W_{em}\eta_m \qquad \text{Eq. 7.52 SI}$$

$$H_i = \frac{W_m\eta_m}{745.7} \qquad \text{Eq. 7.52 I-P}$$

7.8 Fan efficiency

7.8.1 Fan output power

The fan output power (H_o) would be proportional to the product of fan airflow rate (Q) and fan total pressure (P_t) if air were incompressible. Since air is compressible, thermodynamic effects influence output and a compressibility coefficient (K_p) must be applied to make power output proportional to (QP_t) [20].

$$H_o = QP_tK_p \qquad \text{Eq. 7.53 SI}$$

$$H_o = \frac{QP_tK_p}{6343.3} \qquad \text{Eq. 7.53 I-P}$$

7.8.2 Compressibility factor

The compressibility coefficient (K_p) may be determined from:

$$x = \frac{P_t}{P_{t1} + p_b} \qquad \text{Eq. 7.54 SI}$$

$$x = \frac{P_t}{P_{t1} + 13.595p_b} \qquad \text{Eq. 7.54 I-P}$$

And:

$$z = \left(\frac{\gamma - 1}{\gamma}\right)\left(\frac{\left[\frac{H_i}{Q}\right]}{P_{t1} + p_b}\right) \qquad \text{Eq. 7.55 SI}$$

$$z = \left(\frac{\gamma - 1}{\gamma}\right)\left(\frac{\left[\frac{6343.3H_i}{Q}\right]}{P_{t1} + 13.595p_b}\right) \qquad \text{Eq. 7.55 I-P}$$

And:

$$K_p = \left(\frac{\ln(1+x)}{x}\right)\left(\frac{z}{\ln(1+z)}\right) \qquad \text{Eq. 7.56}$$

Which may be evaluated directly [20]. P_t, P_{t1}, p_b, H_i, and Q are all test values when mechanical input power is measured. When electrical input power is measured, H_i shall be estimated using Annex B.2 of ISO Standard 12759: 2010. The isentropic exponent (γ) may be taken as 1.4 for air.

7.8.3 Fan total efficiency
The fan total efficiency (η_t) is the ratio of the fan output power to fan input power, or:

$$\eta_t = \frac{QP_tK_p}{H_i} \qquad \text{Eq. 7.57 SI}$$

$$\eta_t = \frac{QP_tK_p}{6343.3H_i} \qquad \text{Eq. 7.57 I-P}$$

7.8.4 Fan static efficiency
The fan static efficiency (η_s) may be calculated from the fan total efficiency (η_t) and the ratio of the fan static pressure (P_s) to fan total pressure (P_t) using:

$$\eta_s = \eta_t\left(\frac{P_s}{P_t}\right) \qquad \text{Eq. 7.58}$$

7.8.5 Fan with drive total efficiency

$$\eta_{tx} = \frac{QP_tK_F}{W_x} \qquad \text{Eq. 7.59 SI}$$

$$\eta_{tx} = \frac{QP_tK_P}{W_x 8.507} \qquad \text{Eq. 7.59 I-P}$$

7.8.6 Fan with drive static efficiency

$$\eta_{sx} = \eta_{tx}\frac{P_s}{P_t} \qquad \text{Eq. 7.60}$$

K_p is assumed to be 1.

7.9 Conversion of results to other rotational speeds and air densities

Test results may be converted to a different air density or a different rotational speed from the conditions that were present during the test. During a laboratory test, the air density and rotational speed may vary slightly from one determination point to another. It may be desirable to convert all test points to a nominal density, a constant rotational speed or both. If the nominal air density (ρ_c) is within 10% of the fan air density (ρ) and the constant rotational speed (N_c) is within 5% of the actual rotational speed (N), then the air can be treated as if it were incompressible and Section 7.9.1 can be used. The compressible flow methods given in Section 7.9.2 can be used for any correction, but must be used when the air density or rotational speed exceeds the limits given above.

7.9.1 Conversion to other rotational speeds and air densities with incompressible flow
For small changes in air density or rotational speeds, compressibility can be assumed to be constant. Use K_{pc} = K_p and Equations 7.61–70 to make this conversion.

7.9.2 Conversion to other rotational speeds and air densities with compressible flow
For large changes in air density or rotational speed, it is necessary to treat the air as a compressible gas. This is an iterative process as follows (used for $Q > 0$):

Step 1: Using test values for Q, P_t and (H_i) with Equations 7.54, 7.55 and 7.56, find K_p.

Step 2: Use K_p = K_{pc} together with the desired rotational speed (N_c) and the desired density (ρ_c) in Equations 7.61, 7.62 and 7.65 to find Q_c, P_{tc} and H_{ic}.

Step 3: Use Equations 7.54, 7.55 and 7.56 and the new values Q_c, P_{tc}, and H_{ic} to find a new K_{pc}.

Step 4: Using the new value of K_{pc},together with N_c, ρ_c and Equations 7.61, 7.62 and 7.65, find the new Q_c, P_{tc} and H_{ic}.

Step 5: Repeat steps 3 and 4 until Q_c, P_{tc} and H_{ic} do not change (or are of sufficient accuracy).

These values converge rapidly, and usually only two or three iterations are required.

7.9.3 Conversion formulae for new densities and new rotational speeds
Actual test results may be converted to a new density (ρ_c) or to a new rotational speed (N_c) using the following formulae. See Annex E for their derivation.

When electrical input power is measured and results are to be corrected to a different air density, use K_{pc} = Kp in the following formulae. Density corrections shall be limited to 10% and speed corrections shall not be allowed.

$$Q_c = Q\left(\frac{N_c}{N}\right)\left(\frac{K_p}{K_{pc}}\right) \quad \text{Eq. 7.61}$$

$$P_{tc} = P_t\left(\frac{N_c}{N}\right)^2\left(\frac{\rho_c}{\rho}\right)\left(\frac{K_p}{K_{pc}}\right) \quad \text{Eq. 7.62}$$

$$P_{vc} = P_v\left(\frac{N_c}{N}\right)^2\left(\frac{\rho_c}{\rho}\right) \quad \text{Eq. 7.63}$$

$$P_{sc} = P_{tc} - P_{vc} \quad \text{Eq. 7.64}$$

$$H_{ic} = H_i\left(\frac{N_c}{N}\right)^3\left(\frac{\rho_c}{\rho}\right)\left(\frac{K_p}{K_{pc}}\right) \quad \text{Eq. 7.65}$$

$$W_{xc} = W_x\left(\frac{\rho_c}{\rho}\right)\left(\frac{K_p}{K_{pc}}\right) \quad \text{Eq. 7.68}$$

$$\eta_{tc} = \eta_t \quad \text{Eq. 7.69}$$

And:

$$\eta_{sc} = \eta_{tc}\left(\frac{P_{sc}}{P_{tc}}\right) \quad \text{Eq. 7.70}$$

8. Report and Results of Test

8.1 Report

The report of a laboratory fan test shall include the objective, results, test data and descriptions of the test fan, including appurtenances, test figure and installation type, test instruments and personnel, as outlined in Section 6. The test report shall also state the inlet, outlet and power boundaries of the fan and what appurtenances were included with them. The laboratory shall be identified by name and location.

8.2 Performance graphical representation of test results

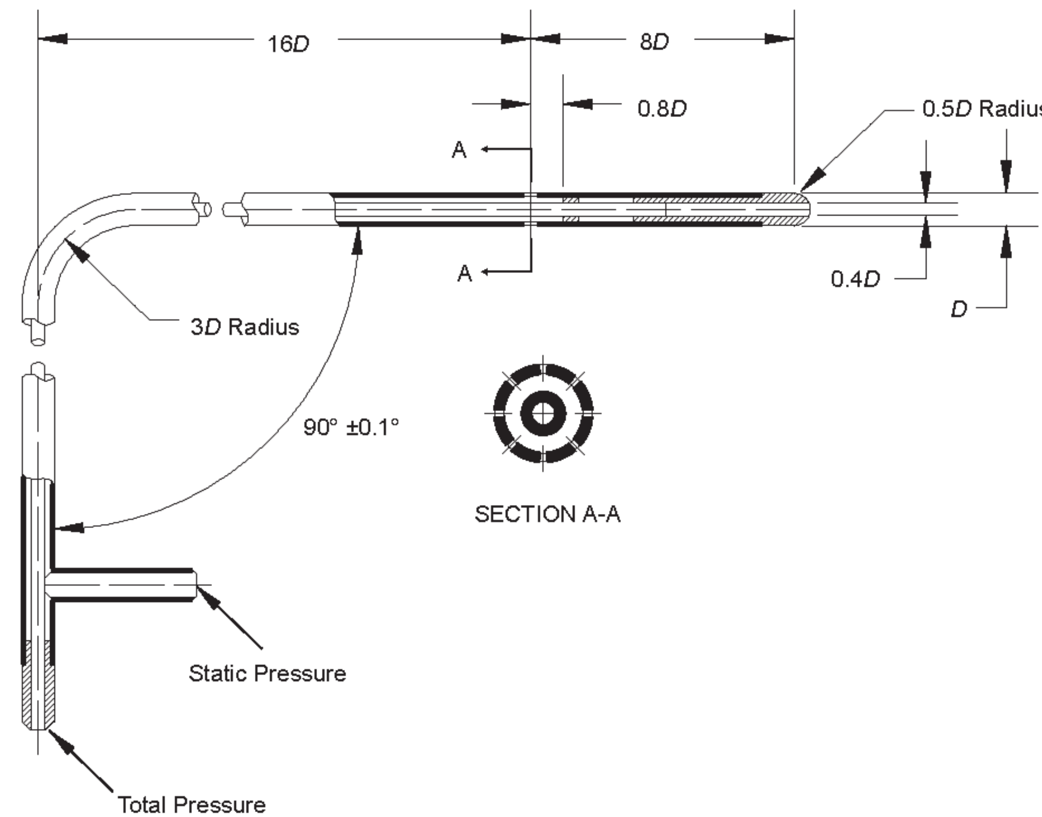
The results of a fan test shall be presented as plots. The result of each determination shall be shown by a marker. The fan performance between the markers can be estimated by a curve or line. Typical fan performance curves are shown in Figure 17.

8.2.1 Coordinates and labeling

Performance plots shall be drawn with the fan airflow rate as abscissa. Fan pressure and fan power shall be plotted as ordinates. Fan total pressure, fan static pressure or both may be shown. If all results were obtained at the same rotational speed or if results were converted to a nominal rotational speed, that speed shall be listed. Otherwise, a plot with fan speed as ordinate shall be drawn. If all results were obtained at the same air density or if results were converted to a nominal air density, that air density shall be listed. Otherwise, a plot with air density as ordinate shall be drawn. Plots with fan total efficiency and/or fan static efficiency as ordinates may be drawn. Barometric pressure shall be listed when fan pressure exceed 2.5 kPa (10 in. wg).

8.2.2 Identification

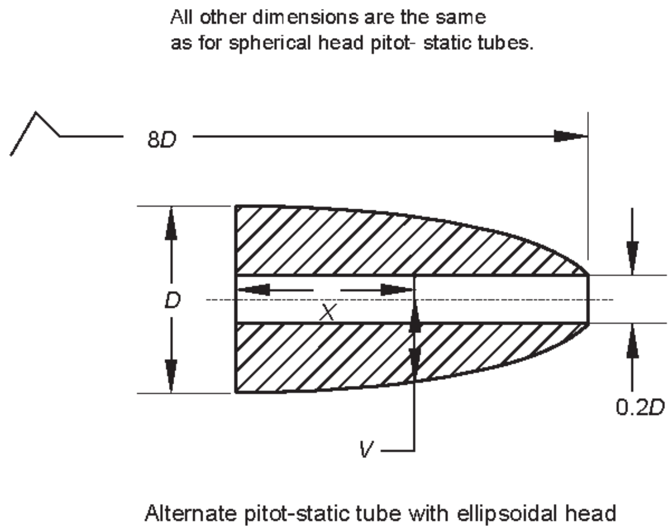
Each sheet with the fan performance plots shall list the fan tested and the test figure (see Figures 7A, 7B, 8A, 8B, 9A, 9B, 9C, 10A, 10B, 10C, 11, 12, 13, 14, 15 and 16). The report that contains the information required in Section 8.1 shall be identified.



Notes:

1. Surface finish shall be 0.8 micrometer (32 micro-in.) or better. The static orifices may not exceed 1 mm (0.04 in.) diameter. The minimum pitot tube stem diameter recognized under this standard shall be 2.5 mm (0.10 in.) in no case shall the stem diameter exceed 1/30 of the test duct diameter.
2. Head shall be free from nicks and burrs.
3. All dimensions shall be within ±2%.
4. Section A-A shows 8 holes equally spaced and free from burrs. Hole diameter shall be 0.13*D*, but not exceeding 1 mm (0.04 in.) hole depth diameter.

Figure 1A
Pitot-Static Tube with Spherical Head



X/D	V/D
0	0.5
0.237	0.496
0.336	0.494
0.474	0.487
0.622	0.477
0.741	0.468
0.936	0.449
1.025	0.436
1.134	0.42
1.228	0.404
1.313	0.388
1.39	0.371
1.442	0.357
1.506	0.343
1.538	0.333
1.57	0.323

X/D	V/D
1.602	0.314
1.657	0.295
1.698	0.279
1.73	0.266
1.762	0.25
1.796	0.231
1.83	0.211
1.858	0.192
1.875	0.176
1.888	0.163
1.9	0.147
1.91	0.131
1.918	0.118
1.92	0.109
1.921	0.1

Figure 1B
Alternate Pitot-Static Tube with Ellipsoidal Head

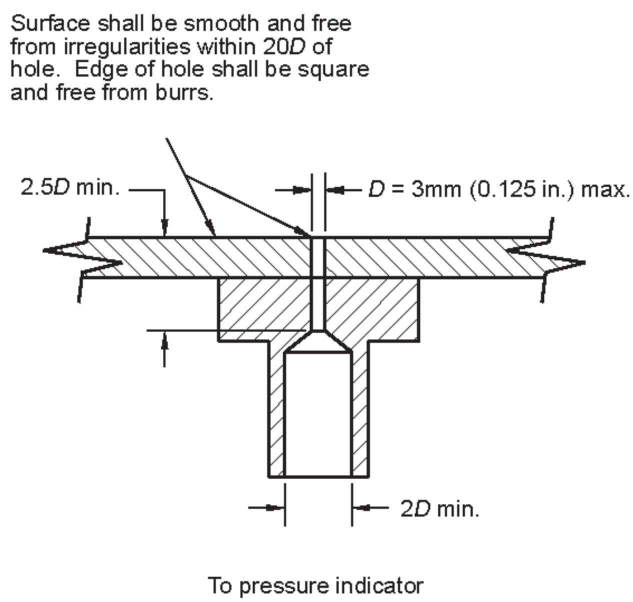


Figure 2A
Static Pressure Tap

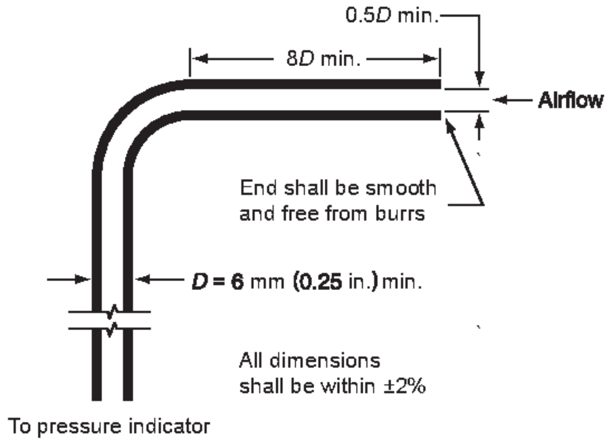
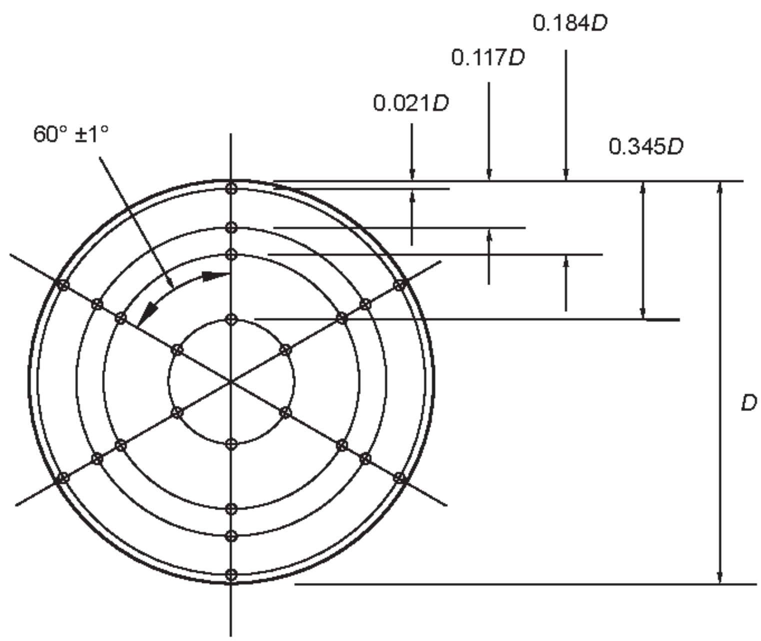


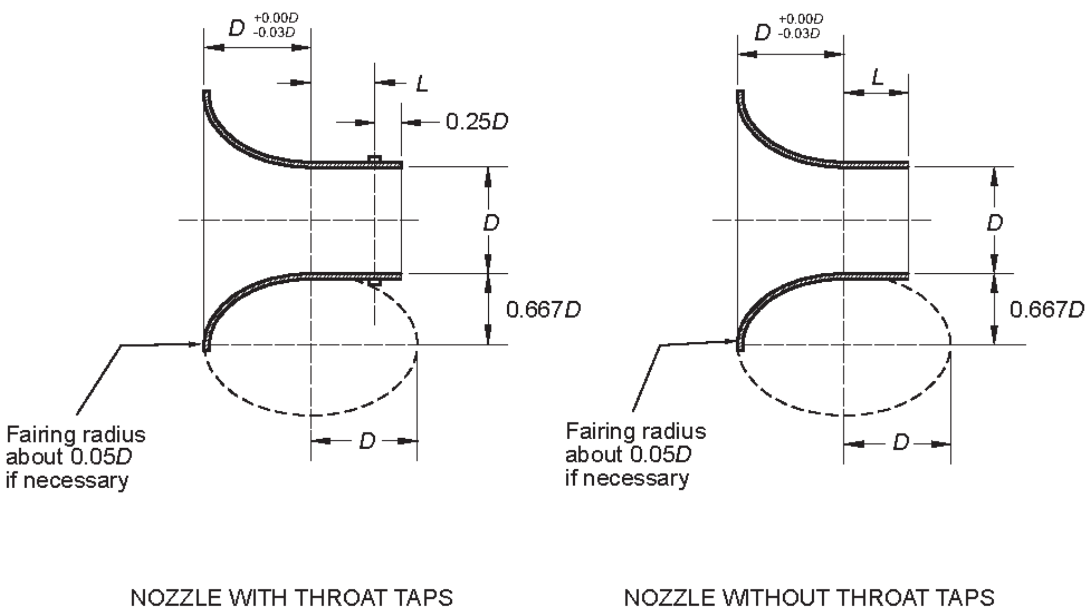
Figure 2B
Total Pressure Tube



Notes:

1. D is the average of four measurements at traverse plane at 45° angles measured to accuracy of 0.2% D.
2. Traverse duct shall be round within 0.5% D at traverse plane and for a distance of 0.5D on either side of traverse plane.
3. All pitot positions ± 0.005D or 4 mm (0.125 in.), whichever is greater.

Figure 3
Traverse Points in a Round Duct



Notes:

1. The nozzle shall have a cross section consisting of elliptical and cylindrical portions, as shown. The cylindrical portion is defined as the nozzle throat.
2. The cross section of the elliptical portion is one quarter of an ellipse, having the large axis *D* and the small axis 0.667*D*. A three-radii approximation to the elliptical form that does not differ at any point in the normal direction more than 1.5% from the elliptical form shall be used. The adjacent arcs, as well as the last arc, shall smoothly meet and blend with the nozzle throat. The recommended approximation which meets these requirements is shown in Figure 4B from John Cermak's memorandum report to AMCA 210/ASHRAE 51 Committee, June 16, 1992.
3. The nozzle throat dimension (*L*) shall be either 0.6*D* +/- 0.005*D* (recommended), or 0.5*D* +/- 0.005*D*.
4. The nozzle throat shall be measured (to an accuracy of 0.001*D*) at the minor axis of the ellipse and the nozzle exit. At each place, four diameters, approximately 45° apart, must be within +/-0.002*D* of the mean. At the entrance of the throat, the mean may be 0.002*D* greater than but no less than the mean of the nozzle exit.
5. The nozzle surface in the direction of flow from the nozzle inlet towards the nozzle exit shall fair smoothly so that a straight-edge may be rocked over the surface without clicking. The macro-pattern of the surface shall not exceed 0.001*D*, peak-to-peak. The edge of the nozzle exit shall be square, sharp and free of burrs, nicks or roundings.
6. In a chamber, the use of either of the nozzle types shown above is permitted. A nozzle with throat taps shall be used when the discharge is direct into a duct, and the nozzle outlet shall be flanged for connection with the duct.
7. A nozzle with throat taps shall have four such taps conforming to Figure 2A, located 90° ± 2° apart. All four taps shall be connected to a piezometer ring.

Figure 4A
Nozzles

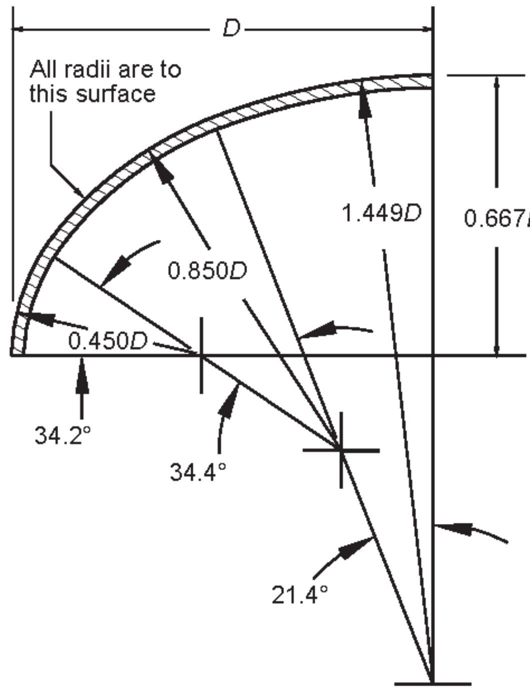


Figure 4B
Three Arc Approximation of Elliptical Nozzle

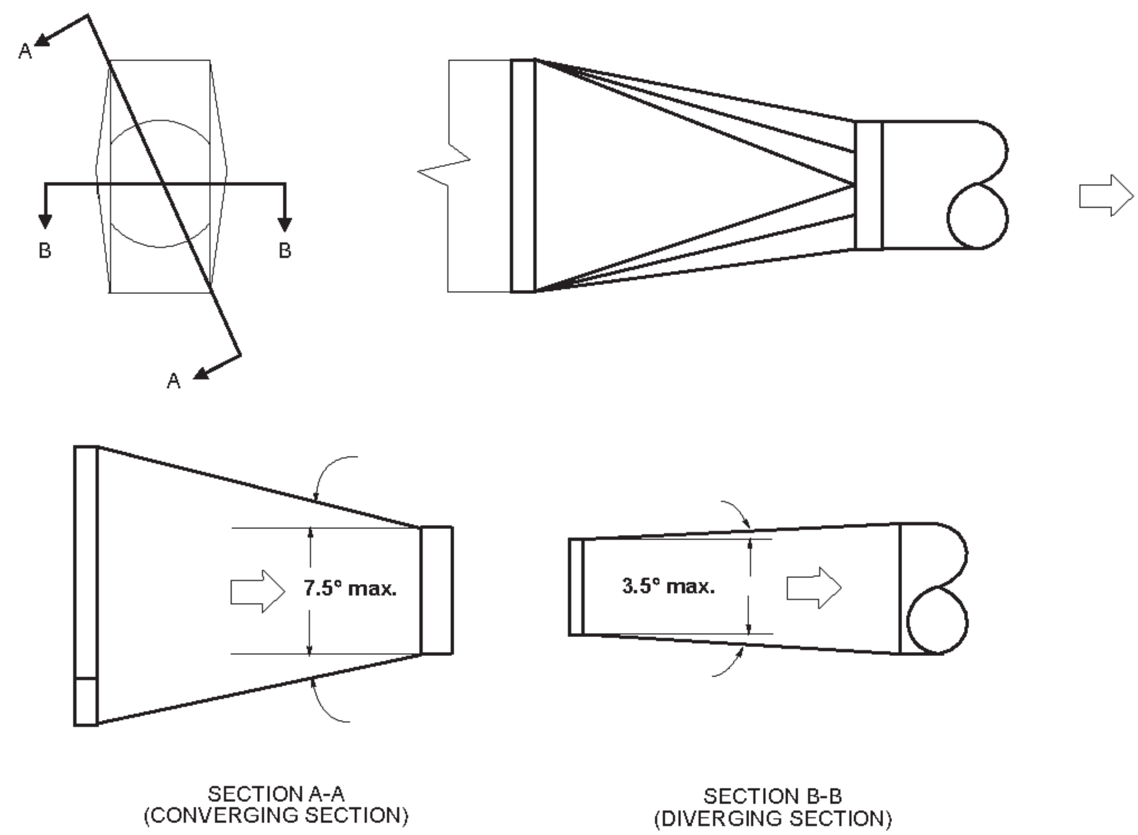
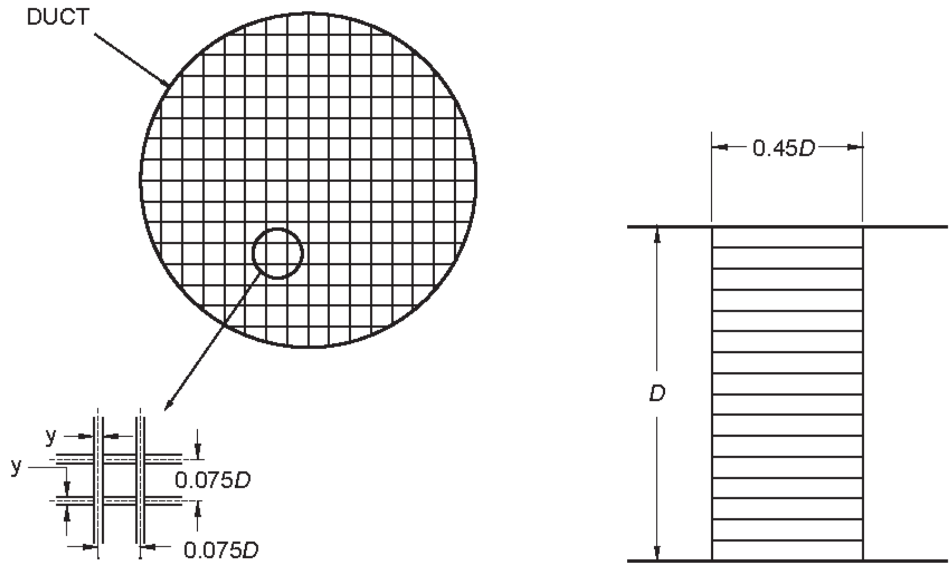


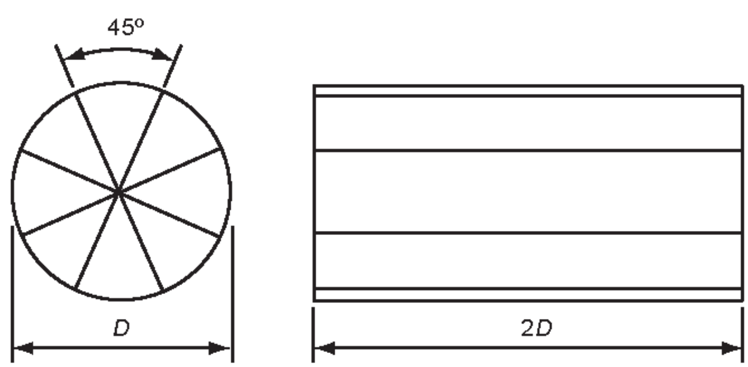
Figure 5
Transition Piece for Long Ducts



Notes:

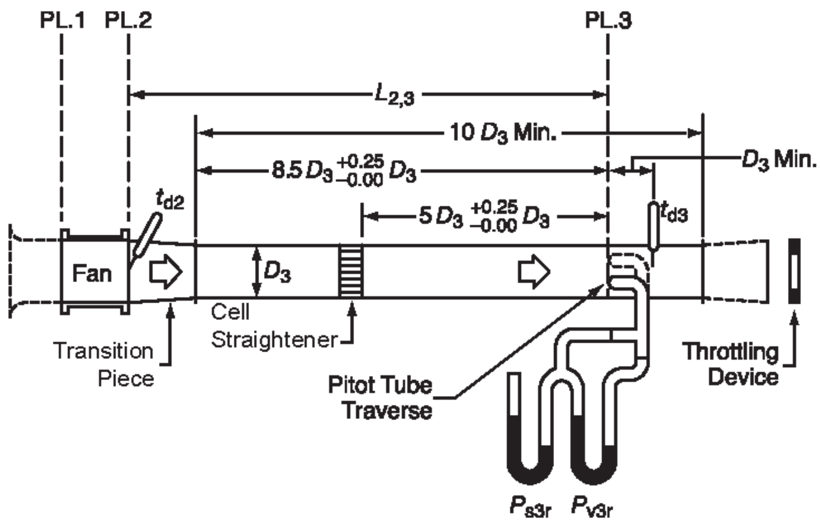
1. All dimensions shall be within ±0.005D except y, which shall not exceed 0.005D
2. Cell sides shall be flat and straight. Where $y > 3$ mm (0.125 in.), the leading edge of each segment shall have a chamfer of 1.3 mm (0.05 in.) per side. The method of joining cell segments (such as tack welds) shall be kept to the minimum required for mechanical integrity and shall result in minimum protrusion into the fluid stream.

Figure 6A
Flow Straightener — Cell Type



The star straightener will be constructed of eight radial blades of length equal to 2D_4 (with a ±1% tolerance) and of thickness not greater than 0.007D_4. The blades will be arranged to be equidistant on the circumference with the angular deviation being no greater than 5º between adjacent plates.

Figure 6B
Flow Straightener — Star Type



Notes:

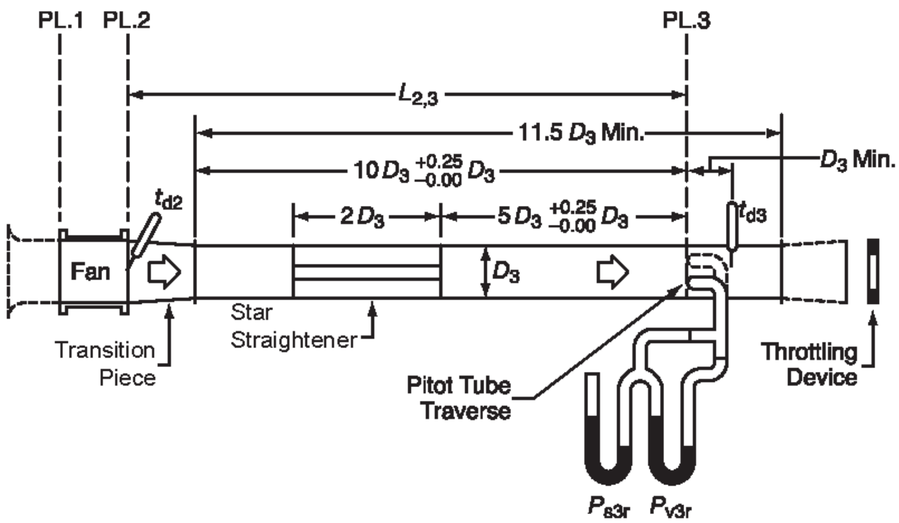
1. Dotted lines on fan inlet indicate an inlet bell and one equivalent duct diameter, which may be used for inlet duct simulation. The duct friction shall not be considered.
2. Dotted lines on the outlet indicate a diffuser cone that may be used to approach more nearly free delivery.

Flow and Pressure Formulae

$Q = Q_3\left(\frac{\rho_3}{\rho}\right)$	$P_t = P_{t2} - P_{t1}$	$P_v = P_{v3}\left(\frac{A_3}{A_2}\right)^2\left(\frac{\rho_3}{\rho_2}\right)$	$P_s = P_t - P_v$
$Q_3 = V_3 A_3$	$P_{t1} = 0$	$P_{v3} = \left(\frac{\sum\sqrt{P_{v3r}}}{n}\right)^2$	$P_{s3} = \frac{\sum P_{s3r}}{n}$
$^*V_3 = \sqrt{2}\sqrt{\frac{P_{v3}}{\rho_3}}$	$P_{t2} = P_{s3} + P_{v3} + f\left(\frac{L_{2,3}}{D_{h3}} + \frac{L_e}{D_{h3}}\right)P_{v3}$		

*The formulae given above are the same in both SI and the I-P systems except for V_3; in the I-P version, the constant $\sqrt{2}$ is replaced with the value 1097.8.

Figure 7A
Outlet Duct Setup — Pitot Traverse in Outlet Duct with Cell Straightener



Notes:

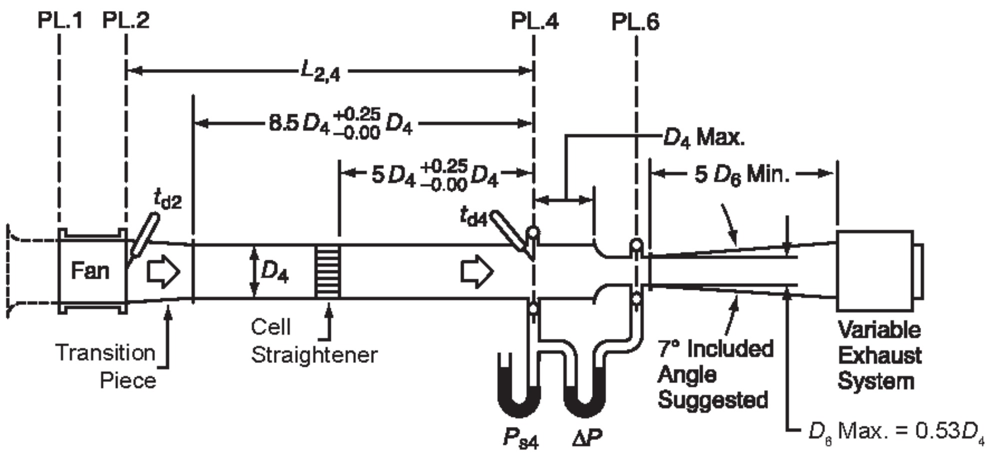
1. Dotted lines on fan inlet indicate an inlet bell and one equivalent duct diameter, which may be used for inlet duct simulation. The duct friction shall not be considered.
2. Dotted lines on the outlet indicate a diffuser cone that may be used to approach more nearly free delivery.

Flow and Pressure Formulae

$Q = Q_3\left(\frac{\rho_3}{\rho}\right)$	$P_t = P_{t2} - P_{t1}$	$P_v = P_{v3}\left(\frac{A_3}{A_2}\right)^2\left(\frac{\rho_3}{\rho_2}\right)$	$P_s = P_t - P_v$
$Q_3 = V_3 A_3$	$P_{t1} = 0$	$P_{v3} = \left(\frac{\sum\sqrt{P_{v3r}}}{n}\right)^2$	$P_{s3} = \frac{\sum P_{s3r}}{n}$
$^*V_3 = \sqrt{2}\sqrt{\frac{P_{v3}}{\rho_3}}$	$P_{t2} = P_{s3} + P_{v3} + f\left(\frac{L_{2,3}}{D_{h3}} - 2\right)P_{v3} + 0.95(\mathrm{Re}_3)^{-0.12}P_{v3}$		

*These formulae are the same in both the SI and I-P systems except for V_3; in the I-P version, the constant $\sqrt{2}$ is replaced with the value 1097.8.

Figure 7B
Outlet Duct Setup — Pitot Traverse in Outlet Duct with Star Straightener



Notes:

1. Dotted lines on fan inlet indicate an inlet bell and one equivalent duct diameter, which may be used for inlet duct simulation. The duct friction shall not be considered.
2. This figure may terminate at Plane 6 and interchangeable nozzles may be employed. In this case $\Delta P = P_{s4}$.
3. Variable exhaust system may be an auxiliary fan or a throttling device.
4. Nozzle shall be in accordance with Figure 4A nozzle with throat taps.

Flow and Pressure Formulae

$$Q = Q_4\left(\frac{\rho_4}{\rho}\right)$$

$$P_t = P_{t2} - P_{t1}$$

$$P_v = P_{v4}\left(\frac{A_4}{A_2}\right)^2\left(\frac{\rho_4}{\rho_2}\right)$$

$$P_s = P_t - P_v$$

$$*Q_4 = \frac{\sqrt{2}CA_6Y\sqrt{\frac{\Delta P}{\rho_4}}}{\sqrt{1-E\beta^4}}$$

$$P_{t1} = 0$$

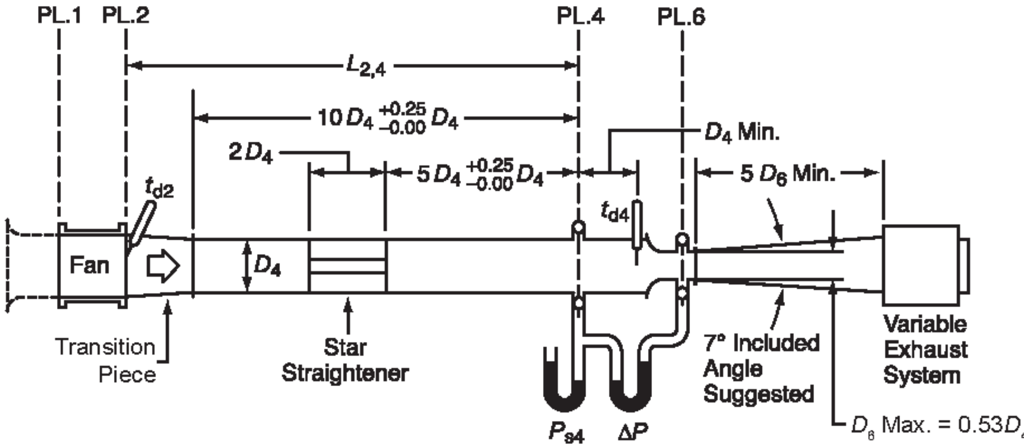
$$*P_{v4} = \left(\frac{V_4}{\sqrt{2}}\right)^2\rho_4$$

$$V_4 = \frac{Q_4}{A_4}$$

$$P_{t2} = P_{s4} + P_{v4} + f\left(\frac{L_{2,4}}{D_{h4}} + \frac{L_e}{D_{h4}}\right)P_{v4}$$

*These formulae are the same in both the SI and the I-P systems except for Q_4 and P_{v4}; in the I-P version, the constant $\sqrt{2}$ is replaced with the value 1097.8.

Figure 8A
Outlet Duct Setup — Nozzle on End of Outlet Duct with Cell Straightener



Notes:

1. Dotted lines on fan inlet indicate an inlet bell and one equivalent duct diameter, which may be used for inlet duct simulation. The duct friction shall not be considered.
2. This figure may terminate at Plane 6 and interchangeable nozzles may be employed. In this case, $\Delta P = P_{s4}$.
3. Variable exhaust system may be an auxiliary fan or a throttling device.
4. Nozzle shall be in accordance with Figure 4A nozzle with throat taps.

Flow and Pressure Formulae

$$Q = Q_4\left(\frac{\rho_4}{\rho}\right)$$

$$P_t = P_{t2} - P_{t1}$$

$$P_v = P_{v4}\left(\frac{A_4}{A_2}\right)^2\left(\frac{\rho_4}{\rho_2}\right)$$

$$P_s = P_t - P_v$$

$$*Q_4 = \frac{\sqrt{2}CA_6Y\sqrt{\frac{\Delta P}{\rho_4}}}{\sqrt{1-E\beta^4}}$$

$$P_{t1} = 0$$

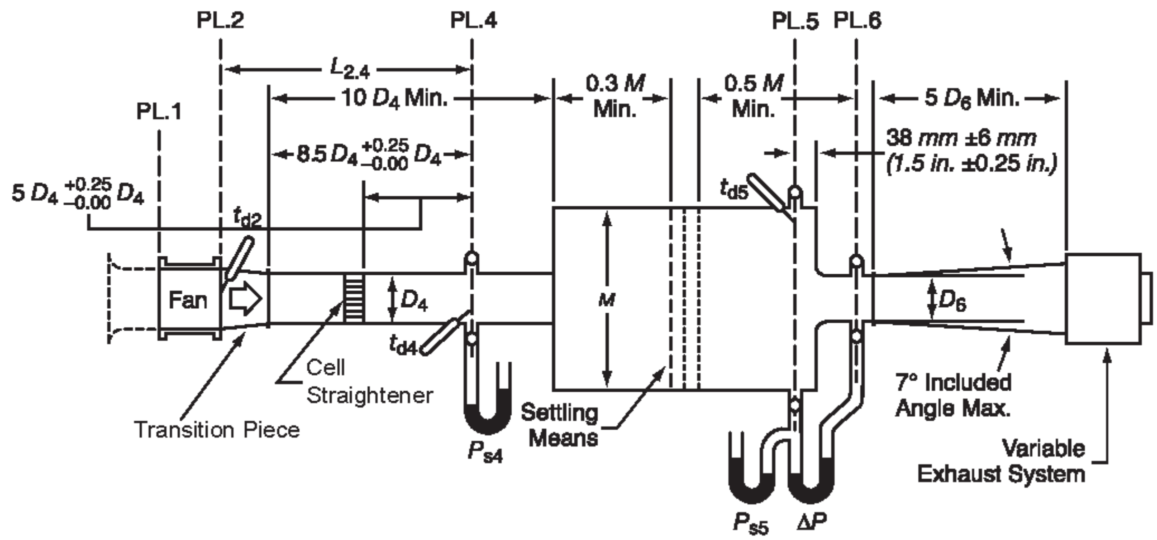
$$*P_{v4} = \left(\frac{V_4}{\sqrt{2}}\right)^2\rho_4$$

$$V_4 = \frac{Q_4}{A_4}$$

$$P_{t2} = P_{s4} + P_{v4} + f\left(\frac{L_{2,4}}{D_{h4}} - 2\right)P_{v4} + 0.95(\text{Re}_4)^{-0.12}P_{v4}$$

*These formulae are the same in both the SI and the I-P systems except for Q_4 and P_{v4}; in the I-P version, the constant $\sqrt{2}$ is replaced with the value 1097.8.

Figure 8B
Outlet Duct Setup — Nozzle on End of Outlet Duct with Star Straightener



Notes:

1. Dotted lines on fan inlet indicate an inlet bell and one equivalent duct diameter, which may be used for inlet duct simulation. The duct friction shall not be considered.
2. Additional ductwork of any size including elbows may be used to connect between the chamber and the exit of the 10D minimum test duct.
3. Variable exhaust system may be an auxiliary fan or a throttling device.
4. Minimum (M) is determined by the requirements of Section 5.3.1 for this figure.
5. Nozzle shall be in accordance with Figure 4A nozzle with throat taps.

Flow and Pressure Formulae

$$Q = Q_5\left(\frac{\rho_5}{\rho}\right)$$

$$P_t = P_{t2} - P_{t1}$$

$$P_v = P_{v4}\left(\frac{A_4}{A_2}\right)^2\left(\frac{\rho_4}{\rho_2}\right)$$

$$P_s = P_t - P_v$$

$$*Q_5 = \sqrt{2}CA_6Y\sqrt{\frac{\Delta P}{\rho_5}}$$

$$P_{t1} = 0$$

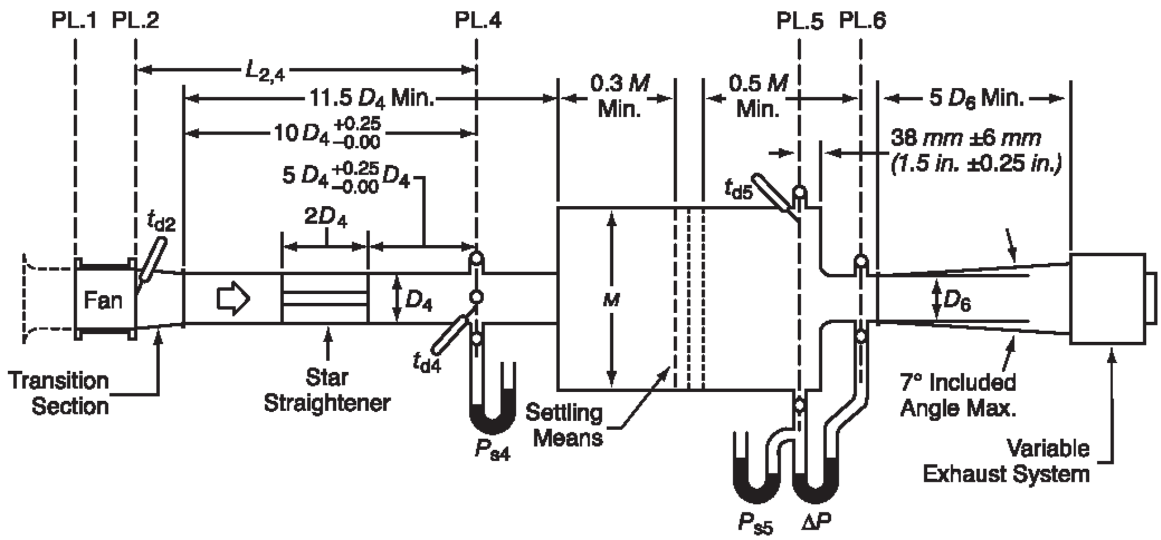
$$*P_{v4} = \left(\frac{V_4}{\sqrt{2}}\right)^2\rho_4$$

$$V_4 = \left(\frac{Q}{A_4}\right)\left(\frac{\rho}{\rho_4}\right)$$

$$P_{t2} = P_{s4} + P_{v4} + f\left(\frac{L_{2,4}}{D_{h4}} + \frac{L_e}{D_{h4}}\right)P_{v4}$$

*These formulae are the same in both the SI and the I-P systems except for Q_5 and P_{v4}; in the I-P version, the constant $\sqrt{2}$ is replaced with the value 1097.8.

Figure 9A
Outlet Duct Setup — Nozzle On End of Chamber with Cell Straightener



Notes:

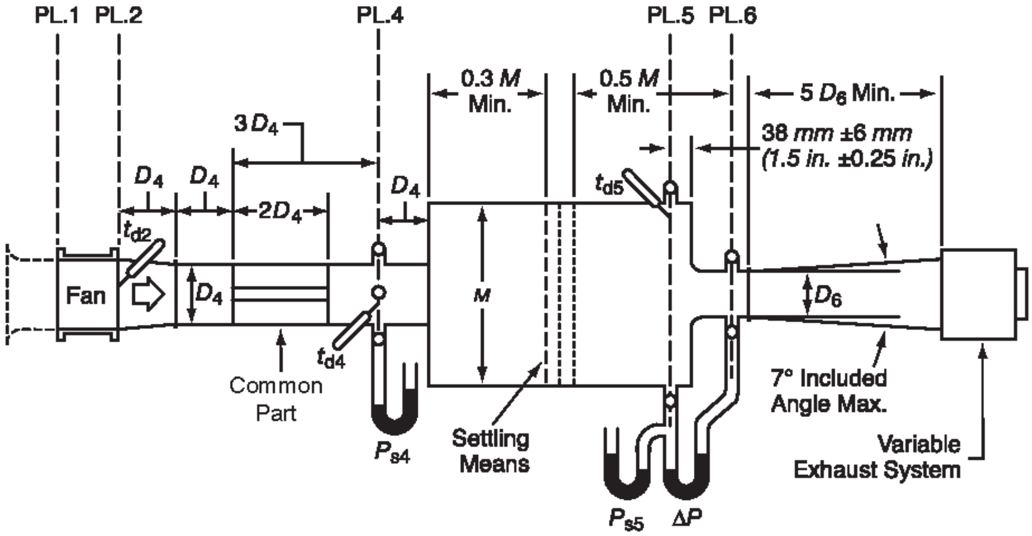
1. Dotted lines on fan inlet indicate an inlet bell and one equivalent duct diameter which may be used for inlet duct simulation. The duct friction shall not be considered.
2. Additional ductwork of any size including elbows may be used to connect between the chamber and the exit of the 11.5*D* minimum test duct.
3. Variable exhaust system may be an auxiliary fan or a throttling device.
4. Minimum (*M*) is determined by the requirements of Section 5.3.1 for this figure.
5. Nozzle shall be in accordance with Figure 4A nozzle with throat taps.

Flow and Pressure Formulae

$Q = Q_5\left(\frac{\rho_5}{\rho}\right)$	$P_t = P_{t2} - P_{t1}$	$P_v = P_{v4}\left(\frac{A_4}{A_2}\right)^2\left(\frac{\rho_4}{\rho_2}\right)$	$P_s = P_t - P_v$
$*Q_5 = \sqrt{2}CA_6Y\sqrt{\frac{\Delta P}{\rho_5}}$	$P_{t1} = 0$	$*P_{v4} = \left(\frac{V_4}{\sqrt{2}}\right)^2\rho_4$	
$V_4 = \left(\frac{Q}{A_4}\right)\left(\frac{\rho}{\rho_4}\right)$	$P_{t2} = P_{s4} + P_{v4} + f\left(\frac{L_{2,4}}{D_{h4}} - 2\right)P_{v4} + 0.95(\text{Re})^{-0.12}P_{v4}$		

*These formulae are the same in both the SI and the I-P systems except for Q_5 and P_{v4}; in the I-P version, the constant $\sqrt{2}$ is replaced with the value 1097.8.

Figure 9B
Outlet Duct Setup — Nozzle On End of Chamber with Star Straightener



Notes:

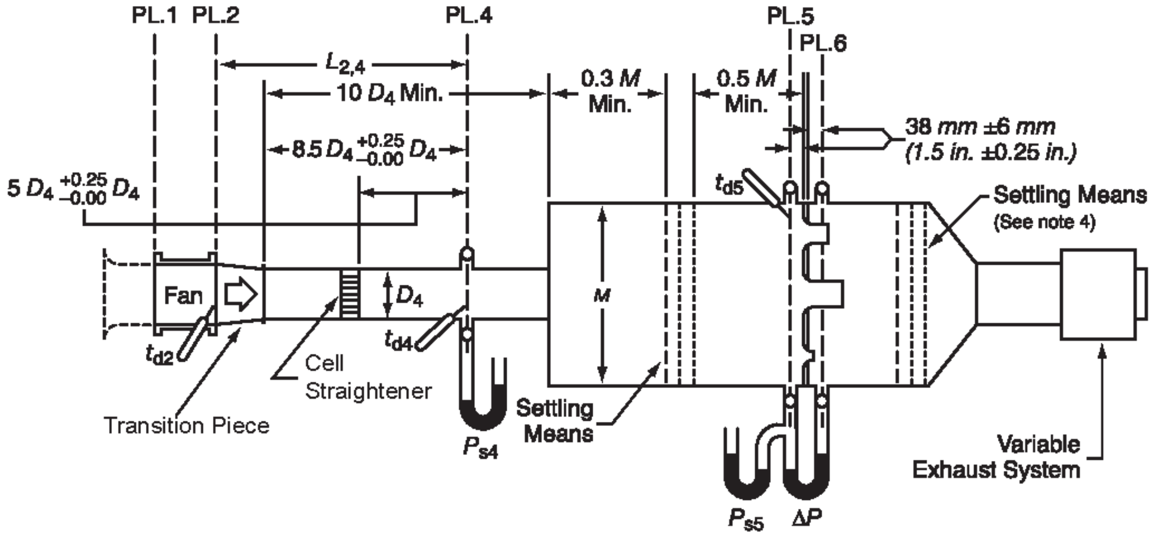
1. Dotted lines on fan inlet indicate an inlet bell and one equivalent duct diameter, which may be used for inlet duct simulation. The duct friction shall not be considered.
2. Additional ductwork of any size including elbows may be used to connect between the chamber and the exit of the test duct shown between the test fan and the chamber.
3. Variable exhaust system may be an auxiliary fan or a throttling device.
4. Minimum (M) is determined by the requirements of Section 5.3.1 for this figure.
5. Nozzle shall be in accordance with Figure 4A — Nozzle with Throat Taps

Flow and Pressure Formulae

$Q = Q_5\left(\frac{\rho_5}{\rho}\right)$	$P_t = P_{t2} - P_{t1}$	$P_v = P_{v4}\left(\frac{A_4}{A_2}\right)^2\left(\frac{\rho_4}{\rho_2}\right)$	$P_s = P_t - P_v$
$^*Q_5 = \sqrt{2}CA_6Y\sqrt{\frac{\Delta P}{\rho_5}}$	$P_{t1} = 0$	$^*P_{v4} = \left(\frac{V_4}{\sqrt{2}}\right)^2\rho_4$	
$V_4 = \left(\frac{Q}{A_4}\right)\left(\frac{\rho}{\rho_4}\right)$	$P_{t2} = P_{s4} + P_{v4} + (0.015 + 1.26(\mathrm{Re})^{-0.3} + 0.95(\mathrm{Re})^{-0.12})P_{v4}$		

*These formulae are the same in both the SI and the I-P systems except for Q5 and Pv4; in the I-P version, the constant $\sqrt{2}$ is replaced with the value 1097.8.

Figure 9C
Outlet Duct Setup — Nozzle On End of Chamber with Common Part



Notes:

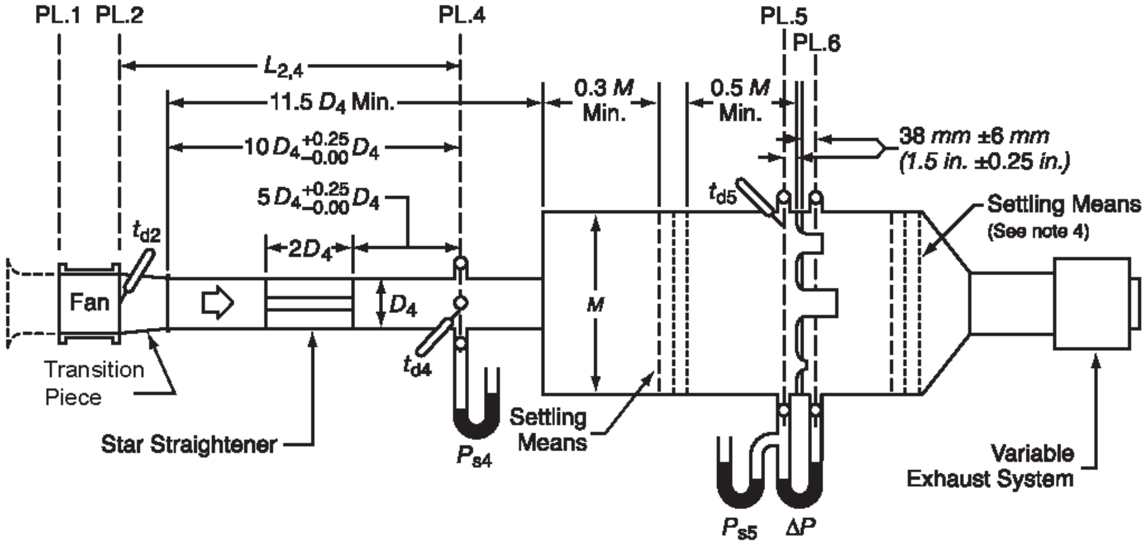
1. Dotted lines on fan inlet indicate an inlet bell and one equivalent duct diameter, which may be used for inlet duct simulation. The duct friction shall not be considered.
2. Additional ductwork of any size, including elbows, may be used to connect between the chamber and the exit of the 10*D* minimum test duct.
3. Variable exhaust system may be an auxiliary fan or a throttling device.
4. The distance from the exit face of the largest nozzle to the downstream settling means shall be a minimum of 2.5 throat diameters of the largest nozzle.
5. Minimum (*M*) is determined by the requirements of Section 5.3.1 for this figure.

Flow and Pressure Formulae

$Q = Q_5\left(\frac{\rho_5}{\rho}\right)$	$P_t = P_{t2} - P_{t1}$	$P_v = P_{v4}\left(\frac{A_4}{A_2}\right)^2\left(\frac{\rho_4}{\rho_2}\right)$	$P_s = P_t - P_v$
$^*Q_5 = \sqrt{2}Y\sqrt{\frac{\Delta P}{\rho_5}}\sum(CA_6)$	$P_{t1} = 0$	$^*P_{v4} = \left(\frac{V_4}{\sqrt{2}}\right)^2\rho_4$	
$V_4 = \left(\frac{Q}{A_4}\right)\left(\frac{\rho}{\rho_4}\right)$	$P_{t2} = P_{s4} + P_{v4} + f\left(\frac{L_{2,4}}{D_{h4}} + \frac{L_e}{D_{h4}}\right)P_{v4}$		

*These formulae are the same in both the SI and the I-P systems except for Q_5 and P_{v4}; in the I-P version, the constant $\sqrt{2}$ is replaced with the value 1097.8.

Figure 10A
Outlet Duct Setup — Multiple Nozzles In Chamber with Cell Straightener



Notes:

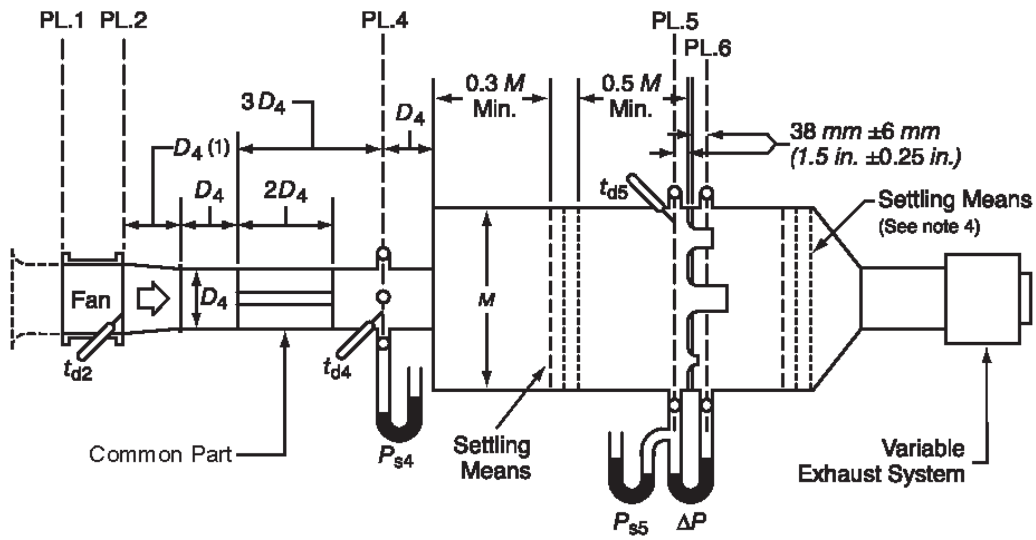
1. Dotted lines on fan inlet indicate an inlet bell and one equivalent duct diameter, which may be used for inlet duct simulation. The duct friction shall not be considered.
2. Additional ductwork of any size, including elbows, may be used to connect between the chamber and the exit of the 11.5*D* minimum test duct.
3. Variable exhaust system may be an auxiliary fan or a throttling device.
4. The distance from the exit face of the largest nozzle to the downstream settling means shall be a minimum of 2.5 throat diameters of the largest nozzle.
5. Minimum (*M*) is determined by the requirements Section of 5.3.1 for this figure.

Flow and Pressure Formulae

$Q = Q_5\left(\frac{\rho_5}{\rho}\right)$	$P_t = P_{t2} - P_{t1}$	$P_v = P_{v4}\left(\frac{A_4}{A_2}\right)^2\left(\frac{\rho_4}{\rho_2}\right)$	$P_s = P_t - P_v$
$*Q_5 = \sqrt{2}Y\sqrt{\frac{\Delta P}{\rho_5}}\sum(CA_6)$	$P_{t1} = 0$	$*P_{v4} = \left(\frac{V_4}{\sqrt{2}}\right)^2\rho_4$	
$V_4 = \left(\frac{Q}{A_4}\right)\left(\frac{\rho}{\rho_4}\right)$	$P_{t2} = P_{s4} + P_{v4} + f\left(\frac{L_{2,4}}{D_{h4}} - 2\right)P_{v4} + 0.95(\mathrm{Re})^{-0.12}P_{v4}$		

*These formulae are the same in both the SI and the I-P systems except for Q_5 and P_{v4}; in the I-P version, the constant $\sqrt{2}$ is replaced with the value 1097.8.

Figure 10B
Outlet Duct Setup — Multiple Nozzles In Chamber with Star Straightener



Notes:

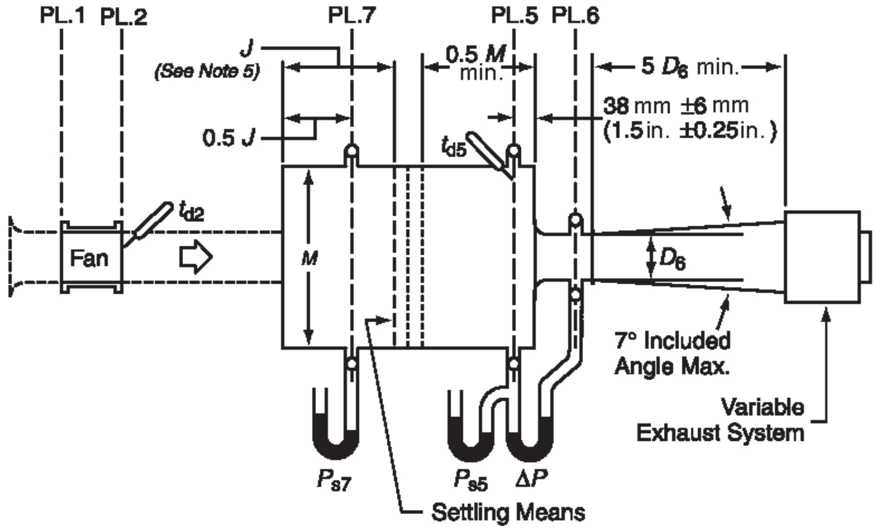
1. Dotted lines on fan inlet indicate an inlet bell and one equivalent duct diameter which may be used for inlet duct simulation. The duct friction shall not be considered.
2. Additional ductwork of any size including elbows may be used to connect between the chamber and the exit of the test duct shown between the test fan and the chamber.
3. Variable exhaust system may be an auxiliary fan or a throttling device.
4. The distance from the exit face of the largest nozzle to the downstream settling means shall be a minimum of 2.5 throat diameters of the largest nozzle.
5. Minimum (*M*) is determined by the requirements of Section 5.3.1 for this figure.

Flow and Pressure Formulae

$Q = Q_5\left(\frac{\rho_5}{\rho}\right)$	$P_t = P_{t2} - P_{t1}$	$P_v = P_{v4}\left(\frac{A_4}{A_2}\right)^2\left(\frac{\rho_4}{\rho_2}\right)$	$P_s = P_t - P_v$
$^*Q_5 = \sqrt{2}Y\sqrt{\frac{\Delta P}{\rho_5}}\sum(CA_6)$	$P_{t1} = 0$	$^*P_{v4} = \left(\frac{V_4}{\sqrt{2}}\right)^2\rho_4$	
$V_4 = \left(\frac{Q}{A_4}\right)\left(\frac{\rho}{\rho_4}\right)$	$P_{t2} = P_{s4} + P_{v4} + (0.015 + 1.26(\mathrm{Re})^{-0.3} + 0.95(\mathrm{Re})^{-0.12})P_{v4}$		

*These formulae are the same in both the SI and the I-P systems except for Q_5 and P_{v4}; in the I-P version, the constant $\sqrt{2}$ is replaced with the value 1097.8.

Figure 10C
Outlet Duct Setup – Multiple Nozzles In Chamber with Common Part



Notes:

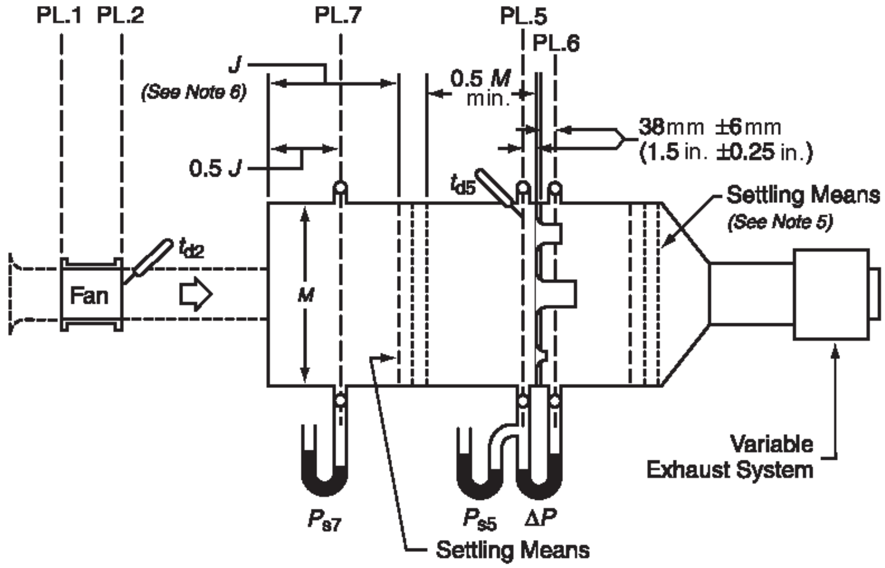
1. Dotted lines on fan inlet indicate an inlet bell and one equivalent duct diameter, which may be used for inlet duct simulation. The duct friction shall not be considered.
2. Dotted lines on fan outlet indicate a uniform duct two to three equivalent diameters long and of an area within ±1% of the fan outlet area and a shape to fit the fan outlet. This may be used to simulate an outlet duct. The outlet duct friction shall not be considered.
3. The fan may be tested without outlet duct. If this is the case, it shall be mounted on the end of the chamber.
4. Variable exhaust system may be an auxiliary fan or a throttling device.
5. Dimension *J* shall be at least 1.0 times the fan equivalent discharge diameter for fans with axis of rotation perpendicular to the discharge flow and at least 2.0 times the fan equivalent discharge diameter for fans with axis of rotation parallel to the discharge flow. **Warning!** A small dimension *J* may make it difficult to meet the criteria given in Annex A. By making dimension *J* at least 0.35*M* this condition is improved, as well as meeting the criteria given in Section 5.3.1 for any fan.
6. Temperature t_{d2} may be considered equal to t_{d5}.
7. For the purpose of calculating the density at Plane 5 only, P_{s5} may be considered equal to P_{s7}.
8. Nozzle shall be in accordance with Figure 4A — Nozzle with Throat Taps

Flow and Pressure Formulae

$Q = Q_5\left(\frac{\rho_5}{\rho}\right)$	$P_t = P_{t2} - P_{t1}$	$P_v = P_{v2}$
$^*Q_5 = \sqrt{2}CA_6Y\sqrt{\frac{\Delta P}{\rho_5}}$	$P_{t1} = 0$	$^*P_{v2} = \left(\frac{V_2}{\sqrt{2}}\right)^2 \rho_2$
$V_2 = \left(\frac{Q}{A_2}\right)\left(\frac{\rho}{\rho_2}\right)$	$P_{t2} = P_{s7} + P_v$	$P_s = P_t - P_v$

*These formulae are the same in both the SI and the I-P systems except for Q_5 and P_{v2}; in the I-P version, the constant $\sqrt{2}$ is replaced with the value 1097.8.

Figure 11
Outlet Chamber Setup – Nozzle On End of Chamber



Notes:

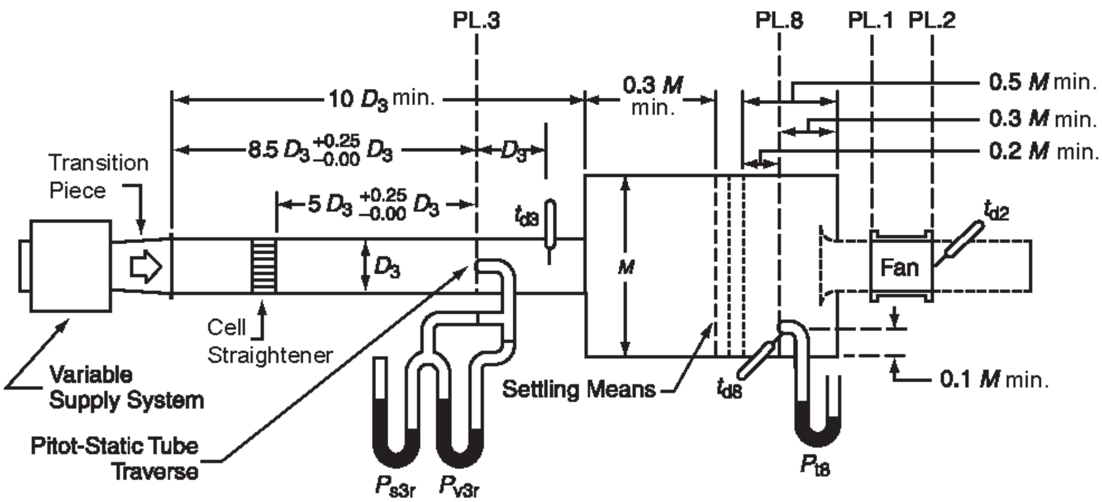
1. Dotted lines on fan inlet indicate an inlet bell and one equivalent duct diameter, which may be used for inlet duct simulation. The duct friction shall not be considered.
2. Dotted lines on fan outlet indicate a uniform duct two to three equivalent diameters long and of an area within ±1% of the fan outlet area and a shape to fit the fan outlet. This may be used to simulate an outlet duct. The outlet duct friction shall not be considered.
3. The fan may be tested without outlet duct. If this is the case, it shall be mounted on the end of the chamber.
4. Variable exhaust system may be an auxiliary fan or a throttling device.
5. The distance from the exit face of the largest nozzle to the downstream settling means shall be a minimum of 2.5 throat diameters of the largest nozzle.
6. Dimension J shall be at least 1.0 times the fan equivalent discharge diameter for fans with axis of rotation perpendicular to the discharge flow and at least 2.0 times the fan equivalent discharge diameter for fans with axis of rotation parallel to the discharge flow. **Warning!** A small dimension J may make it difficult to meet the criteria given in Annex A. By making dimension J at least $0.35M$ this condition is improved, as well as meeting the criteria given in Section 5.3.1 for any fan.
7. Temperature t_{d2} may be considered equal to t_{d5}.
8. For the purpose of calculating the density at Plane 5 only, P_{s5} may be considered equal to P_{s7}.

Flow and Pressure Formulae

$Q = Q_5\left(\frac{\rho_5}{\rho}\right)$	$P_t = P_{t2} - P_{t1}$	$P_v = P_{v2}$
$^*Q_5 = \sqrt{2}Y\sqrt{\frac{\Delta P}{\rho_5}}\sum(CA_6)$	$P_{t1} = 0$	$^*P_{v2} = \left(\frac{V_2}{\sqrt{2}}\right)^2 \rho_2$
$V_2 = \left(\frac{Q}{A_2}\right)\left(\frac{\rho}{\rho_2}\right)$	$P_{t2} = P_{s7} + P_v$	$P_s = P_t - P_v$

*These formulae are the same in both the SI and the I-P systems except for Q_5 and P_{v2}; in the I-P version, the constant $\sqrt{2}$ is replaced with the value 1097.8.

Figure 12
Outlet chamber Setup — Multiple Nozzles In Chamber



Notes:

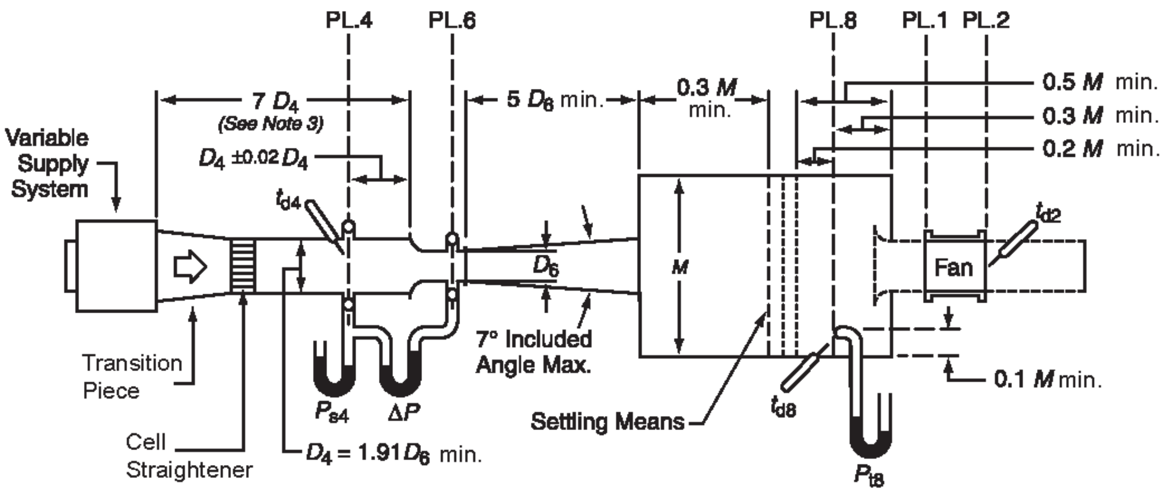
1. Dotted lines on fan inlet indicate an inlet bell and one equivalent duct diameter, which may be used for inlet duct simulation. The duct friction shall not be considered.
2. Dotted lines on fan outlet indicate a uniform duct two or three equivalent diameters long and of an area within ±1 of the fan outlet area and a shape to fit the fan outlet. This may be used to simulate an outlet duct. The outlet duct friction shall not be considered.
3. Additional ductwork of any size including elbows may be used to connect between the chamber and the exit of the 10*D* minimum test duct.
4. Variable supply system may be an auxiliary fan or a throttling device.
5. In lieu of a total pressure tube, a piezometer ring can be used to measure static pressure at Plane 8. If this alternate arrangement is used, and the calculated Plane 8 velocity is greater than 400 fpm then the calculated Plane 8 velocity pressure shall be added to the measured static pressure.

Flow and Pressure Formulae

$Q = Q_3\left(\frac{\rho_3}{\rho}\right)$	$P_t = P_{t2} - P_{t1}$	$P_s = P_t - P_v$	$P_v = P_{v3}\left(\frac{A_3}{A_2}\right)^2\left(\frac{\rho_3}{\rho_2}\right)$
$Q_3 = V_3 A_3$	$P_{t1} = P_{t8}$	$P_{s3} = \frac{\sum P_{s3r}}{n}$	$P_{v3} = \left(\frac{\sum\sqrt{P_{v3r}}}{n}\right)^2$
$^*V_3 = \sqrt{2}\sqrt{\frac{P_{v3}}{\rho_3}}$	$P_{t2} = P_v$		

*These formulae are the same in both SI and I-P systems except for V_3; in the I-P version, the constant $\sqrt{2}$ is replaced with the value 1097.8.

Figure 13
Inlet Chamber Setup — Pitot Traverse in Duct



Notes:

1. Dotted lines on fan inlet indicate an inlet bell and one equivalent duct diameter, which may be used for inlet duct simulation. The duct friction shall not be considered.
2. Dotted lines on fan outlet indicate a uniform duct two to three equivalent diameters long and of an area within ±1% of the fan outlet area and a shape to fit the fan outlet. This may be used to simulate an outlet duct. The outlet duct friction shall not be considered.
3. Duct length 7*D*4 may be shortened to not less than 2*D*4 when it can be demonstrated, by a traverse of *D*4 by pitot-static tube located a distance *D*4 upstream from the nozzle entrance or downstream from the straightener or smoothing means, that the energy ratio (*E*) is less than 1.1 when the velocity is greater than 6.1 m/s (1200 fpm). Smoothing means such as screens, perforated plates or other media may be used.
4. Variable supply system may be an auxiliary fan or a throttling device. One or more supply systems, each with its own nozzle, may be used.
5. In lieu of a total pressure tube, a piezometer ring can be used to measure static pressure at Plane 8. If this alternate arrangement is used and the calculated Plane 8 velocity is greater than 400 fpm, then the calculated Plane 8 velocity pressure shall be added to the measured static pressure.
6. Nozzle shall be in accordance with Figure 4A — Nozzle with Throat Taps

Flow and Pressure Formulae

$$Q = Q_4\left(\frac{\rho_4}{\rho}\right)$$

$$*Q_4 = \frac{\sqrt{2}CA_6Y\sqrt{\frac{\Delta P}{\rho_4}}}{\sqrt{1-E\beta^4}}$$

$$V_2 = \left(\frac{Q}{A_2}\right)\left(\frac{\rho}{\rho_2}\right)$$

$$P_t = P_{t2} - P_{t1}$$

$$P_{t1} = P_{t8}$$

$$P_{t2} = P_v$$

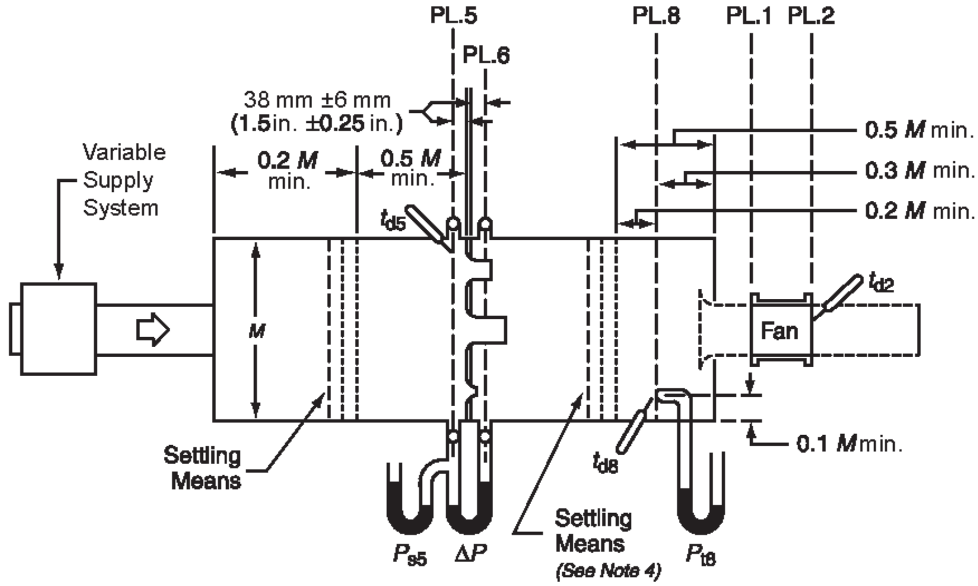
$$P_v = P_{v2}$$

$$*P_{v2} = \left(\frac{V_2}{\sqrt{2}}\right)^2\rho_2$$

$$P_s = P_t - P_v$$

*These formulae are the same in both the SI and I-P systems except for Q_4 and P_{v2}; in the I-P version, the constant $\sqrt{2}$ is replaced with the value 1097.8.

Figure 14
Inlet Chamber Setup — Ducted Nozzle on Chamber



Notes:

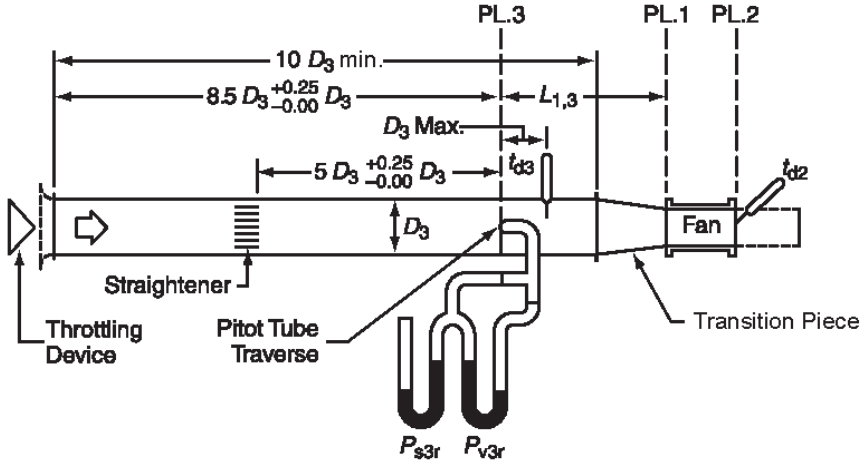
1. Dotted lines on fan inlet indicate an inlet bell and one equivalent duct diameter, which may be used for inlet duct simulation. The duct friction shall not be considered.
2. Dotted lines on fan outlet indicate a uniform duct two to three equivalent diameters long and of an area within ±1% of the fan outlet area and a shape to fit the fan outlet. This may be used to simulate an outlet duct. The outlet duct friction shall not be considered.
3. Variable supply system may be an auxiliary fan or throttling device.
4. The distance from the exit face of the largest nozzle to the downstream settling means shall be a minimum of 2.5 throat diameters of the largest nozzle.
5. For the purpose of calculating the density at Plane 5 only, P_{s5} may be considered equal to ($P_{t8} + \Delta P$).
6. In lieu of a total pressure tube, a piezometer ring can be used to measure static pressure at Plane 8. If this alternate arrangement is used, and the calculated Plane 8 velocity is greater than 400 fpm, then the calculated Plane 8 velocity pressure shall be added to the measured static pressure.

Flow and Pressure Formulae

$Q = Q_5\left(\frac{\rho_5}{\rho}\right)$	$P_t = P_{t2} - P_{t1}$	$P_v = P_{v2}$
$*Q_5 = \sqrt{2}Y\sqrt{\frac{\Delta P}{\rho_5}}\sum(CA_6)$	$P_{t1} = P_{t8}$	$*P_{v2} = \left(\frac{V_2}{\sqrt{2}}\right)^2 \rho_2$
$V_2 = \left(\frac{Q}{A_2}\right)\left(\frac{\rho}{\rho_2}\right)$	$P_{t2} = P_v$	$P_s = P_t - P_v$

*These formulae are the same in both the SI and the I-P systems except for Q_5 and P_{v2}; in the I-P version, the constant $\sqrt{2}$ is replaced with the value 1097.8.

Figure 15
Inlet Chamber Setup — Multiple Nozzles In Chamber



Notes:

1. Dotted lines on inlet indicate an inlet bell, which may be used to approach more nearly free delivery.
2. Dotted lines on fan outlet indicate a uniform duct two to three equivalent diameters long and of an area within ±1% of the fan outlet area and a shape to fit the fan outlet. This may be used to simulate an outlet duct. The outlet duct friction shall not be considered.

Flow and Pressure Formulae

$Q_3 = V_3 A_3$	$P_t = P_{t2} - P_{t1}$	$P_s = P_t - P_v$	$P_v = P_{v3}\left(\frac{A_3}{A_2}\right)^2\left(\frac{\rho_3}{\rho_2}\right)$
$Q = Q_3\left(\frac{\rho_3}{\rho}\right)$	$P_{t1} = P_{s3} + P_{v3} - f\left(\frac{L_{1,3}}{D_{h3}}\right)P_{v3}$	$P_{s3} = \frac{\sum P_{s3r}}{n}$	$P_{v3} = \left(\frac{\sum\sqrt{P_{v3r}}}{n}\right)^2$
$^*V_3 = \sqrt{2}\sqrt{\frac{P_{v3}}{\rho_3}}$	$P_{t2} = P_v$		

*The formulae given above are the same in both the SI and the I-P systems except for V_3; in the I-P version, the constant $\sqrt{2}$ is replaced with the value 1097.8.

Figure 16
Inlet Duct Setup — Pitot Traverse In Inlet Duct

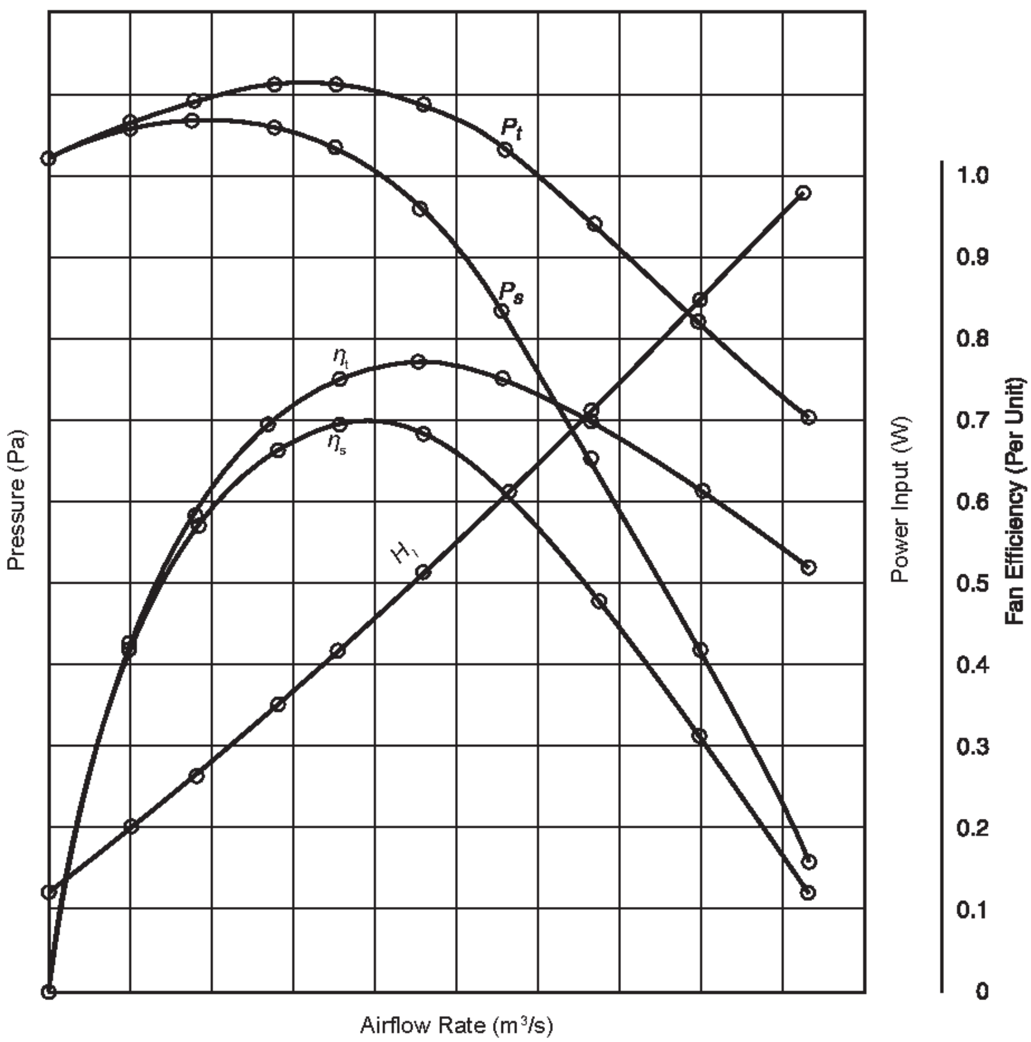


Figure 17A
Example of Typical Fan Performance Curve (SI)

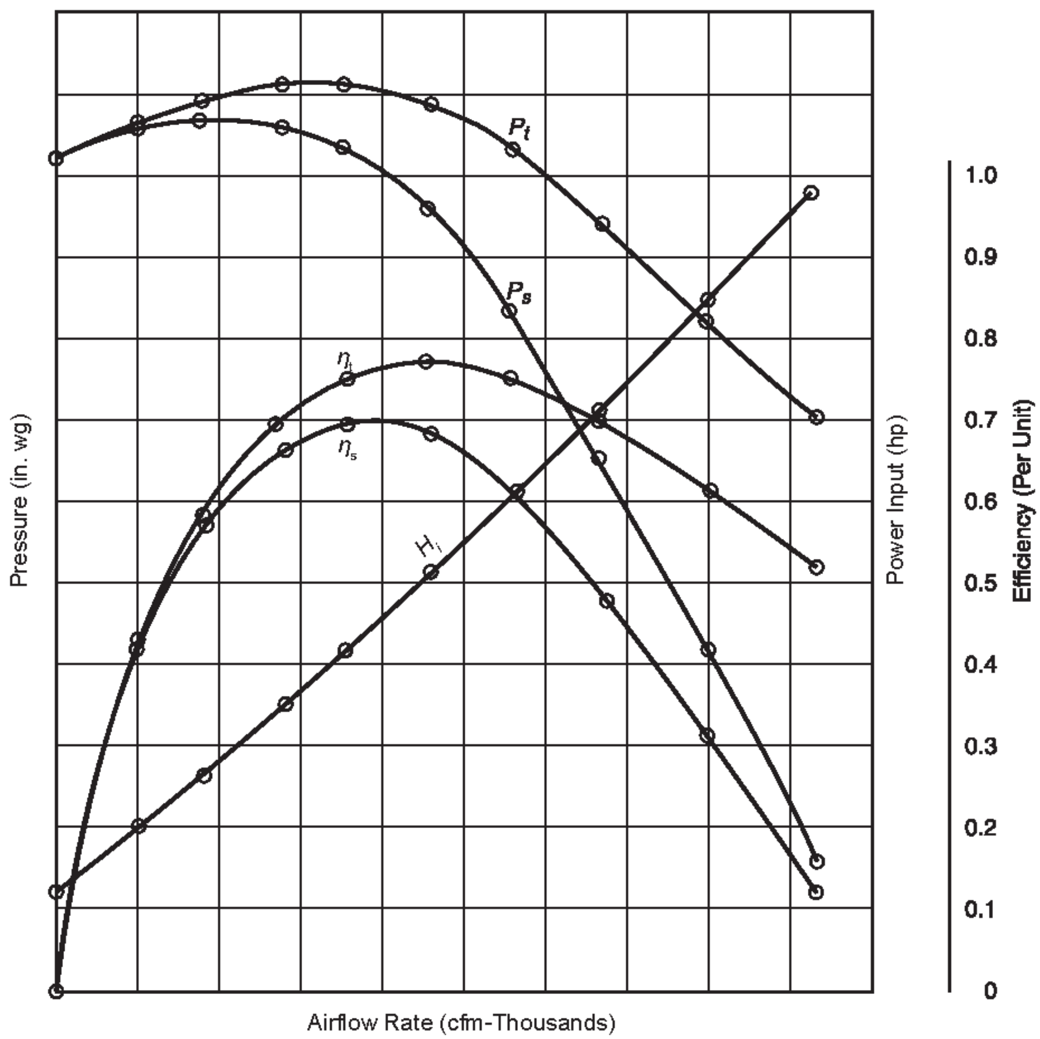


Figure 17B
Example of Typical Fan Performance Curve (I-P)

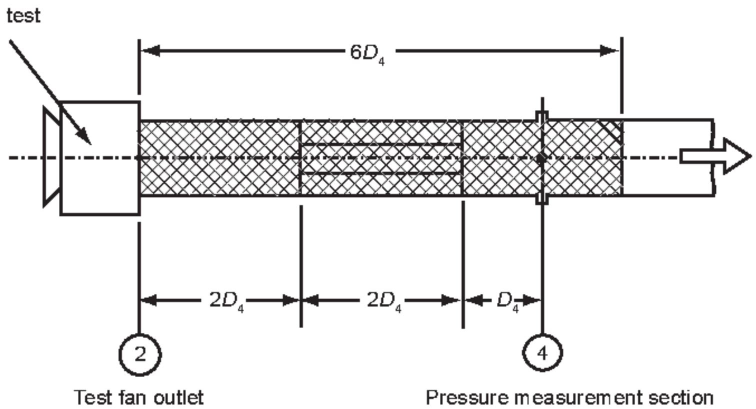
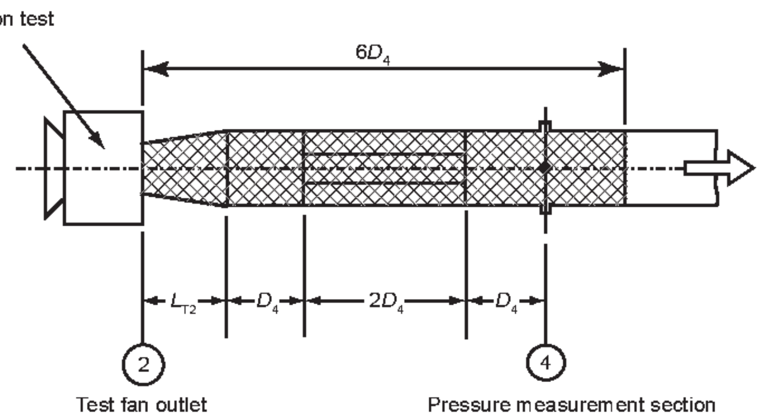


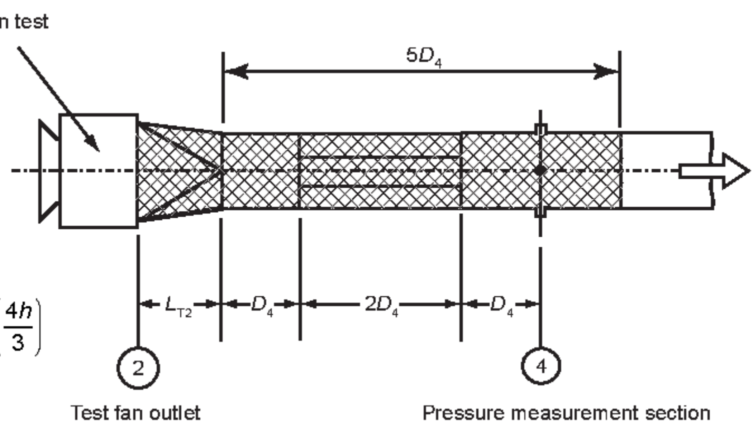
Figure 18
Common Part for Circular Fan Outlet When $D_2 = D_4$ [21]



$$0.95 \leq \left(\frac{D_4}{D_2}\right)^2 \leq 1.07$$

$$L_{T2} = D_4$$

Figure 19
Common Part For Circular Fan Outlet When $D_2 \neq D_4$ [21]



$$0.95 \leq \left(\frac{\pi D_4^2}{4bh}\right) \leq 1.07$$

$$L_{T2} = 1.0D_4 \text{ when } b \leq \left(\frac{4h}{3}\right)$$

$$L_{T2} = 0.75\left(\frac{b}{h}\right)D_4 \text{ when } b > \left(\frac{4h}{3}\right)$$

Note: The dimensions *b* and *h* are the width and height of a rectangular section of a duct.

Figure 20
Common Part for Rectangular Fan Outlet Where $b \geq h$ [21]

Annex A
Airflow Settling Means Effectiveness Check (Normative)

A.1 General requirements

The effectiveness of the airflow settling means in all chambers shall be verified by tests. The tests are described in Sections A.2, A.3 and A.4. Each style of chamber has different conditions, and the required tests are defined for each in these sections.

Some validation tests require that the flow and pressure be determined prior to the settling means having proved their effectiveness. It can be assumed that the tests taken in this condition (with the non-verified settling means) are sufficiently accurate to be used to establish acceptance criteria for all Annex A testing.

Once the airflow settling means have demonstrated that all applicable test criteria have been met, the chamber can be used for all future testing within the limits defined by the test criteria. If any of the criteria are not met, the settling means must be altered and all testing restarted.

A.2 Piezometer ring check (optional)

This test applies chambers per Figures 9A, 9B, 9C, 10A, 10B and 10C in Plane 5; Figures 11 and 12 in Planes 5 and 7; and Figure 15 in Plane 5.

Individual pressure readings for each pressure tap of the piezometer ring are to be measured. When the mean of these readings is less than or equal to 1000 Pa (4 in. wg), all of the individual readings must be within 5% of the mean. When the mean of these readings is greater than 1000 Pa (4 in. wg) all of the individual readings must be within 2% of the mean.

A.3 Blow through verification test

This test applies to chambers per Figures 9A, 9B, 9C, 10A, 10B, 10C, 11, 12 and 15 in Plane 5; and Figures 13, 14 and 15 in Plane 8.

This test evaluates the ability of the airflow settling means to provide a substantially uniform airflow ahead of the measurement plane. For this test, equally spaced measurement points are located in a plane 0.1*M* downstream of the settling means. The number of measurement points shall be in accordance with AMCA Publication 203.

For tests of settling means upstream of the nozzle wall, the auxiliary fan shall be set at its maximum flow rate, all the nozzles shall be open, the inlet of the chamber shall be open and the inlet area shall be equal to the largest area allowed by the chamber cross-sectional area.

For tests of settling means upstream of the test fan, the auxiliary fan shall be set at its maximum flow rate, half of the nozzles shall be open, the outlet of the chamber shall be open and the outlet area shall be equal to the largest area allowed by the chamber cross sectional area.

The flow velocities shall be measured, and the average determined. If the maximum velocity is less than 2 m/s (400 fpm) or if the maximum velocity value does not exceed 125% of the average, the settling screens are acceptable.

A.4 Reverse flow verification test

One purpose of the settling means is to absorb the kinetic energy of an 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. If the settling means are too restrictive, excessive backflow will result.

A series of tests shall be run to verify that reverse flow is not excessive at Plane 7. Each test shall be run with a varying opening in the chamber entrance starting from 11% of the chamber area and proceeding to lower percentage openings. Each test shall be run with all of the nozzles open and the auxiliary at its maximum flow rate. At each test, it shall be verified that the pressure at Plane 5 is less than the pressure at Plane 7. The series of tests may be stopped at the first set of conditions that verify the above requirement.

Annex B
Chamber Leakage Rate Test Procedure (Informative)

The volume of interest is the volume between the measurement plane and the air moving device. For an inlet chamber, the test pressure could be negative, and for outlet chambers, the test pressures could be positive.

Two methods of testing for leakage rate are proposed. These test procedures assume isothermal conditions.

B.1 Pressure decay method

Figure B.1 shows the test setup. The test chamber is pressurized and the valve is closed. The initial static pressure is noted (P_0) at time t = 0. The pressure is recorded at periodic intervals (at intervals short enough to develop a pressure vs. time curve) until the pressure (P) reaches a steady state value.

Using ideal gas law:

$$PV = m\mathrm{R}T \text{ or } P = \rho \mathrm{R}T \qquad \text{Eq. B.1}$$

Where P = Static pressure
V = Chamber volume
m = mass of air in chamber
R = Gas constant
T = Absolute air temperature
ρ = Air density
Q = Leakage airflow rate

Differentiating with respect to time:

$$V\frac{dP}{dt} = \frac{dm}{dt}\mathrm{R}T$$

And:

$$Q = \left(\frac{1}{\rho}\right)\left(\frac{dm}{dt}\right) \text{ or } \frac{dm}{dt} = \rho Q$$

Substituting and rearranging gives:

$$\frac{dP}{dt} = \frac{\rho Q \mathrm{R}T}{V}$$

Or:

$$Q = \left(\frac{V}{\rho \mathrm{R}T}\right)\left(\frac{dP}{dt}\right)$$

And:

$$Q = \left(\frac{V}{P}\right)\left(\frac{dP}{dt}\right)$$

Or:

$$Q = \left(\frac{V}{P_t}\right)\left(\frac{\Delta P_t}{\Delta t}\right) \qquad \text{Eq. B.2}$$

Thus, leakage rate (Q) can be determined from Equation B.2 once the pressure decay curve (Figure B.2) is known for the chamber.

1. Pressurize or evacuate the test chamber to a test pressure (P_t) greater in magnitude than the pressure at which leakage is to be measured. Close the control valve.
2. At time t = 0, start a stopwatch and record the pressure at periodic time intervals (a minimum of three readings is recommended) to get a decay curve as above. Continue to record until the pressure reaches a state in which the pressure does not change significantly.
3. Quick pressure changes indicate substantial leakage which must be located and may have to be reduced.

B.2 Flow meter method

Figure B.3 shows the test setup. The procedure is to pressurize or evacuate the test chamber and use a flow meter to establish the leakage flow rate. The pressure in the chamber is maintained constant. The flow meter will give a direct reading of the leakage rate.

The source used to evacuate or pressurize the chamber must be sized to maintain a constant pressure in the chamber.

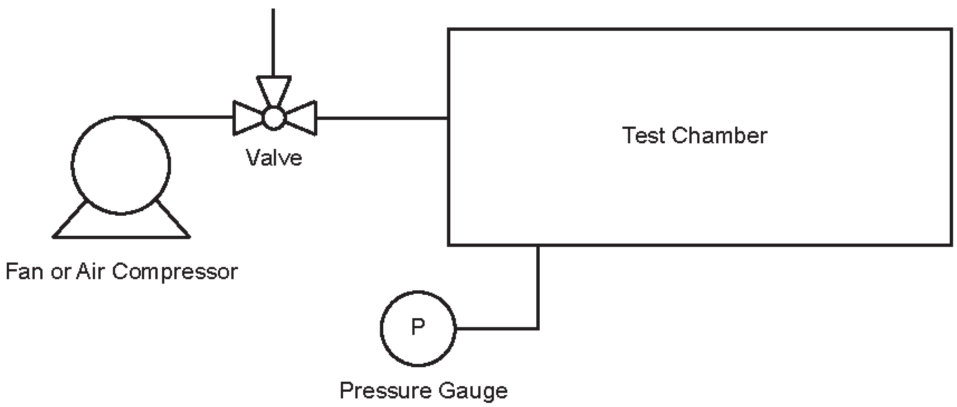
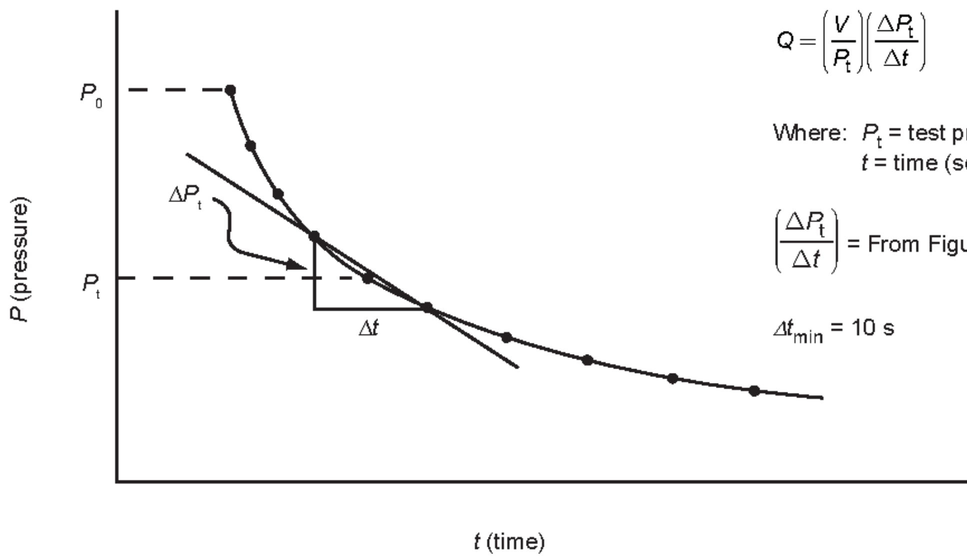


Figure B.1
Pressure Decay Leakage Method Setup



$$Q = \left(\frac{V}{P_t}\right)\left(\frac{\Delta P_t}{\Delta t}\right)$$

Where: P_t = test pressure
t = time (seconds)

$\left(\frac{\Delta P_t}{\Delta t}\right)$ = From Figure B.2

Δt_{min} = 10 s

Figure B.2
Pressure Decay History

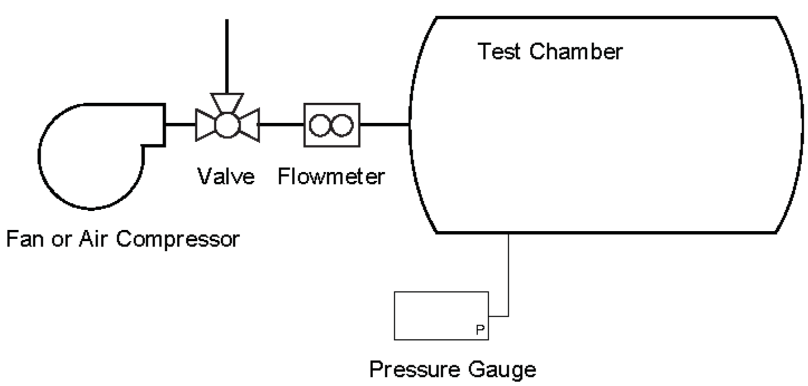


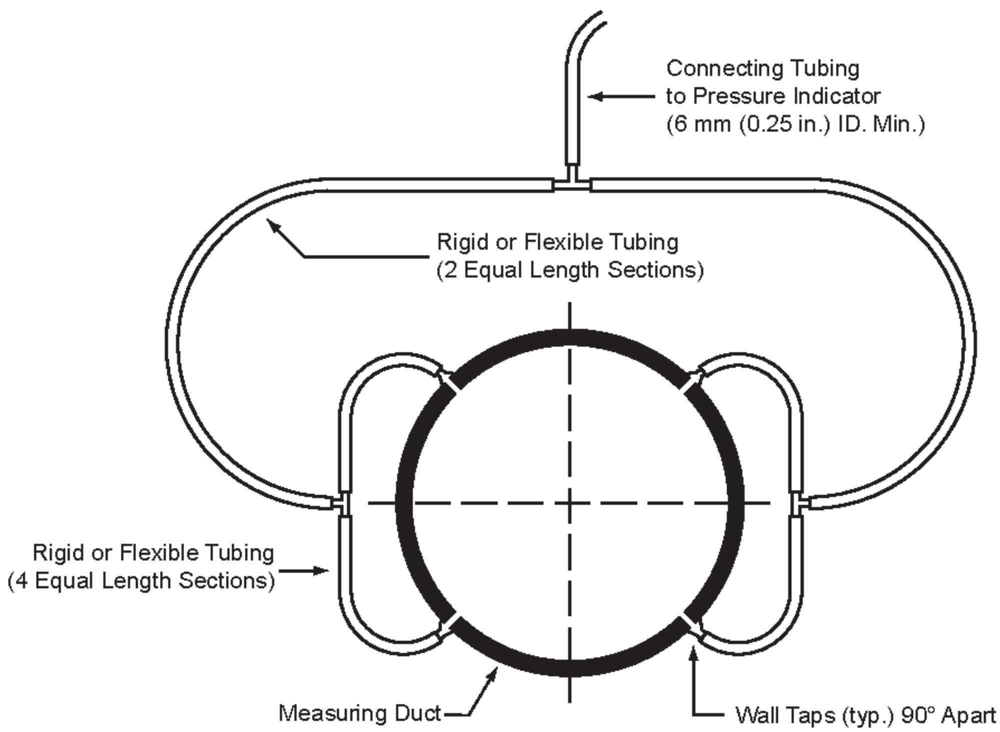
Figure B.3
Leakage Test Setup, Flow Meter Method

Annex C
Tubing (Informative)

Large tubing shall be used to help prevent blockage from dust, water, ice, etc. Accumulations of dirt are especially noticeable in the bottom of round ducts; it is recommended that duct piezometer fittings be located at 45° from the horizontal. Tubing longer than 1.5 m (5 ft) shall be a minimum of 6 mm (0.25 in.) inside diameter to avoid long pressure response times. When pressure response times are long, inspect for possible blockage.

Hollow flexible tubing used to connect measurement devices to measurement locations shall be of relatively large inside diameter. The larger size is helpful in preventing blockage due to dust, water, ice, etc.

Piezometer connections to a round duct are recommended to be made at points 45° away from the vertical centerline of the duct. See Figure C.1 for an example.



Notes:

1. Static pressure taps shall be in accordance with Figure 2A.
2. Manifold tubing internal area shall be at least four times that of a wall tap.
3. Connecting tubing to pressure indicator shall be 6 mm (0.25 in.) or larger in ID.
4. Taps shall be within ± 13 mm (0.5 in.) in the longitudinal direction.

Figure C.1
Piezometer Ring Manifolding

Annex D
Derivations of Equations (Informative)

D.1 General

Various formulae appear in the standard. The origin of these formulae will be obvious to an engineer. Some, like the equations for α, β, P_t, P_s and P_v, are algebraic expressions of fundamental definitions. Others, like the equations for p_e, μ and C, are simply polynomials derived to fit the indicated data. Still others are derived from the equation of state, the Bernoulli equation, the equation of continuity and other fundamental considerations. Only the less obvious formulae will be derived here, using SI units of measure.

D.2 Symbols

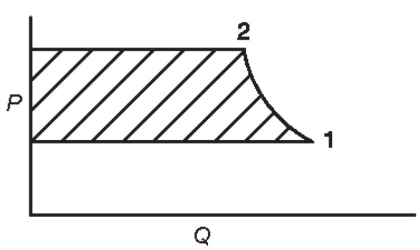
In the derivations which follow, certain symbols and notations are used in addition to those which are also used in the standard.

Symbol	Description	Unit
H_i	Power input to impeller	W (hp)
n	Polytropic exponent	dimensionless
P	Absolute total pressure	Pa (in. wg)

D.3 Fan total efficiency equation

The values of the fan airflow rate, fan total pressure and fan input power, which are determined during a test, are the compressible flow values for the fan speed and fan air density prevailing. A derivation of the fan total efficiency equation based on compressible flow values follows [20].

The process during compression may be plotted on a chart of absolute total pressure (P) versus flow rate (Q). By using total pressure, all of the energy is accounted for including kinetic energy.



The fan output power(H_o) is proportional to the shaded area which leads to:

$$H_o = \frac{1}{6343.3}\int_1^2 Q\,dP \qquad \text{Eq. D.1}$$

The compression process may be assumed to be polytropic for which, from thermodynamics:

$$Q = Q_1\left(\frac{P}{P_1}\right)^{-1/n} \qquad \text{Eq. D.2}$$

Substituting:

$$H_o = \frac{Q_1}{6343.3}\int_1^2 \left(\frac{P}{P_1}\right)^{-1/n} dP \qquad \text{Eq. D.3}$$

Integrating between limits:

$$H_o = \frac{Q_1 P_1}{6343.3}\left(\frac{n}{n-1}\right)\left[\left(\frac{P_2}{P_1}\right)^{(n-1)/n} - 1\right] \qquad \text{Eq. D.4}$$

But from the definition of fan total pressure (P_t):

$$P_1 = \frac{P_t}{\left(\frac{P_2}{P_1} - 1\right)} \qquad \text{Eq. D.5}$$

And the definition of fan total efficiency (η_t):

$$\eta_t = \frac{H_o}{H_i} \qquad \text{Eq. D.6}$$

It follows that:

$$\eta_t = \frac{\frac{Q_1 P_t}{6343.3 H_i}\left(\frac{n}{n-1}\right)\left[\left(\frac{P_2}{P_1}\right)^{(n-1)/n} - 1\right]}{\left(\frac{P_2}{P_1} - 1\right)} \qquad \text{Eq. D.7}$$

D.4 Compressibility coefficient

The efficiency equation derived above can be rewritten:

$$\eta_t = \frac{Q_1 P_t K_p}{H_i} \qquad \text{Eq. D.8 SI}$$

$$\eta_t = \frac{Q_1 P_t K_p}{6343.3 H_i} \qquad \text{Eq. D.8 I-P}$$

Where:

$$K_p = \frac{\left(\frac{n}{n-1}\right)\left[\left(\frac{P_2}{P_1}\right)^{(n-1)/n} - 1\right]}{\left(\frac{P_2}{P_1} - 1\right)} \qquad \text{Eq. D.9}$$

This is one form of the compressibility coefficient.

D.5 Derivation of K_p in terms of x and z

The compressibility coefficient (K_p) was derived above in terms of the polytropic exponent (n) and the pressure ratio (P_2/P_1). The polytropic exponent can be evaluated from the isentropic exponent (γ) and the polytropic efficiency. The latter may be considered equal to the fan total efficiency for a fan without drive losses. From thermodynamics:

$$\left(\frac{n}{n-1}\right) = \eta_t\left(\frac{\gamma}{\gamma-1}\right) \qquad \text{Eq. D.10}$$

Two new coefficients (x and z), may be defined in terms of the information which is known from a fan test:

$$x = \frac{P_t}{P_1} \qquad \text{Eq. D.11}$$

And:

$$z = \left(\frac{\gamma-1}{\gamma}\right)\left(\frac{H_i}{Q_1 P_1}\right) \qquad \text{Eq. D.12 SI}$$

$$z = \left(\frac{\gamma-1}{\gamma}\right)\left(\frac{6343.3 H_i}{Q_1 P_1}\right) \qquad \text{Eq. D.12 I-P}$$

Manipulating algebraically:

$$\left(\frac{\gamma}{\gamma-1}\right) = \frac{x}{z}\left(\frac{H_i}{Q_1 P_t}\right) \qquad \text{Eq. D.13 SI}$$

And:

$$\left(\frac{\gamma}{\gamma-1}\right) = \frac{x}{z}\left(\frac{6343.3 H_i}{Q_1 P_t}\right) \qquad \text{Eq. D.13 I-P}$$

And:

$$\frac{P_2}{P_1} = (1+x) \qquad \text{Eq. D.14}$$

Substituting in the equation for K_p:

$$K_p = \frac{\eta_t \frac{x}{z}\left(\frac{H_i}{Q_1 P_t}\right)\left[(1+x)^{(\gamma-1)/\gamma\eta_t} - 1\right]}{(1+x) - 1} \qquad \text{Eq. D.15 SI}$$

$$K_p = \frac{\eta_t \frac{x}{z}\left(\frac{6343.3 H_i}{Q_1 P_t}\right)\left[(1+x)^{(\gamma-1)/\gamma\eta_t} - 1\right]}{(1+x) - 1} \qquad \text{Eq. D.15 I-P}$$

This reduces to:

$$(1+z) = (1+x)^{(\gamma-1)/\gamma\eta_t} \qquad \text{Eq. D.16}$$

Taking logarithms and rearranging:

$$\eta_t = \left(\frac{\gamma-1}{\gamma}\right)\left(\frac{\ln(1+x)}{\ln(1+z)}\right) \qquad \text{Eq. D.17}$$

Substituting:

$$\eta_t = \left(\frac{Q_1 P_t}{H_i}\right)\left(\frac{z}{x}\right)\left(\frac{\ln(1+x)}{\ln(1+x)}\right) \qquad \text{Eq. D.18 SI}$$

$$\eta_t = \left(\frac{Q_1 P_t}{6343.3 H_i}\right)\left(\frac{z}{x}\right)\left(\frac{\ln(1+x)}{\ln(1+x)}\right) \qquad \text{Eq. D.18 I-P}$$

And:

$$K_p = \left(\frac{z}{x}\right)\left(\frac{\ln(1+x)}{\ln(1+z)}\right) \qquad \text{Eq. D.19}$$

Since the coefficients x and z have been defined in terms of test quantities, direct solutions of K_p and η_t can be obtained for a test situation. An examination of x and z will reveal that x is the ratio of the total pressure rise to the absolute total pressure at the inlet, and that z is the ratio of the total temperature rise to the absolute total temperature at the inlet. If the total temperature rise could be measured with sufficient accuracy, it could be used to determine z, but in most cases, better accuracy is obtained from the other measurements.

D.6 Conversion equations

The conversion equations that appear in Section 7.9.3 of the standard are simplified versions of the fan laws which are derived in Annex E. Diameter ratio has been omitted in Section 7.9.3 because there is no need for size conversions in a test standard.

D.7 Derivation of constants used in I-P system formulae

The formulae given in the I-P system incorporate constants needed for unit cancellation. Their derivation is as follows:

D.7.1

The constant 13.595 is used in Equations 7.4 I-P, 7.5 I-P, 7.11 I-P, 7.54 I-P and 7.55 I-P. These formulae use absolute pressure ratios in inches of water. The barometric pressure is given in inches of mercury. The standard density of mercury is 13595.1 kg/m^3. Using the formula $P = \rho g H$ and converting to the I-P system, we find:

$$P = 13595.1\,\text{kg/m}^3 \times 9.80665\,\text{N/m}^3 \times 1.0\,\text{in.} \times \frac{1.0\,\text{m}}{39.37\,\text{in.}} \times \frac{1.0\,\text{in. wg}}{249.089\,\text{Pa}} = 13.595\,\text{in. wg}$$

D.7.2

The constant 1097.8 is used in Equations 7.8 I-P, 7.18 I-P, 7.21 I-P, 7.22 I-P, 7.27 I-P, 7.28 I-P, 7.31 I-P, E.23 I-P, E.25 I-P, E.27 I-P, E.28 I-P and in Figures 7A, 7B, 8A, 8B, 9A, 9B, 9C, 10A, 10B, 10C, 11, 12, 13 and 14. This constant is derived by converting to the SI equivalent units:

$$V\left(\frac{0.3048\,\text{m}}{1\,\text{ft}}\right)\left(\frac{1\,\text{min}}{60\,\text{s}}\right) = \sqrt{\left(\frac{2P_v \times 249.089\,\text{Pa}}{1.0\,\text{in. wg}}\right)\left(\frac{1.0\,\text{lbm/ft}^3}{\rho \times 16.018\,\text{kg/m}^3}\right)}$$

This gives: $V = 1097.8\sqrt{\dfrac{P_v}{\rho}}$

D.7.3

The constant 6343.3 is used in Equations 7.53 I-P, 7.55 I-P, 7.57 I-P, D.1, D.3, D.7, D.8 I-P, D.12 I-P, D.13 I-P, D.15 I-P, D.18 I-P, E.10 I-P, E.11 I-P, E.14 I-P, E.1 I-P and E.21 I-P. This constant is derived by converting to the SI equivalent units:

$$\eta_t = Q\left(\frac{0.3048\,\text{m}}{1\,\text{ft}}\right)^3\left(\frac{1\,\text{min}}{60\,\text{s}}\right)\left(\frac{P_t \times 249.089\,\text{Pa}}{1.0\,\text{in. wg}}\right) \times \left(\frac{1.0\,\text{hp}}{H_i \times 745.7\,\text{W}}\right) = \left(\frac{Q \times P_t}{H_i \times 6343.3}\right)$$

D.7.4

The constant 5.2014 is used in Equation 7.12 I-P. This constant is derived by converting to the SI equivalent units:

$$\alpha = 1 - \left(\frac{\Delta P \times 249.089\,\text{Pa}}{1.0\,\text{in. wg}}\right)\left(\frac{1.0\,\text{lbm/ft}^3}{\rho_x \times 16.018\,\text{kg/m}^3}\right) \times \left(\frac{53.35\,\text{ft} \times \text{lb/lbm} \times {}^\circ\text{R}}{R \times 287.1\,\text{J/kg} \times \text{K}}\right)\left(\frac{1.8\,{}^\circ\text{R}}{(t_{dx} + 459.67) \times 1.0\,\text{K}}\right)$$

$$\alpha = 1 - \left(\frac{5.2014 \times \Delta P}{\rho_x \times R(t_{dx} + 459.67)}\right)$$

Annex E
Similarity and Fan Laws (Informative)

E.1 Similarity

Two fans that are similar and have similar airflow conditions will have similar performance characteristics. The degree of similarity of the performance characteristics will depend on the degree of similarity of the fans and of the airflow through the fans.

E.1.1 Geometric similarity
Complete geometric similarity requires that the ratios of all corresponding dimensions for the two fans be equal. This includes ratios of thicknesses, clearances and roughness, as well as all the other linear dimensions of the airflow passages. All corresponding angles must be equal.

E.1.2 Kinematic similarity
Complete kinematic similarity requires that the ratios of all corresponding velocities for the two fans be equal. This includes the ratios of the magnitudes of corresponding velocities of the air and corresponding peripheral velocities of the impeller. The directions and points of application of all corresponding vectors must be the same.

E.1.3 Dynamic similarity
Complete dynamic similarity requires that the ratios of all corresponding forces in the two fans be equal. This includes ratios of forces due to elasticity, dynamic viscosity, gravity, surface tension and inertia, as well as the pressure force. The directions and points of application of all corresponding vectors must be the same.

E.2 Symbols

In the derivations that follow, certain symbols and notations are used in addition to those which are used in the standard.

Symbol	Description	Unit
n	Polytropic exponent	dimensionless
P	Absolute total pressure	Pa (in. wg)
$\overline{Q}$	Mean flow rate	m^3/s (cfm)
' (Prime)	Incompressible value	-------------

E.3 Fan laws for incompressible flow

The fan laws are the mathematical expressions of the similarity of performance for similar fans at similar flow conditions. These laws may be deduced from similarity considerations, dimensional analysis, or various other lines of reasoning [22].

E.3.1 Fan total efficiency
The efficiencies of completely similar fans at completely similar flow conditions are equal. This is the fundamental relationship of the fan laws. It emphasizes the fact that the fan laws can be applied only if the points of operation are similarly situated for the two fans being compared. The fan law equation for fan total efficiency (η_t) is, therefore:

$$\eta_{tc} = \eta_t \qquad \text{Eq. E.1}$$

E.3.2 Fan airflow rate
The requirements of kinematic similarity lead directly to the airflow rate relationships expressed by the fan laws. Air velocities must be proportional to peripheral velocities. Since flow rate is proportional to air velocity times flow area, and since area is proportional to the square of any dimension, say impeller diameter (D), it follows that the fan law equation for fan airflow rate (Q) is:

$$Q_c = Q\left(\frac{D_c}{D}\right)^3\left(\frac{N_c}{N}\right) \qquad \text{Eq. E.2}$$

E.3.3 Fan total pressure
The requirements of dynamic similarity lead directly to the pressure relationships expressed by the fan laws. Pressure forces must be proportional to inertia forces. Since inertia force per unit area is proportional to air density (ρ) and air velocity squared and since air velocity is proportional to peripheral speed, it follows that the fan law equation for fan total pressure (P_t), which is also force per unit area, is:

$$P_{tc} = P_t\left(\frac{D_c}{D}\right)^2\left(\frac{N_c}{N}\right)^2\left(\frac{\rho_c}{\rho}\right) \qquad \text{Eq. E.3}$$

E.3.4 Fan input power
For incompressible flow, the compressibility coefficient is unity and power input is proportional to airflow rate times pressure divided by efficiency. From the above fan law relationships for fan airflow rate, fan total pressure and fan total efficiency, it follows that the fan law equation for fan input power (H_i) is:

$$H_c = H_i\left(\frac{D_c}{D}\right)^5\left(\frac{N_c}{N}\right)^3\left(\frac{\rho_c}{\rho}\right) \qquad \text{Eq. E.4}$$

E.3.5 Fan velocity pressure
The fan law equation for fan velocity pressure (P_v) follows from that for fan total pressure:

$$P_{vc} = P_v\left(\frac{D_c}{D}\right)^2\left(\frac{N_c}{N}\right)^2\left(\frac{\rho_c}{\rho}\right) \quad \text{Eq. E.5}$$

E.3.6 Fan static pressure
By definition:

$$P_{sc} = P_{tc} - P_{vc} \quad \text{Eq. E.6}$$

E.3.7 Fan static efficiency
By definition:

$$\eta_{sc} = \eta_{tc}\left(\frac{P_{sc}}{P_{tc}}\right) \quad \text{Eq. E.7}$$

E.4 Fan laws for compressible flow

More general versions of the fan laws, which recognize the compressibility of air, can also be deduced from similarity considerations [20].

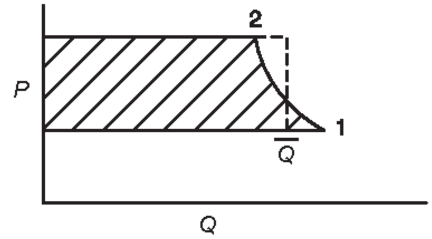
E.4.1 Fan total efficiency
Airflow conditions can never be completely similar, even for two completely similar fans, if the degree of compression varies. Nevertheless, it is useful and convenient to assume that the fan law equation for fan total efficiency (η_t) need not be modified.

$$\eta_{tc} = \eta_t \quad \text{Eq. E.8}$$

E.4.2 Fan airflow rate
Continuity requires that the mass flow rate at the fan outlet equal that at the fan inlet. If the volumetric airflow rate at the inlet (Q_1) is proportional to peripheral speed, the volumetric airflow rate at the outlet (Q_2) cannot be proportional to peripheral speed or vice versa except for the same degree of compression. There is some average airflow rate that is proportional to peripheral speed and flow area. Since, for a polytropic process, the airflow rate is an exponential function of pressure, the geometric mean of the airflow rates at the inlet and outlet will be a very close approximation of the average airflow rate ($\overline{Q}$). The geometric mean is the square root of the product of the two end values:

$$\overline{Q} \approx \sqrt{Q_1 Q_2} \quad \text{Eq. E.9}$$

The value ($\overline{Q}$) illustrated in the following diagram is the average airflow rate based on power output. This value yields the same power output as the polytropic process over the same range of pressures.



For the polytropic process:

$$H_o = Q_1 P_t K_p \quad \text{Eq. E.10 SI}$$

$$H_o = \frac{Q_1 P_t K_p}{6343.3} \quad \text{Eq. E.10 I-P}$$

For the rectangle:

$$H_o = \overline{Q} P_t \quad \text{Eq. E.11 SI}$$

$$H_o = \frac{\overline{Q} P_t}{6343.3} \quad \text{Eq. E.11 I-P}$$

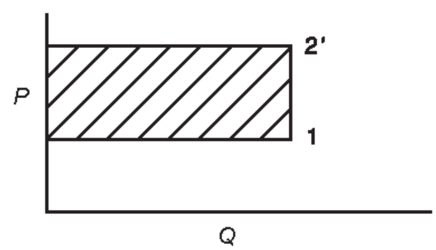
Therefore:

$$\overline{Q} = Q_1 K_1 = Q K_p \quad \text{Eq. E.12}$$

This average airflow rate can be substituted in Equation E.2 to give the compressible flow fan law equation for fan airflow rate:

$$Q_c = Q\left(\frac{D_c}{D}\right)^3\left(\frac{N_c}{N}\right)\left(\frac{K_p}{K_{pc}}\right) \quad \text{Eq. E.13}$$

E.4.3 Fan total pressure
The incompressible flow fan laws are based on a process that can be diagrammed as shown below.



The fan output power is proportional to the shaded area, which leads to:

$$H_o = Q_1(P_{2'} - P_1) \quad \text{Eq. E.14 SI}$$

$$H_o = \frac{Q_1(P_{2'} - P_1)}{6343.3} \quad \text{Eq. E.14 I-P}$$

Extending the definition of fan total pressure to the incompressible case:

$$P_{t'} = (P_{2'} - P_1) \quad \text{Eq. E.15}$$

Therefore:

$$H_o = Q_1 P_{t'} \quad \text{Eq. E.16 SI}$$

$$H_o = \frac{Q_1 P_{t'}}{6343.3} \quad \text{Eq. E.16 I-P}$$

For the same airflow rate (Q_1), absolute inlet pressure (P_1) and power output (H_o), the corresponding equation for compressible flow is:

$$H_o = Q_1 P_t K_p \quad \text{Eq. E.17 SI}$$

$$H_o = \frac{Q_1 P_t K_p}{6343.3} \quad \text{Eq. E.17 I-P}$$

It follows that:

$$P_{t'} = P_t K_p \quad \text{Eq. E.18}$$

The compressible flow fan law equation for fan total pressure can, therefore, be obtained by substitution:

$$P_{tc} = P_t \left(\frac{D_c}{D}\right)^2 \left(\frac{N_c}{N}\right)^2 \left(\frac{\rho_c}{\rho}\right)\left(\frac{K_p}{K_{pc}}\right) \quad \text{Eq. E.19}$$

E.4.4 Fan input power

The equation for efficiency may be rearranged to give either:

$$H_i = \frac{Q P_t K_p}{\eta_t} \quad \text{Eq. E.20 SI}$$

$$H_i = \frac{Q P_t K_p}{6343.3 \eta_t} \quad \text{Eq. E.20 I-P}$$

Or:

$$H_{ic} = \frac{Q_c P_{tc} K_{pc}}{\eta_{tc}} \quad \text{Eq. E.21 SI}$$

$$H_{ic} = \frac{Q_c P_{tc} K_{pc}}{6343.3 \eta_{tc}} \quad \text{Eq. E.21 I-P}$$

Combining and using the compressible flow fan law relationships for fan airflow rate, fan total pressure, and fan total efficiency, it follows that the compressible flow fan law equation for fan input power is:

$$H_{ic} = H_i \left(\frac{D_c}{D}\right)^5 \left(\frac{N_c}{N}\right)^3 \left(\frac{\rho_c}{\rho}\right)\left(\frac{K_p}{K_{pc}}\right) \quad \text{Eq. E.22}$$

E.4.5 Fan velocity pressure

By definition:

$$P_v = P_{v2} = \left(\frac{Q_2}{\sqrt{2} A_2}\right)^2 \rho_2 \quad \text{Eq. E.23 SI}$$

$$P_v = P_{v2} = \left(\frac{Q_2}{1097.8 A_2}\right)^2 \rho_2 \quad \text{Eq. E.23 I-P}$$

But from continuity:

$$\rho_2 Q_2 = \rho_1 Q_1 = \rho Q_1 \quad \text{Eq. E.24}$$

Therefore:

$$P_v = \frac{\rho Q_1 Q_2}{\left(\sqrt{2} A_2\right)^2} \quad \text{Eq. E.25 SI}$$

$$P_v = \frac{\rho Q_1 Q_2}{(1097.8 A_2)^2} \quad \text{Eq. E.25 I-P}$$

But from Equations E.9 and E.12:

$$\overline{Q}^2 = Q^2 K_p{}^2 \approx Q_1 Q_2 \quad \text{Eq. E.26}$$

It follows that:

$$P_v = \frac{\rho Q^2 K_p{}^2}{\left(\sqrt{2} A_2\right)^2} \quad \text{Eq. E.27 SI}$$

$$P_v = \frac{\rho Q^2 K_p{}^2}{(1097.8 A_2)^2} \quad \text{Eq. E.27 I-P}$$

By similar reasoning:

$$P_{vc} = \frac{\rho_c Q_c K_{pc}{}^2}{\left(\sqrt{2} A_{2c}\right)^2} \quad \text{Eq. E.28 SI}$$

$$P_{vc} = \frac{\rho_c Q_c K_{pc}{}^2}{(1097.8 A_{2c})^2} \quad \text{Eq. E.28 I-P}$$

By using the compressible flow fan law relationships for fan airflow rate and the proportionality of outlet area to diameter squared, it follows that the compressible flow fan law equation for fan velocity pressure is:

$$P_{vc} = P_v \left(\frac{D_c}{D}\right)^2 \left(\frac{N_c}{N}\right)^2 \left(\frac{\rho_c}{\rho}\right) \quad \text{Eq. E.29}$$

E.4.6 Fan static pressure
By definition:

$$P_{sc} = P_{tc} - P_{vc} \quad \text{Eq. E.30}$$

E.4.7 Fan static efficiency
By definition:

$$\eta_{sc} = \eta_{tc} \left(\frac{P_{sc}}{P_{tc}}\right) \quad \text{Eq. E.31}$$

E.5 Fan law deviations

Among the requirements for complete similarity are those for equal force ratios that lead to Reynolds and Mach number considerations.

E.5.1 Reynolds number
There is some evidence that efficiency improves with an increase in Reynolds number. However, that evidence is not considered sufficiently documented enough to incorporate any rules in this annex. There is also some evidence that performance drops off with a significant decrease in Reynolds number [23]. The fan laws shall not be employed if it is suspected that the airflow regimes are significantly different because of a difference in Reynolds number.

E.5.2 Mach number
There is evidence that choking occurs when the Mach number at any point in the flow passages approaches unity. The fan laws shall not be employed if this condition is suspected.

E.5.3 Bearing and drive losses
While there may be other similarity laws covering bearings and other drive elements, the fan laws cannot be used to predict bearing or drive losses. The correct procedure is to subtract the losses for the first condition, make fan law projections of power input for the corrected first condition to the second condition and then add the bearing and drive losses for the second condition.

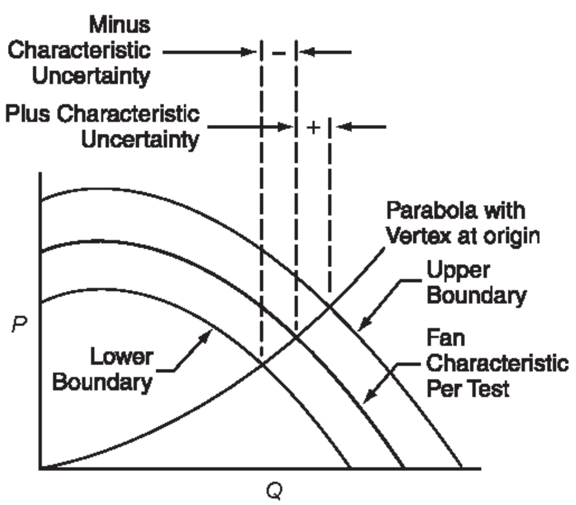
Annex F
Uncertainty Analysis [10] (Informative)

F.1 General

This analysis is based on the assumption that fan performance can be treated as a statistical quantity and that the performances derived from repeated tests would have a normal distribution. The best estimate of the true performance would therefore be the mean results based on repeated observations at each point of operation. Since only one set of observations is specified in the standard, this analysis must deal with the uncertainties in the results obtained from a single set of observations.

The results of a fan test are a complex combination of variables that must be presented graphically according to the standard. In order to simplify this analysis, test results will be considered to be the curves of fan static pressure versus fan airflow rate and fan static efficiency versus fan airflow rate. Analysis of fan input power is unnecessary since it is a part of efficiency analysis. The findings from a total pressure analysis would be similar to those of a static pressure analysis.

The uncertainty in the results will be expressed in two parts, both of which will be based on the uncertainties in various measurements. That part dealing with the pressure versus airflow rate curve will be called the characteristic uncertainty and that dealing with the efficiency versus airflow rate curve will be called the efficiency uncertainty. The characteristic uncertainty can be defined with reference to the following diagram:



The diagram shows a plot of the fan static pressure versus fan airflow rate as determined by test per this standard. Surrounding this curve is a band of uncertainties, the boundaries of which are roughly parallel to the test curve. Also shown is a parabola with the vertex at the origin that intersects the fan curve and both of the boundaries. The characteristic uncertainty is defined as the difference in airflow rate between the intersection of the parabola with the test curve and the intersections of the parabola with the boundaries. Typically, the absolute characteristic uncertainty would be ± a certain number of m^3/s (cfm). The relative characteristic uncertainty would be the absolute characteristic uncertainty divided by the airflow rate at the intersection with the test curve.

The absolute efficiency uncertainty is defined as the difference in efficiency between that at points corresponding to the above mentioned intersections with the boundaries and that at the above mentioned intersection with the fan test curve. Typically, this would be expressed as ± so many percentage points. The relative efficiency uncertainty would be the absolute efficiency uncertainty divided by the efficiency at the point corresponding to the above mentioned intersection with the test curve.

The accuracies specified in the standard are based on two standard deviations. This means that there shall be a 95% probability that the uncertainty in any measurement will be less than the specified value. Since the characteristic uncertainty and the efficiency uncertainty are based on these measurements, there will be a 95% probability that these uncertainties will be less than the calculated value.

F.2 Symbols

In the analysis which follows, certain symbols and notations are used in addition to those that are used in the standard.

Symbol	Quantity
dP/dQ	Slope of fan characteristic
e_x	Per unit uncertainty in X
ΔX	Absolute uncertainty in X
F_x	Correlation factor for X

Subscript	Description
A	Area
b	Barometric pressure
C	Nozzle discharge coefficient
d	Dry-bulb temperature
f	Pressure for airflow rate
g	Pressure for fan pressure

H	Fan input power
K	Character
m	Maximum
N	Fan speed
o	Fan output power
P	Fan pressure
Q	Fan airflow rate
T	Torque
V	Variable as defined in Equation F.11
w	For wet-bulb depression, in tw
X	Generalized quantity (A, b, ...ρ)
η	Fan efficiency
ρ	Fan air density

F.3 Measurement uncertainties

The various measurement uncertainties which are permitted in the standard are listed below with some of the considerations that led to their adoption.

(1) Barometric pressure is easily measured within the ±170 Pa (±0.05 in. Hg) specified.

$$e_b = \frac{1.70}{p_b} \qquad \text{Eq. F.1 SI}$$

$$e_b = \frac{0.05}{p_b} \qquad \text{Eq. F.1 I-P}$$

(2) Dry-bulb temperature is easily measured within the ±1 °C (±2.0 °F) specified if there are no significant radiation sources.

$$e_d = \frac{1.0}{t_d + 273.15} \qquad \text{Eq. F.2 SI}$$

$$e_d = \frac{2.0}{t_d + 459.67} \qquad \text{Eq. F.2 I-P}$$

(3) Wet-bulb depression is easily measured within 3 °C (5.0 °F) if temperature measurements are within 1 °C (2.0 °F) and if air velocity is maintained in the specified range:

$$e_w = \frac{3}{t_d - t_w} \qquad \text{Eq. F.3 SI}$$

$$e_w = \frac{5}{t_d - t_w} \qquad \text{Eq. F.3 I-P}$$

(4) Fan speed requires careful measurement to hold the 0.5% tolerance specified.

$$e_N = 0.005 \qquad \text{Eq. F.4}$$

(5) Torque requires careful measurement to hold the 2.0% tolerance specified:

$$e_T = 0.02 \qquad \text{Eq. F.5}$$

(6) Nozzle discharge coefficients given in the standard have been obtained from ISO data and nozzles made to specifications shall perform within a tolerance of 1.2% according to that data.

A properly performed laboratory traverse is assumed to have equal accuracy:

$$e_c = 0.012 \qquad \text{Eq. F.6}$$

(7) The area at the flow measuring station will be within 0.5% when the diameter measurements are within the 0.2% specified:

$$e_A = 0.005 \qquad \text{Eq. F.7}$$

(8) The tolerance on the pressure measurement for determining flow rate is specified as 1% of the maximum reading during the test. This is easily obtained by using the specified calibration procedures. In addition, an allowance must be made for the mental averaging that is performed on fluctuating readings. This is estimated to be 1% of the reading. Using the subscript *m* to denote the condition for the maximum reading, a combined uncertainty can be written:

$$e_f = \sqrt{(0.01)^2 + \left[0.01\left(\frac{Q_m}{Q}\right)^2\right]^2} \qquad \text{Eq. F.8}$$

(9) The pressure measurement for determining fan pressure is also subject to an instrument tolerance of 1% of the maximum reading and an averaging tolerance of 1% of the reading. In addition, there are various uncertainties that are related to the velocity pressure. A tolerance of 10% of the fan velocity pressure shall cover the influence of yaw on pressure sensors, friction factor variances and other possible effects:

$$e_g = \sqrt{(0.01)^2 + \left[0.01\left(\frac{P_m}{P}\right)\right]^2 + \left[0.1\left(\frac{P_v}{P}\right)\right]^2} \qquad \text{Eq. F.9}$$

F.4 Combined uncertainties

The uncertainties in the test performance are the result of using various values, each of which is associated with an uncertainty. The combined uncertainty for each of the fan performance variables is given below. The characteristic uncertainty and the efficiency uncertainty are also given.

(1) Fan air density involves the various psychrometric measurements and the approximate formula:

$$\rho = \frac{p_b V}{R(t_d + 273.15)} \quad \text{Eq. F.10 SI}$$

$$\rho = \frac{70.73 p_b V}{R(t_d + 459.67)} \quad \text{Eq. F.10 I-P}$$

Where:

$$V = \left\{1.0 - 0.378\left[\frac{p_e}{p_b} - \frac{(t_d - t_w)}{1500}\right]\right\} \quad \text{Eq. F.11 SI}$$

$$V = \left\{1.0 - 0.378\left[\frac{p_e}{p_b} - \frac{(t_d - t_w)}{2700}\right]\right\} \quad \text{Eq. F.11 I-P}$$

For random and independent uncertainties in products, the combined uncertainty is determined as follows:

$$\frac{\Delta\rho}{\rho} = \sqrt{\left(\frac{\Delta 1.0}{1}\right)^2 + \left(\frac{\Delta p_b}{p_b}\right)^2 + \left(\frac{\Delta V}{V}\right)^2 + \left(\frac{\Delta R}{R}\right)^2 + \left(\frac{\Delta t_d}{T_d + 273.15}\right)^2}$$

Eq. F.12 SI

$$\frac{\Delta\rho}{\rho} = \sqrt{\left(\frac{\Delta 70.73}{70.73}\right)^2 + \left(\frac{\Delta p_b}{p_b}\right)^2 + \left(\frac{\Delta V}{V}\right)^2 + \left(\frac{\Delta R}{R}\right)^2 + \left(\frac{\Delta t_d}{T_d + 459.67}\right)^2}$$

Eq. F.12 I-P

Assuming $\Delta 70.73$ and ΔR are both zero:

$$e_\rho = \sqrt{e_b{}^2 + e_V{}^2 + e_d{}^2} \quad \text{Eq. F.13}$$

It can be shown that:

$$e_V{}^2 = \left[(0.00002349 t_w - 0.0003204)\Delta(t_d - t_w)\right]^2$$

Eq. F.14 SI

$$e_V{}^2 = \left[(0.00000725 t_w - 0.0000542)\Delta(t_d - t_w)\right]^2$$

Eq. F.14 I-P

(2) Fan airflow rate directly involves the area at the airflow measuring station, the nozzle discharge coefficient, the square root of the pressure measurement for flow and the square root of the air density. When making fan law conversions, fan speed has a first power effect on airflow rate. The effects of uncertainties in each of these variables can be expressed mathematically as follows, where e_{QX} is the uncertainty in flow rate due to the uncertainty in X.

$$\begin{array}{ll} e_{QA} = e_A & e_{QN} = e_N \\ e_{QC} = e_C & e_{Q\rho} = \dfrac{e_\rho}{2} \\ e_{Qf} = \dfrac{e_f}{2} & e_{QT} = 0 \\ e_{Qg} = 0 & \end{array} \quad \text{Eq. F.15}$$

The uncertainty in the airflow rate only can be determined from the above uncertainties by combining:

$$e_Q = \sqrt{e_c{}^2 + e_A{}^2 + \left(\frac{e_f}{2}\right)^2 + \left(\frac{e_\rho}{2}\right)^2 + e_N{}^2} \quad \text{Eq. F.15A}$$

(3) Fan pressure directly involves the pressure measurement for fan pressure. In addition, when making fan law conversions, air density has a first power effect on fan pressure while fan speed produces a second power effect. Mathematically:

$$\begin{array}{ll} e_{PA} = 0 & e_{PN} = 2e_N \\ e_{PC} = 0 & e_{Pp} = e_p \\ e_{Pf} = 0 & e_{PT} = 0 \\ e_{Pg} = e_g & \end{array} \quad \text{Eq. F.16}$$

The uncertainty in the fan pressure only can be determined from the above uncertainties by combining:

$$e_P = \sqrt{e_g{}^2 + e_\rho{}^2 + (2e_N)^2} \quad \text{Eq. F.16A}$$

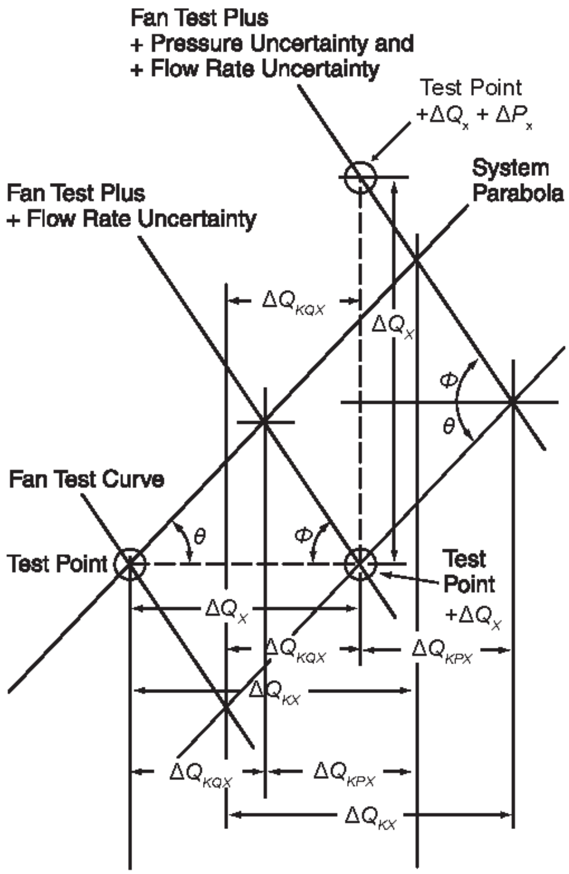
(4) Fan input power directly involves the torque and speed measurements. In addition, when making fan law conversions, density has a first power effect and speed a third power effect on fan input power. The net effect with respect to speed is second power. Mathematically:

$$\begin{array}{ll} e_{HA} = 0 & e_{HN} = 2e_N \\ e_{HC} = 0 & e_{Hp} = e_p \\ e_{Hf} = 0 & e_{HT} = e_T \\ e_{Hg} = 0 & \end{array} \quad \text{Eq. F.17}$$

The uncertainty in the fan input power can only be determined from the above uncertainties by combining:

$$e_H = \sqrt{e_T{}^2 + e_\rho{}^2 + (2e_N)^2} \quad \text{Eq. F.17A}$$

(5) The uncertainties in the measurements for fan flow rate and fan pressure create the characteristic uncertainty as defined in Section F.1. Assuming the uncertainties are small, the characteristic curves and parabola can be replaced by their tangents, and the effects of uncertainty in each measurement, (X), on the characteristic uncertainty can be determined. At a point (Q, P), the uncertainty in measurement (X) results in an uncertainty in Q and P of ΔQ_X and ΔP_X.



For ΔQ_X:

$$\Delta Q_{KQX}\tan\theta = (\Delta Q_x - \Delta Q_{KQX})\tan\phi \quad \text{Eq. F.18}$$

$$\Delta Q_{KQX} = \Delta Q_x\left[\frac{\tan\phi}{\tan\theta + \tan\phi}\right] \quad \text{Eq. F.19}$$

For ΔP_X:

$$\Delta Q_{KPX}\left(\tan\theta + \tan\phi\right) = \Delta P_x \quad \text{Eq. F.20}$$

$$\Delta Q_{KPX} = \Delta P_x\left[\frac{1}{\tan\theta + \tan\phi}\right] \quad \text{Eq. F.21}$$

Summing and simplifying by relating the tangents to the slopes of the parabola and the fan characteristic curve:

$$\Delta Q_{KX} = \Delta Q_{KQX} + \Delta Q_{KPX} \quad \text{Eq. F.22}$$

$$\tan\phi = 2\left(\frac{P}{Q}\right) \quad \text{Eq. F.23}$$

And:

$$\tan\phi = -\left(\frac{dP}{dQ}\right) \quad \text{Eq. F.24}$$

$$\Delta Q_{KX} = \Delta Q_x\left[\frac{-\left(\frac{dp}{dQ}\right)}{2\left(\frac{P}{Q}\right) - \left(\frac{dP}{dQ}\right)}\right] + \Delta P_x\left[\frac{1}{2\left(\frac{P}{Q}\right) - \left(\frac{dP}{dQ}\right)}\right] \quad \text{Eq. F.25}$$

$$e_{KX} = e_{QX}\left[\frac{-\left(\frac{dp}{dQ}\right)}{2\left(\frac{P}{Q}\right) - \left(\frac{dP}{dQ}\right)}\right] + \frac{e_{PPX}}{2}\left[\frac{2\left(\frac{P}{Q}\right)}{2\left(\frac{P}{Q}\right) - \left(\frac{dP}{dQ}\right)}\right] \quad \text{Eq. F.26}$$

Introducing correlation factors:

$$F_Q = \left[\frac{-\left(\frac{dp}{dQ}\right)}{2\left(\frac{P}{Q}\right) - \left(\frac{dP}{dQ}\right)}\right] \quad \text{Eq. F.27}$$

And:

$$F_P = \left[\frac{2\left(\frac{P}{Q}\right)}{2\left(\frac{P}{Q}\right) - \left(\frac{dP}{dQ}\right)}\right] \quad \text{Eq. F.28}$$

$$e_{KX} = e_{QX}F_Q + \left(\frac{e_{PX}}{2}\right)F_P \quad \text{Eq. F.29}$$

Combining Equations F.15, F.16 and F.29:

$$\begin{aligned} e_{KA} &= e_A F_Q & e_{Kg} &= \left(\frac{e_g}{2}\right)F_P \\ e_{KC} &= e_C F_Q & e_{KN} &= e_N\left(F_Q + F_P\right) \\ e_{Kf} &= \left(\frac{e_f}{2}\right)F_Q & e_{K\rho} &= \frac{e_\rho}{2}\left(F_Q + F_P\right) \end{aligned} \quad \text{Eq. F.30}$$

Assuming these uncertainties are independent, they can be combined for the characteristic uncertainty as follows, noting that $F_Q + F_P = 1$:

$$e_K = \sqrt{\left(\frac{e_\rho}{2}\right)^2 + e_N^2 + F_P^2\left(\frac{e_g}{2}\right)^2 + F_Q^2\left[e_C^2 + e_A^2 + \left(\frac{e_f}{2}\right)^2\right]}$$

Eq. F.31

(6) Fan output power is proportional to the third power of airflow rate along a system characteristic. Therefore:

$e_O = 3e_K$ Eq. F.32

(7) Fan efficiency uncertainty was defined in Equation F.1. Using the above noted correlation factors and recombining the components:

$$e_\eta = \sqrt{\left(\frac{e_\rho}{2}\right)^2 + e_N^2 + e_T^2 + 9\left[F_P^2\left(\frac{e_g}{2}\right)^2 + F_Q^2\left(e_C^2 + e_A^2 + \left(\frac{e_f}{2}\right)^2\right)\right]}$$

Eq. F.33

F.5 Example

The characteristic test curve for a typical backward-curve centrifugal fan was normalized on the basis of shut-off pressure and free-delivery airflow rate. The resultant curve is shown in Figure F.1.

An uncertainty analysis based on this curve and the maximum allowable measurement tolerances follows:

(1) The maximum allowable measurement tolerances can be determined using the information from Section F.3. Where appropriate, lowest expected barometer and temperature for a laboratory at sea level are assumed.

Per unit uncertainties are:

$$e_b = \left[\frac{0.05}{28.5}\right] = 0.0018$$

$$e_d = \left[\frac{2.0}{(60+459.7)}\right] = 0.0038$$

$$e_W = \left[\frac{5.0}{(60-50)}\right] = 0.5$$

$e_N = 0.005$

$e_T = 0.02$

$e_C = 0.012$

$e_A = 0.005$

$$e_f = \sqrt{(0.01)^2 + \left[0.01\left(\frac{Q_m}{Q}\right)^2\right]^2}$$

And:

$$e_g = \sqrt{(0.01)^2 + \left[0.01\left(\frac{P_m}{P}\right)\right]^2 + \left[0.1\left(\frac{P_v}{P}\right)\right]^2}$$

Note that e_f and e_g vary with point of operation. In this example, the values of Q_m, Q, P_m and P are taken from Figure F.1. The velocity pressure at free delivery is taken to be 20% of the maximum static pressure.

(2) The various combined uncertainties and factors can be determined using the information from Section F.4. To illustrate, the per unit uncertainty in air density will be calculated:

$$e_\rho = \sqrt{e_b^2 + e_v^2 + e_d^2}$$

$$e_b^2 = \left(\frac{0.05}{28.5}\right)^2 = 0.00000308$$

$e_v^2 = [(0.00000725 \times 50 - 0.0000542)5.0]^2$

$= 0.00000238$

$$e_d^2 = \left[\frac{2.0}{(60+459.7)}\right]^2 = 0.00001481$$

And:

$e_r = 0.0045$

This is the expected accuracy for a laboratory at sea level. For extremes of altitude and wet-bulb temperatures, the limit is:

$e_r = 0.005$

(3) The characteristic uncertainty and the efficiency uncertainty can be calculated for various points of operation as indicated in Table F.1.

The values of Q, P and $-(dP/dQ)$ have been read directly from the normalized fan curve. The results have been plotted as curves of per unit uncertainty versus airflow rate in Figure F.2.

F.6 Summary

The example is based on uncertainties that, in turn, are based on 95% confidence limits. Accordingly, the results of 95% of all tests will be better than indicated. Per unit uncertainties of one half those indicated will be achieved in 68% of all tests, while indicated per unit uncertainties will be exceeded in 5% of all tests. The examples from above provide the following conclusions:

(1) The characteristic uncertainty for the specified tolerances is about 1% near the best efficiency point and approaches 2% at free delivery. The uncertainty also increases rapidly as shutoff is approached.

(2) The fan efficiency uncertainty is about 3% near the best efficiency point and exceeds 5% at free delivery. The uncertainty increases rapidly near shutoff.

(3) Psychrometric measurement uncertainties have very little effect on overall accuracy. Calibration corrections are unnecessary in most cases.

(4) The nozzle discharge coefficient uncertainty has a very significant effect on overall accuracy. The 1.2% tolerance specified was based on the current state of the art. Any significant improvement in the accuracy of test results will depend on further work to reduce the uncertainty of this quantity.

(5) While the example was based on a typical characteristic for a backward-curve centrifugal fan, analyses of different characteristics for other fan types will yield sufficiently similar results that the same conclusion can be drawn.

(6) This analysis has been limited to a study of measurement uncertainties in laboratory setups. Other factors may have an equal or greater effect on fan performance. The results of an on-site test may deviate from predicted values because of additional uncertainties in measurements such as poor approach conditions to measuring stations. Deviations may also be due to conditions affecting the flow into or out of the fan which, in turn, affects the ability of the fan to perform. Differences in construction, which arise from manufacturing tolerances, may cause full-scale test performance to deviate from model performance.

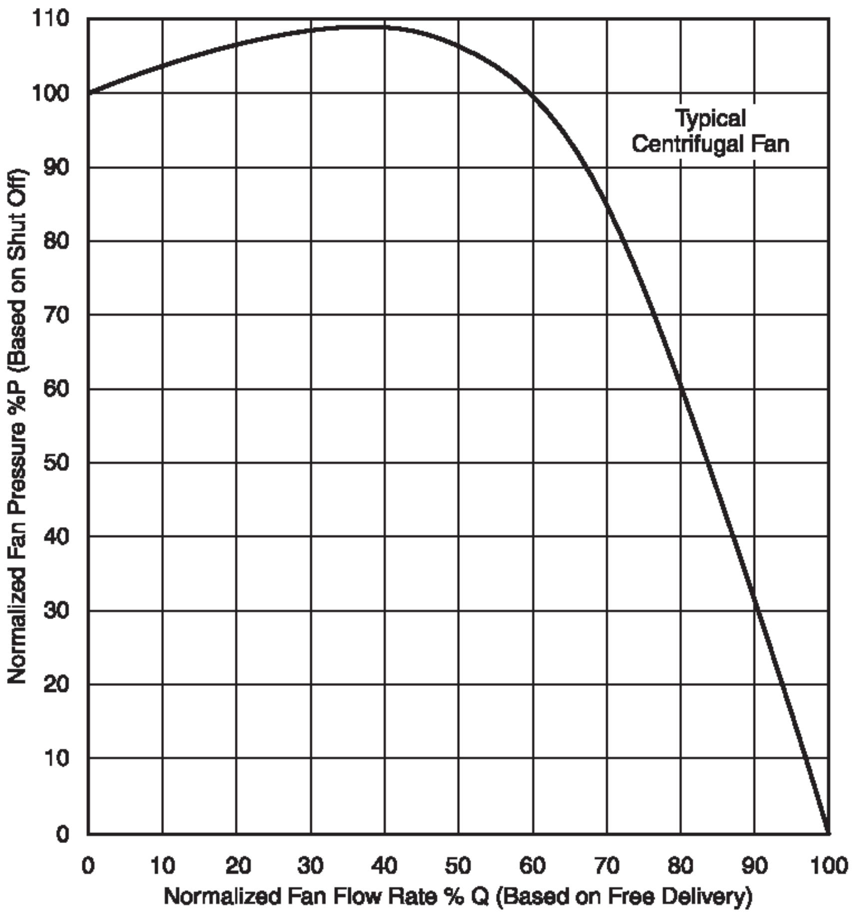


Figure F.1
Normalized Fan Flow vs. Pressure Curve

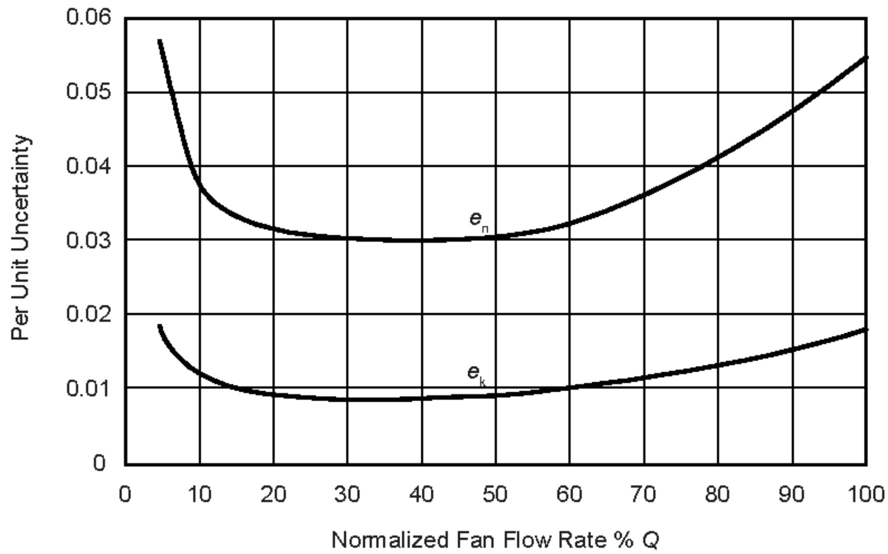


Figure F.2
Normalized Test Results Uncertainties

Table F.1
Tabulation for Uncertainty Analysis of Figure F.1

$\%Q$	$\%P$	$\left(\frac{dP}{dQ}\right)$	F_P	F_Q	$\left[\left(\frac{e_\rho}{2}\right)^2 + e_N^2\right]$	$\left[F_P^2\left(\frac{e_g}{2}\right)^2\right]$	$\left[F_Q^2\left(e_c^2 + e_A^2 + \frac{e_f^2}{4}\right)\right]$	e_K	e_0
99	3.2	3.215	0.01971	0.98029	31.2×10^{-6}	53.5×10^{-6}	211.4×10^{-6}	0.0172	0.0531
95	16	3.075	0.09873	0.90127	31.2×10^{-6}	47.5×10^{-6}	182.5×10^{-6}	0.0162	0.0500
90	31.5	2.900	0.19444	0.80556	31.2×10^{-6}	41.2×10^{-6}	150.6×10^{-6}	0.0149	0.0464
85	46	2.700	0.28616	0.71384	31.2×10^{-6}	36.8×10^{-6}	123.2×10^{-6}	0.0138	0.0433
80	59.5	2.500	0.37304	0.62696	31.2×10^{-6}	33.7×10^{-6}	100.2×10^{-6}	0.0129	0.0405
75	72	2.275	0.45769	0.54231	31.2×10^{-6}	31.9×10^{-6}	80.2×10^{-6}	0.0120	0.0379
70	82.7	1.950	0.54786	0.45214	31.2×10^{-6}	32.5×10^{-6}	60.9×10^{-6}	0.0112	0.0357
65	91.2	1.575	0.64051	0.35949	31.2×10^{-6}	34.9×10^{-6}	43.1×10^{-6}	0.0105	0.0337
60	98	1.150	0.73962	0.26038	31.2×10^{-6}	38.8×10^{-6}	26.2×10^{-6}	0.0098	0.0319
55	102.6	0.800	0.82343	0.17657	31.2×10^{-6}	42.6×10^{-6}	14.5×10^{-6}	0.0094	0.0307
50	105.3	0.500	0.89389	0.10611	31.2×10^{-6}	46.2×10^{-6}	6.6×10^{-6}	0.0092	0.0301
45	107	0.250	0.95006	0.04994	31.2×10^{-6}	49.3×10^{-6}	2.0×10^{-6}	0.0091	0.0299
40	107.9	0.050	0.99082	0.00918	31.2×10^{-6}	51.6×10^{-6}	0×10^{-6}	0.0091	0.0299
35	108	-0.025	1.00407	-0.00407	31.2×10^{-6}	51.9×10^{-6}	0×10^{-6}	0.0091	0.0300
30	107.6	-0.100	1.01414	-0.01414	31.2×10^{-6}	52.4×10^{-6}	0.6×10^{-6}	0.0092	0.0301
25	107	-0.175	1.02087	-0.02087	31.2×10^{-6}	53.0×10^{-6}	2.8×10^{-6}	0.0093	0.0306
20	106	-0.225	1.02169	-0.02169	31.2×10^{-6}	53.5×10^{-6}	7.4×10^{-6}	0.0096	0.0313
15	104.7	-0.275	1.02009	-0.02009	31.2×10^{-6}	53.7×10^{-6}	20.0×10^{-6}	0.0102	0.0331
10	103.2	-0.325	1.01600	-0.016	31.2×10^{-6}	54.0×10^{-6}	64.0×10^{-6}	0.0122	0.0386
5	101.6	-0.325	1.00806	-0.0086	31.2×10^{-6}	54.1×10^{-6}	259.8×10^{-6}	0.0186	0.0571

Annex G
Iterative Procedure (Informative)

G.1 Calculating the value of C

To obtain the value of *C* to be used in calculating the chamber nozzle airflow rate in Section 7.3.1.6, an iteration process or, in some instances, an approximate process can be used.

G.2 Iterative procedure

A calculated value of Re is made using an estimated value of *C*. The calculated value of Re is then used to recalculate *C* until the difference between two successive trial values of *C* is ≤ 0.001, at which point the last trial value of *C* is taken as the value to be used in calculating chamber nozzle volume. In the following example, the first estimate of Re is made using an estimated value of *Ce* = 0.99. It is suggested that calculations be carried out to at least five decimal places.

G.3 Example iteration

Iteration 1

Step 1-1 — Calculate Re, using:

$$\mathrm{Re} = \frac{1097.8}{60\mu_6} Ce D_6 Y \sqrt{\frac{\Delta P \rho_5}{1 - E\beta^4}}$$

Where:

μ_6 = 1.222 × 10^{-5} lbm/ft•s
Ce = 0.99 (estimated)
D_6 = 6 in. = 0.5 ft
Y = 0.998 (calculate per Section 7.3.1.3)
ΔP = 1.005 in. wg
ρ = 0.0711 lbm/ft^3
$(1 - E\beta^4)$ = 1 for iteration purposes

$$\mathrm{Re}_1 = \frac{1097.8}{(60)\left(1.222 \times 10^{-5}\right)}(0.99)(0.5)(0.998)\sqrt{(1.005)(0.0711)}$$

Re_1 = 197,397

Step 1-2
Calculate Ce_1, using Re_1 from the previous step, assuming that *L/D* = 0.6:

$$Ce_1 = 0.9986 - \frac{7.006}{\sqrt{(\mathrm{Re}_1)}} + \frac{134.6}{\mathrm{Re}_1}$$

$$Ce_1 = 0.9986 - \frac{7.006}{\sqrt{197{,}397}} + \frac{134.6}{197{,}397}$$

$$Ce_1 = 0.9831$$

Check: $\left|Ce - Ce_1\right| = \left|0.99 - 0.9831\right| = 0.0069$

Since 0.0069 > 0.001, a second iteration is required.

Iteration 2

Step 2-1 — Re-estimate Re, using Ce_1:

$$\mathrm{Re}_2 = \mathrm{Re}_1\left(\frac{Ce_1}{Ce}\right)$$

$$\mathrm{Re}_2 = 197{,}397\left(\frac{0.9831}{0.99}\right)$$

$$\mathrm{Re}_2 = 196{,}020$$

Step 2-2 — Recalculate C, using Re_2:

$$Ce_2 = 0.9986 - \frac{7.006}{\sqrt{\mathrm{Re}_2}} + \frac{134.6}{\mathrm{Re}_2}$$

$$Ce_2 = 0.9986 - \frac{7.006}{\sqrt{196{,}020}} + \frac{134.6}{196{,}020}$$

$$Ce_2 = 0.9835$$

Check: $\left|Ce_1 - Ce_2\right| = \left|0.9831 - 0.9835\right| = 0.0004$

Since 0.0004 < 0.001, no further iterations are required, and Ce_2 = 0.9835 = *C*.

If, for some unusual conditions, the iterations do not converge, then try a different starting initial guess for *Ce*.

G.4 Approximate procedure

For the range of temperature from 40°F to 100°F, a calculated value of Re can be obtained from:

$$\mathrm{Re} = 1{,}363{,}000 D_6 \sqrt{\frac{\Delta P \rho_x}{1 - \beta^4}}$$

The formula is based on *C* = 0.95, *Y* = 0.96, *E* = 1.0 and 1.222 × 10^{-5} lbm/ft-s.

Annex H
Fan Outlet Area (Normative)

H.1 General requirements

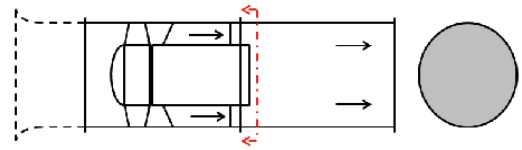
The fan area outlet can sometimes be difficult to define and measure. For certain test setups and installation types, the calculation of fan total pressure, P_t, is dependent on the value of the fan outlet area. This annex provides general requirements for determining where the fan outlet area is measured for various fan types. While an exhaustive description of each fan type is impractical, some examples and illustrations are provided. Fan outlet areas for other fan types can be found in ANSI/AMCA Standard 99.

H.2 Fans tested with outlet ducts — installation types B and D

For fans tested using installation types B and D, the fan outlet area is always planar and is perpendicular to the axis of the duct. While there may be localized turbulence, swirl or even a small amount of reverse flow at the discharge of the fan, the outlet test duct is intended to remove most of this and provide a nearly fully developed flow by the time the static pressure is measured, either in the duct or in an outlet chamber.

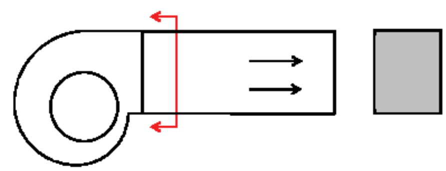
The fan outlet area used for the calculation of P_v and P_t is the gross cross-sectional area at the fan discharge. The equations for P_{t2} in the outlet chamber test figures are valid only when the outlet test duct has a uniform cross-sectional area equal to the fan outlet area.

H.2.1 Examples



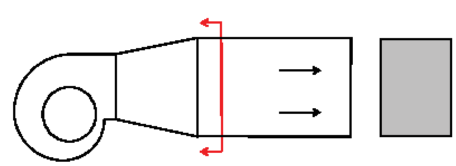
Fan outlet area for a ducted axial fan is the gross cross-sectional area at the fan outlet, which is also equal to the test duct cross-sectional area, regardless of whether the motor or inner shroud extends into the test duct.

Figure H.1
From Figure 15, Installation Type D: Ducted Inlet, Ducted Outlet



Fan outlet area for a centrifugal fan tested with an outlet duct is the gross cross-sectional area at the fan outlet, which is also equal to the test duct cross-sectional area, regardless of whether a cutoff plate is used to block a portion of the fan outlet.

Figure H.2
From Figure 12, Installation Type B: Free Inlet, Ducted Outlet



Fan outlet area for a fan tested with an outlet diffuser is the cross-sectional area at the diffuser outlet, which is also equal to the test duct cross-sectional area.

Figure H.3
From Figure 12, Installation Type B: Free Inlet, Ducted Outlet

TAC: Mechanical

Total Mods for **Mechanical** in **No Affirmative Recommendation: 25**

Total Mods for report: 55

Sub Code: Mechanical

M7276

31

Date Submitted	11/15/2018	**Section**	202	**Proponent**	James Bickford
Chapter	2	**Affects HVHZ**	No	**Attachments**	No

TAC Recommendation No Affirmative Recommendation
Commission Action Pending Review

Comments

General Comments No

Alternate Language No

Related Modifications

Summary of Modification

Clarifies definition of Machine Room

Rationale

The proposed definition is consistent with the definition in IIAR 2 and resolves a problem with the current definition. The current definition implies that any room with refrigeration equipment is a machinery room, which is incorrect. Only those rooms that are required to contain certain refrigeration machinery and refrigerant quantities are classified as machinery rooms.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

None

Impact to building and property owners relative to cost of compliance with code

None

Impact to industry relative to the cost of compliance with code

Will not increase the cost of construction.
This proposal is a clarification that should have no impact on the cost of construction

Impact to small business relative to the cost of compliance with code

none

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

Clarifies what is a Machinery room

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

Clarifies what is a Machinery room

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

Has no impact on materials

Does not degrade the effectiveness of the code

Improves the code by fixing a definition

1st Comment Period History

M7276-G1

Proponent pete quintela **Submitted** 1/14/2019 **Attachments** No

Comment:

I agree that the original definition needs improvement. Please take a look at M1104.2, I think a reference in the definition to this code section might be all we need.

MACHINERY ROOM. A<u>n enclosed space that is required by Chapter 11 to contain refrigeration equipment and to comply with </u>~~room meeting prescribed safety requirements and in which refrigeration systems or components thereof are located (see~~ Sections 1105 and 1106).

M7442

Date Submitted	11/26/2018	**Section**	202	**Proponent**	James Bickford
Chapter	2	**Affects HVHZ**	No	**Attachments**	No

TAC Recommendation No Affirmative Recommendation
Commission Action Pending Review

Comments

General Comments **No** **Alternate Language** **No**

Related Modifications

1104.2.2 exception 7

Summary of Modification

The modification of the 100 HP power threshold in Item 7 clarifies that this is compressor drive power, which is the terminology used in IIAR 2 Section 4.2.3 and ASHRAE 15 Section 7.2.2(g).

Rationale

The modification of the 100 HP power threshold in Item 7 clarifies that this is compressor drive power, which is the terminology used in IIAR 2 Section 4.2.3 and ASHRAE 15 Section 7.2.2(g). The change ensures that the drive power for liquid pumps and other motorized equipment attached to the system is not improperly added.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

Enhances enforcement by providing an optional path to compliance. Standard pumps will continue to be permitted when they are located in refrigerant machinery rooms.

Impact to building and property owners relative to cost of compliance with code

Will not increase the cost of construction

Impact to industry relative to the cost of compliance with code

Will not increase the cost of construction

Impact to small business relative to the cost of compliance with code

Will not increase the cost of construction

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

Provides optional path to compliance with code, no affect on health, safety or welfare

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

Improves code by providing optional path to compliance.

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

Improves code by providing optional path to compliance.

Does not degrade the effectiveness of the code

Improves code by providing optional path to compliance.

Add new definition as follows:

SECTION 202 DEFINITIONS

LOW-PROBABILITY PUMP. A pump that does not rely on a dynamic shaft seal as a singular means of containment to prevent atmospheric release of the pumped fluid.

Revise as follows:

1104.2.2 Industrial occupancies and refrigerated room.

The only change is to condition 7, all other portions remain unchanged

7. All refrigerant-containing parts in systems with a total connected compressor power exceeding 100 horsepower (hp) (74.6 kW) ~~drive power~~, except evaporators used for refrigeration or dehumidification; condensers used for heating; control and pressure relief valves for either; low-probability pumps; and connecting piping, shall be located either outdoors or in a machinery room.

M7166

Date Submitted	11/2/2018	**Section**	307.2	**Proponent**	Brad Ketner
Chapter	3	**Affects HVHZ**	No	**Attachments**	No

TAC Recommendation No Affirmative Recommendation
Commission Action Pending Review

Comments

General Comments **No** **Alternate Language** **No**

Related Modifications

Summary of Modification

We have developed a new safety control, the No Freeze Control, that prevents the evaporator coils on an ac unit from freezing up. This stops potential water in the unit and prevents mold and mildew damage to the unit and home.

Rationale

This safety control will prevent the freezing and water damage that occurs due to the HVAC system freezing up. It will also prevent dangerous mold and mildew damage in the unit and home. In upstairs units, as well as commercial roof top units, it prevents structural damage from water from the melting coils. This is potentially thousands of dollars for insurance company's and homeowners. This is the only control that stops the freezing event before it happens.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

There is no impact to local code enforcement.

Impact to building and property owners relative to cost of compliance with code

The impact would be minimum. The cost to install the part is around $200. The home owner and business owner save potentially thousands in property damage repairs from water damage.

Impact to industry relative to the cost of compliance with code

The impact would be reduced liability for the HVAC companies and contractors. This would also save insurance company thousands in potential claims due to water damage.

Impact to small business relative to the cost of compliance with code

Minimal impact.

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

The No Freeze Control stops the water damage in a home or business due to a freeze up event. This prevents the potential mold and mildew that would be present. This potentially could make employees or homeowner sick. It also prevents injuries due to water damage in ceilings.

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

The No Freeze Control is a new safety device that makes an ac unit safer to operate. When there is a malfunction, the technician is able to fix the problem right away and avoids the water damage potential associated with these events.

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

This product has no negative impact on other products that are currently used in an hvac unit.

Does not degrade the effectiveness of the code

The No Freeze Control makes the code stronger and provides a safer result than currently available.

This part should be listed in section 307.2.3.3.The "No Freeze Control" shall be used on all hvac units to prevent the freezing of the evaporator coils.

M7281

Date Submitted	11/15/2018	**Section**	303.7	**Proponent**	James Bickford
Chapter	3	**Affects HVHZ**	No	**Attachments**	No

TAC Recommendation No Affirmative Recommendation
Commission Action Pending Review

Comments

General Comments **No** **Alternate Language** **No**

Related Modifications

Summary of Modification

This modification completes this section and has all the information necessary for a complete and code compliant installation.

Rationale

This Section lacks some detail in floor and control side language found in the other codes. This modification completes this section and has all the information necessary for a complete and code compliant installation.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

This proposal is just for correlation between codes for consistency

Impact to building and property owners relative to cost of compliance with code

This proposal is just for correlation between codes for consistency

Impact to industry relative to the cost of compliance with code

Will not increase the cost of construction

Impact to small business relative to the cost of compliance with code

This proposal is just for correlation between codes for consistency

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

This proposal is just for correlation between codes for consistency

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

This proposal is just for correlation between codes for consistency

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

This proposal is just for correlation between codes for consistency

Does not degrade the effectiveness of the code

This proposal is just for correlation between codes for consistency

303.7Pit locations.

Appliances installed in pits or excavations shall not come in direct contact with the surrounding soil <u>and shall be installed not less than 6 inches above the pit floor</u>. The sides of the pit or excavation shall be held back not less than 12 inches (305 mm) from the *appliance*. Where the depth exceeds 12 inches (305 mm) below adjoining grade, the walls of the pit or excavation shall be lined with concrete or masonry. Such concrete or masonry shall extend not less than 4 inches (102 mm) above adjoining grade and shall have sufficient lateral load-bearing capacity to resist collapse. . <u>Excavation on the control side of the appliance shall extend not less than 30 inches (762mm) horizontally</u> The *appliance* shall be protected from flooding in an *approved* manner.

M7282

Date Submitted 11/16/2018
Chapter 3
Section 303.9
Affects HVHZ No
Proponent James Bickford
Attachments No
TAC Recommendation No Affirmative Recommendation
Commission Action Pending Review

Comments

General Comments **No**

Alternate Language **No**

Related Modifications

901.5

Summary of Modification

Adds new section 303.9 "Fireplaces in Group I-2 Condition 2 Occupancies" and 901.5 "Solid fuel-burning fireplaces and appliances in Group I-2 Condition 2"

Rationale

This change provides limitations for the use of gas-fired fireplaces and decorative equipment and the restriction of solid-fuel burning fireplaces and appliances in the Group I-2, Condition 2 occupancies, these are not new requirements for the I-2 Occupancy facilities but are needed in the code for coordination of the long-standing provision of the construction and operational requirements for healthcare facilities

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

None

Impact to building and property owners relative to cost of compliance with code

Will not increase the cost of construction
Wood burning fireplaces are not permitted by the federal CMS regulations, therefore, there is no change in cost of construction.

Impact to industry relative to the cost of compliance with code

Will not increase the cost of construction
Wood burning fireplaces are not permitted by the federal CMS regulations, therefore, there is no change in cost of construction.

Impact to small business relative to the cost of compliance with code

Will not increase the cost of construction
Wood burning fireplaces are not permitted by the federal CMS regulations, therefore, there is no change in cost of construction.

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

Wood burning fireplaces are not permitted by the federal CMS regulations, therefore, there is no change in cost of construction.

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

Wood burning fireplaces are not permitted by the federal CMS regulations, therefore, there is no change in cost of construction.

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

Wood burning fireplaces are not permitted by the federal CMS regulations, therefore, there is no change in cost of construction.

Does not degrade the effectiveness of the code

Improves safety in the code

303.9 Fireplaces in Group I-2 Condition 2 occupancies. Fuel burning appliances and fireplaces in Group I-2 condition 2 occupancies shall be in accordance with Section 901.5.

901.5 Solid fuel-burning fireplaces and appliances in Group I-2 Condition 2. In Group I-2 Condition 2 occupancies, solid fuel-burning fireplaces and appliances are prohibited.

M8209

Date Submitted	12/14/2018	**Section**	401.4	**Proponent**	Mike Moore
Chapter	4	**Affects HVHZ**	No	**Attachments**	No
TAC Recommendation	No Affirmative Recommendation				
Commission Action	Pending Review				

Comments

General Comments **No** **Alternate Language** **No**

Related Modifications

This proposal also addresses Section 501.3.1 to ensure that it does not introduce any conflicts.

Summary of Modification

Aligns with 2021 IMC in approving limited applications of factory-built intake/exhaust combination termination fittings.

Rationale

Factory-built Intake/exhaust combination terminations are regularly installed with heating and energy recovery ventilators (H/ERVs) used for dwelling units. Their use reduces building penetrations, labor, and associated system costs. By reducing the number of penetrations, air leakage can also be reduced, resulting in space conditioning energy savings. Further, the durability of the structure can be improved through reducing entry pathways for bulk water.
Manufacturer tests conducted Natural Resources Canada (NRC) have demonstrated that use of intake/exhaust combination terminations results in minimum cross-contamination of airflows (i.e., not exceeding 4%; see NRC report A1-007793). These results are aligned with ASHRAE 62.2 approval of such devices which limits cross-contamination to 10%, as verified by the manufacturer. If approved, this proposed modification is expected to result in more affordable and architecturally flexible terminations.

This proposal is on the consent agenda for the 2021 IMC (proposal M17), so it is very likely to be in the final language of the International Mechanical Code. Approval of this proposal will align the Florida Building Code - Mechanical with the 2021 IMC.

Note: The IRC defines living space as, “space within a dwelling unit utilized for living, sleeping, eating, cooking, bathing, washing and sanitation purposes”.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

None.

Impact to building and property owners relative to cost of compliance with code

Reduces cost of compliance.

Impact to industry relative to the cost of compliance with code

Reduces cost of compliance.

Impact to small business relative to the cost of compliance with code

Reduces cost of compliance.

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

Research has demonstrated good separation of exhaust and supply air streams to promote health when these devices are used.

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

Improves code by aligning with 2021 IMC and permitting innovative products.

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

No discrimination results from this requirement, provided the fitting is factory-built.

Does not degrade the effectiveness of the code

Improves code by supporting innovative systems with similar performance.

1st Comment Period History

M8209-G1

Proponent pete quintela **Submitted** 1/14/2019 **Attachments** No

Comment:

Proposed for the 2021 IMC ?

Modify 401.4 as follows:

401.4 Intake opening location. Air intake openings shall comply with all of the following:

1. Intake openings shall be located not less than 10 feet (3048 mm) from lot lines or buildings on the same lot.

2. Mechanical and gravity outdoor air intake openings shall be located not less than 10 feet (3048 mm) horizontally from any hazardous or noxious contaminant source, such as vents, streets, alleys, parking lots and loading docks, except as specified in Item 3 or Section 501.3.1. Outdoor air intake openings shall be permitted to be located less than 10 feet (3048 mm) horizontally from streets, alleys, parking lots and loading docks provided that the openings are located not less than 25 feet (7620 mm) vertically above such locations. Where openings front on a street or public way, the distance shall be measured from the closest edge of the street or public way.

3. Intake openings shall be located not less than 3 feet (914 mm) below contaminant sources where such sources are located within 10 feet (3048 mm) of the opening. Separation is not required between intake air openings and living space exhaust air openings of an individual dwelling unit or sleeping unit where an approved factory-built intake/exhaust combination termination fitting is used to separate the air streams in accordance with the manufacturer's instructions.

4. Intake openings on structures in flood hazard areas shall be at or above the elevation required by Section 1612 of the International Building Code for utilities and attendant equipment.

IMC 501.3.1 Location of exhaust outlets. The termination point of exhaust outlets and ducts discharging to the outdoors shall be located with the following minimum distances:

1. For ducts conveying explosive or flammable vapors, fumes or dusts: 30 feet (9144 mm) from property lines; 10 feet (3048 mm) from operable openings into buildings; 6 feet (1829 mm) from exterior walls and roofs; 30 feet (9144 mm) from combustible walls and operable openings into buildings that are in the direction of the exhaust discharge; 10 feet (3048 mm) above adjoining grade.

2. For other product-conveying outlets: 10 feet (3048 mm) from the property lines; 3 feet (914 mm) from exterior walls and roofs; 10 feet (3048 mm) from operable openings into buildings; 10 feet (3048 mm) above adjoining grade.

3. For all environmental air exhaust: 3 feet (914 mm) from property lines; 3 feet (914 mm) from operable openings into buildings for all occupancies other than Group U, and 10 feet (3048 mm) from mechanical air intakes. Such exhaust shall not be considered hazardous or noxious. Separation is not required between intake air openings and living space exhaust air openings of an individual dwelling unit or sleeping unit where an approved factory-built intake/exhaust combination termination fitting is used to separate the air streams in accordance with the manufacturer's instructions.

4. Exhaust outlets serving structures in flood hazard areas shall be installed at or above the elevation required by Section 1612 of the International Building Code for utilities and attendant equipment.

5. For specific systems, see the following sections:

5.1. Clothes dryer exhaust, Section 504.4.

5.2. Kitchen hoods and other kitchen exhaust equipment, Sections 506.3.13, 506.4 and 506.5.

5.3. Dust, stock and refuse conveying systems, Section 511.2.

5.4. Subslab soil exhaust systems, Section 512.4.

5.5. Smoke control systems, Section 513.10.3.

5.6. Refrigerant discharge, Section 1105.7.

5.7. Machinery room discharge, Section 1105.6.1.

M8217

Date Submitted	12/14/2018	**Section**	403.3.2.5	**Proponent**	Mike Moore
Chapter	4	**Affects HVHZ**	No	**Attachments**	No

TAC Recommendation No Affirmative Recommendation
Commission Action Pending Review

Comments

General Comments **No** **Alternate Language** **No**

Related Modifications

Summary of Modification

Aligns with Section 301.7 of the 2017 FBC, Mechanical; the 2021 IMC; and the 2021 IRC in requiring listing and labeling of ventilation fans to ANSI/AMCA 210 - ANSI/ASHRAE 51.

Rationale

This language is copied directly from the 2018 IMC.

Industry experience and research have shown that "for advertised airflows that are not certified, the actual installed airflow can be a small fraction of the advertised value". The 2018 IMC and IRC now require listing and labeling flows in accordance with ANSI/AMCA 210-ANSI/ASHRAE 51 for exhaust equipment serving single dwelling units. This requirement should be expanded to all fans under the scope of the ANSI standard to ensure that flows are reported on an equivalent basis. AMCA and HVI maintain listings of products tested in accordance with the standard.
This proposal is on the consent agenda for the 2021 IMC, so it is very likely to be in the final language of the International Mechanical Code. Approval of this proposal will align the Florida Building Code - Mechanical with the 2021 IMC.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

Eases enforcement by identifying the required consensus standard for listing and labeling, which is already required in Section 301.7.

Impact to building and property owners relative to cost of compliance with code

None. This general requirement already exists in Section 301.7 and is provided here for specification and clarification.

Impact to industry relative to the cost of compliance with code

None. This general requirement already exists in Section 301.7 and is provided here for specification and clarification.

Impact to small business relative to the cost of compliance with code

None. This general requirement already exists in Section 301.7 and is provided here for specification and clarification.

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

Ensures minimum performance of appliances providing for health, safety, and welfare.

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

Improves code by helping clarifying the consensus test standard needed for compliance with listing and labeling requirements.

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

Any manufacturer may provide a fan for listing and labeling.

Does not degrade the effectiveness of the code

Improves code by clarifying and supporting enforcement.

1st Comment Period History

M8217-G1

Proponent pete quintela **Submitted** 1/14/2019 **Attachments** No

Comment:

Proposed for the 2021 IMC. Need 2021 IMC code to review.

Insert new section as follows:

403.3.2.5 Ventilating equipment. Fans providing exhaust or outdoor air shall be listed and labeled to provide the minimum required air flow in accordance with ANSI/AMCA 210- ANSI/ASHRAE 51.

M7292

Date Submitted	11/16/2018	**Section**	501.2	**Proponent**	James Bickford
Chapter	5	**Affects HVHZ**	No	**Attachments**	No

TAC Recommendation No Affirmative Recommendation
Commission Action Pending Review

Comments

General Comments **No**

Alternate Language **No**

Related Modifications

507.1, 509.1

Summary of Modification

Clarify the intent of these sections

Rationale

Clarifies code sections

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

Will help enforcement by making sections clear

Impact to building and property owners relative to cost of compliance with code

Will not increase the cost of construction
The code change is for purposes of clarification, and does not change the overall requirements of the section, thus will not change the cost of compliance

Impact to industry relative to the cost of compliance with code

Will not increase the cost of construction
The code change is for purposes of clarification, and does not change the overall requirements of the section, thus will not change the cost of compliance

Impact to small business relative to the cost of compliance with code

Will not increase the cost of construction
The code change is for purposes of clarification, and does not change the overall requirements of the section, thus will not change the cost of compliance

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

The code change is for purposes of clarification, and does not change the overall requirements of the section, thus will not change the cost of compliance

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

The code change is for purposes of clarification, and does not change the overall requirements of the section, thus will not change the cost of compliance

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

The code change is for purposes of clarification, and does not change the overall requirements of the section, thus will not change the cost of compliance

Does not degrade the effectiveness of the code

The code change is for purposes of clarification, and does not change the overall requirements of the section, thus will not change the cost of compliance

1st Comment Period History

M7292-G1

Proponent pete quintela **Submitted** 1/14/2019 **Attachments** No

Comment:

This code mod is related to mod#M7275. I do not see a need to change the current code sections related to this mod.

501.2 Independent system required. Single or combined mechanical exhaust systems for environmental air shall be independent of all other exhaust systems. Dryer exhaust shall be independent of all other systems.TypeI exhaust systems shall be independent of all other exhaust systems except as provided in Section 506.3.5. Single or combined Type II exhaust systems for food-processing operations shall be independent of all other exhaust systems. Kitchen exhaust systems shall be constructed in accordance with Section 505 for domestic ~~equipment~~ cooking operations and Sections 506 through 509 for commercial ~~equipment~~ cooking operations

507.1 General. Commercial kitchen exhaust hoods shall comply with the requirements of this section. Hoods shall be Type I or II and shall be designed to capture and confine cooking vapors and residues. A Type I or Type II hood shall be installed at or above ~~all~~ *~~commercial cooking~~ appliances* in accordance with Sections and 507.3.Where any cooking *appliance* under a single hood requires a Type I hood, a Type I hood shall be installed. Where a Type II hood is required, a Type I or Type II hood shall be installed. Where a Type I hood is installed, the installation of the entire system, including the hood, ducts, exhaust equipment and makeup air system shall comply with the requirements of Sections 506, 507, 508 and 509

Exceptions:

1. Factory-built commercial exhaust hoods that are listed and labeled in accordance with UL710, and installed in accordance with Section 304.1 , shall not be required to comply with Sections 507.1.5, 507.2.3, 507.2.5, 507.2.8, 507.3.1, 507.3.3, 507.4 and 507.5.
2. Factory-built commercial cooking recirculating systems that are listed and labeled in accordance with UL710B, and installed in accordance with Section 304.1, shall not be required to comply with Sections 507.1.5, 507.2.3, 507.2.5, 507.2.8, 507.3.1, 507.3.3, 507.4 and 507.5. Spaces in which such systems are located shall be considered to be kitchens and shall be ventilated in accordance with Table 403.3.1.1. For the purpose of determining the floor area required to be ventilated, each individual *appliance* shall be considered as occupying not less than 100 square feet (9.3m 2).
3. Where cooking appliances are equipped with integral down-draft exhaust systems and such appliances and exhaust systems are listed and labeled for the application in accordance with NFPA96, a hood shall not be required at or above them.

509.1Whererequired. *~~Commercial cooking~~ Cooking appliances* required by Section 507.2 to have a Type I hood shall be provided with an *approved* automatic fire suppression system complying with the *Florida Building Code* and the *Florida Fire Code*.

M7293

Date Submitted	11/16/2018	**Section**	504.4	**Proponent**	James Bickford
Chapter	5	**Affects HVHZ**	No	**Attachments**	No

TAC Recommendation No Affirmative Recommendation
Commission Action Pending Review

Comments

General Comments No **Alternate Language** No

Related Modifications

Summary of Modification

Section 504 covers duct construction for dryers, however, it is unclear on the requirement to seal dryer ducts. Sealing is specified in 603.9.

Rationale

Section 504 covers duct construction for dryers, however, it is unclear on the requirement to seal dryer ducts. Sealing is specified in 603.9. Because we don't have a reference directing the code official to 603.9 do we inadvertently lose the duct sealing requirements? This code change clarifies that dryer ducts must be sealed in accordance with 603.9 removing any doubt.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

None

Impact to building and property owners relative to cost of compliance with code

Will not increase the cost of construction

The requirement has always been in the code to seal ducts. This code change proposal just reminds you that it is also required for dryer ducts within the section that regulates dryer ducts.

Impact to industry relative to the cost of compliance with code

The requirement has always been in the code to seal ducts. This code change proposal just reminds you that it is also required for dryer ducts within the section that regulates dryer ducts.

Impact to small business relative to the cost of compliance with code

The requirement has always been in the code to seal ducts. This code change proposal just reminds you that it is also required for dryer ducts within the section that regulates dryer ducts.

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

The requirement has always been in the code to seal ducts. This code change proposal just reminds you that it is also required for dryer ducts within the section that regulates dryer ducts.

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

The requirement has always been in the code to seal ducts. This code change proposal just reminds you that it is also required for dryer ducts within the section that regulates dryer ducts.

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

The requirement has always been in the code to seal ducts. This code change proposal just reminds you that it is also required for dryer ducts within the section that regulates dryer ducts.

Does not degrade the effectiveness of the code

The requirement has always been in the code to seal ducts. This code change proposal just reminds you that it is also required for dryer ducts within the section that regulates dryer ducts.

504.4 Exhaust installation.

Dryer exhaust ducts for clothes dryers shall terminate on the outside of the building and shall be equipped with a backdraft damper. Screens shall not be installed at the duct termination. Ducts shall not be connected or installed with sheet metal screws or other fasteners that will obstruct the exhaust flow. Clothes dryer exhaust ducts shall not be connected to a vent connector, vent or *chimney*. Clothes dryer exhaust ducts shall not extend into or through ducts or plenums. <u>Clothes dryer exhaust ducts shall be sealed in accordancewithSection603.9</u>

M7295

Date Submitted	11/16/2018	**Section**	505	**Proponent**	James Bickford
Chapter	5	**Affects HVHZ**	No	**Attachments**	No

TAC Recommendation No Affirmative Recommendation
Commission Action Pending Review

Comments

General Comments No **Alternate Language** No

Related Modifications

505.1, 505.1(new), 505.2(new), 505.4

Summary of Modification

The code needs added coverage for domestic exhaust equipment and downdraft equipment and needs to reference the relevant product standards

Rationale

The FMC currently has no criteria for exhaust hoods and downdraft equipment

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

Will provide additional guidance for enforcement

Impact to building and property owners relative to cost of compliance with code

In most cases there should be no increase in costs if exhaust hoods and downdraft equipment are listed to the specified standards, which appears to be common practice.

Impact to industry relative to the cost of compliance with code

In most cases there should be no increase in costs if exhaust hoods and downdraft equipment are listed to the specified standards, which appears to be common practice.

Impact to small business relative to the cost of compliance with code

In most cases there should be no increase in costs if exhaust hoods and downdraft equipment are listed to the specified standards, which appears to be common practice.

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

Provides nationally recognized standards

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

Provides nationally recognized standards

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

Provides nationally recognized standards

Does not degrade the effectiveness of the code

Provides nationally recognized standards

1st Comment Period History

M7295-G1

Proponent pete quintela **Submitted** 1/14/2019 **Attachments** No

Comment:

While I agree with the intent of this mod, I believe each code section should be dealt with separately

Add new text as follows:

505.1 General. Domestic cooking exhaust equipment shall comply with the requirements of this section.

505.2 Domestic cooking exhaust. Where domestic cooking exhaust equipment is provided it shall comply with the following asapplicable:

1. Overhead range hoods and downdraft exhaust equipment not integral with the cooking appliance shall be listed and labeled in accordance with UL 507.
2. Domestic cooking appliances with integral downdraft exhaust equipment shall be listed and labeled in accordance with UL 858 or ANSIZ21.1.
3. Microwave ovens with integral exhaust for installation over the cooking surface shall be listed and labeled in accordance with UL923.

Revise as follows:

~~**505.1**~~ **505.3**~~**Domestic systems**~~ **Exhaust ducts**. ~~Where domestic range hoods and domestic appliances equipped with downdraft~~ Domestic cooking exhaust ~~are provided, such hoods and appliances~~ equipment shall discharge to the outdoors through sheet metal ducts constructed of galvanized steel, stainless steel, aluminum or copper. Such ducts shall have smooth inner walls, shall be air tight, shall be equipped with a backdraft damper, and shall be independent of all other exhaust systems.

Exceptions:

1. In other than Group I-1 and I-2, where installed in accordance with the manufacturer's instructions and where mechanical or natural ventilation is otherwise provided in accordance with Chapter 4, listed and labeled ductless range hoods shall not be required to discharge to the outdoors.
2. Ducts for domestic kitchen cooking appliances equipped with downdraft exhaust systems shall be permitted to be constructed of Schedule 40 PVC pipe and fittings provided that the installation complies with all of the following:
   - 2.1 The duct shall be installed under a concrete slab poured ongrade.
   - 2.2 The underfloor trench in which the duct is installed shall be completely backfilled with sand or gravel.
   - 2.3 The PVC duct shall extend not more than 1 inch (25 mm) above the indoor concrete floor surface.
   - 2.4 The PVC duct shall extend not more than 1 inch (25 mm) above grade outside of the building.
   - 2.5 The PVC ducts shall be solvent cemented.

~~505.2~~ 505.4 Makeup air required.

Exhaust hood systems capable of exhausting in excess of 400 cfm (0.19 m^3/s) shall be provided with *makeup air* at a rate approximately equal to the *exhaust air* rate. Such *makeup air* systems shall be equipped with a means of closure and shall be automatically controlled to start and operate simultaneously with the exhaust system.

Exception: In a single-family dwelling, make-up air is not required for range hood exhaust systems capable of exhausting:

1. (a)Four hundred cubic feet per minute or less; or
2. (b)More than 400 cubic feet per minute but no more than 800 cubic feet per minute if there are no gravity vent appliances within the conditioned living space of the structure.

~~505.3~~ 505.5 Common exhaust systems for domestic kitchens located in multistory structures.

Where a common multistory duct system is designed and installed to convey exhaust from multiple domestic kitchen exhaust systems, the construction of the system shall be in accordance with all of the following:

1. 1.The shaft in which the duct is installed shall be constructed and fire-resistance rated as required by the *Florida Building Code, Building*.
2. 2.Dampers shall be prohibited in the exhaust duct, except as specified in Section 505.1. Penetrations of the shaft and ductwork shall be protected in accordance with Section 607.5.5, Exception 2.
3. 3.Rigid metal ductwork shall be installed within the shaft to convey the exhaust. The ductwork shall be constructed of sheet steel having a minimum thickness of 0.0187 inch (0.4712 mm) (No. 26 gage) and in accordance with SMACNA *Duct Construction Standards*.
4. 4.The ductwork within the shaft shall be designed and installed without offsets.

5. 5.The exhaust fan motor design shall be in accordance with Section 503.2.
6. 6. The exhaust fan motor shall be located outside of the airstream.
7. 7.The exhaust fan shall run continuously, and shall be connected to a standby power source.
8. 8Exhaust fan operation shall be monitored in an approved location and shall initiate an audible or visual signal when the fan is not in operation.
9. 9.Where the exhaust rate for an individual kitchen exceeds 400 cfm (0.19 m^3/s) makeup air shall be provided in accordance with Section 505.2.
10. 10.A cleanout opening shall be located at the base of the shaft to provide access to the duct to allow for cleanout and inspection. The finished openings shall be not less than 12 inches by 12 inches (305 mm by 305 mm).
11. 11.Screens shall not be installed at the termination.
12. 12.The common multistory duct system shall serve only kitchen exhaust and shall be independent of other exhaust systems.

~~505.4~~ 505.6 Other than Group R. In other than Group R occupancies, where domestic cooktops, ranges, and open-top broilers are ~~installed~~ used for domestic purposes, domestic cooking exhaust systems shall be provided.

Add new standard(s) as follows:
ANSI Z21.1 - 2010 Household Cooking Gas Appliances
UL 507 - 2014 Standard for Safety Electric Fans

M7311

Date Submitted	11/19/2018	**Section**	505.1	**Proponent**	James Bickford
Chapter	5	**Affects HVHZ**	No	**Attachments**	No

TAC Recommendation No Affirmative Recommendation
Commission Action Pending Review

Comments

General Comments **No** **Alternate Language** **No**

Related Modifications

Summary of Modification

Adds text to Section 505.1 “Domestic systems.” Modification regarding fire suppression for range hoods installation in Groups I-1 and I-2 occupancies.

Rationale

These pointers are going to aid the user in finding the pertinent information regarding fire suppression for these range hoods. It can be very time consuming trying to locate the correct language for a code compliant installation. The user would never know that fire suppression is even required without these pointers.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

This proposal is strictly editorial in nature.

Impact to building and property owners relative to cost of compliance with code

Will not increase the cost of construction
There is no cost impact as this proposal is strictly editorial in nature.

Impact to industry relative to the cost of compliance with code

Will not increase the cost of construction
There is no cost impact as this proposal is strictly editorial in nature.

Impact to small business relative to the cost of compliance with code

Will not increase the cost of construction
There is no cost impact as this proposal is strictly editorial in nature.

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

Will not impact health, safety and welfare of public

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

This proposal is strictly editorial in nature.

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

This proposal is strictly editorial in nature.

Does not degrade the effectiveness of the code

This proposal is strictly editorial in nature.

505.1 Domestic systems.
Where domestic range hoods and domestic appliances equipped with downdraft exhaust are provided, such hoods and appliances shall discharge to the outdoors through sheet metal ducts constructed of galvanized steel, stainless steel, aluminumorcopper.Suchductsshallhavesmoothinnerwalls,shallbeairtight,shallbeequippedwithabackdraftdamper, and shall be independent of all other exhaust systems. Installations in Group I-1 and Group I-2 occupancies shall be in accordance with the Florida Building Code and the Florida Fire Prevention Code.

Exceptions:

1. **In other than Group I-1 and I-2, where installed in accordance with the manufacturer's instructions and where mechanical or natural ventilation is otherwise provided in accordance with Chapter 4, listed and labeled ductless range hoods shall not be required to discharge to the outdoors.**
2. **Ducts for domestic kitchen cooking appliances equipped with downdraft exhaust systems shall be permitted to be constructedofSchedule40PVCpipeandfittingsprovidedthattheinstallationcomplieswithallofthefollowing:**
   2.1 The duct shall be installed under a concrete slab poured ongrade.
   2.2 The underfloor trench in which the duct is installed shall be completely backfilled with sand orgravel.
   2.3 The PVC duct shall extend not more than 1 inch (25 mm) above the indoor concrete floorsurface.
   2.4 The PVC duct shall extend not more than 1 inch (25 mm) above grade outside of thebuilding.
   2.5 The PVC ducts shall be solventcemented.

M7322

Date Submitted	11/19/2018	**Section**	507.6.1	**Proponent**	James Bickford
Chapter	5	**Affects HVHZ**	No	**Attachments**	No

TAC Recommendation No Affirmative Recommendation
Commission Action Pending Review

Comments

General Comments **No** **Alternate Language** **No**

Related Modifications

Summary of Modification

Clarifies what a smoke generator is.

Rationale

The term "smoke generators" includes all forms of smoke producing products and cleans up the section a little bit.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

Clarifies section

Impact to building and property owners relative to cost of compliance with code

Will not increase the cost of construction
There will be no additional cost as this in only an editorial modification and clarification

Impact to industry relative to the cost of compliance with code

Will not increase the cost of construction
There will be no additional cost as this in only an editorial modification and clarification

Impact to small business relative to the cost of compliance with code

Will not increase the cost of construction
There will be no additional cost as this in only an editorial modification and clarification

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

There will be no additional cost as this in only an editorial modification and clarification

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

There will be no additional cost as this in only an editorial modification and clarification

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

Clarification does not discriminate

Does not degrade the effectiveness of the code

Clarifies code.

1st Comment Period History

M7322-G1

Proponent pete quintela **Submitted** 1/14/2019 **Attachments** No

Comment:

In order avoid future conflicts with what type of "smoke generators" would be acceptable a (Chapter 2) definition would have to be included

507.6.1 Capture and containment test. The permit holder shall verify capture and containment performance of the exhaust system. This field test shall be conducted with all appliances under the hood at operating temperatures, with all sources of outdoor air providing *makeup air* for the hood operating and with all sources of recirculated air providing conditioning for the space in which the hood is located operating. Capture and containment shall be verified visually by observing smoke or steam produced by actual or simulated cooking, such as ~~with~~ that provided by smoke ~~candles, smoke puffers, and similar means~~ generators.

M7341

Date Submitted	11/20/2018	**Section**	602.1	**Proponent**	James Bickford
Chapter	6	**Affects HVHZ**	No	**Attachments**	No

TAC Recommendation No Affirmative Recommendation
Commission Action Pending Review

Comments

General Comments **No** **Alternate Language** **No**

Related Modifications

Summary of Modification

Modification of text for Section 602.1 “General” to permit as a plenum framing cavities addressed in Section 602.3.

Rationale

Section 602.3 is in the plenum Section 602 and covers stud and joist space plenums, however, Section 602.1 does not recognize such plenums. Section 602.1 limits plenums to a list of spaces that excludes stud and joist space plenums.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

Will help with enforcement as this is a clarification

Impact to building and property owners relative to cost of compliance with code

Will not increase the cost of construction

This proposal will not increase the cost of construction because no additional labor, materials, equipment, appliances or devices are mandated beyond what is currently required by the code nor are the code requirements made more stringent.

Impact to industry relative to the cost of compliance with code

Will not increase the cost of construction

This proposal will not increase the cost of construction because no additional labor, materials, equipment, appliances or devices are mandated beyond what is currently required by the code nor are the code requirements made more stringent.

Impact to small business relative to the cost of compliance with code

Will not increase the cost of construction

This proposal will not increase the cost of construction because no additional labor, materials, equipment, appliances or devices are mandated beyond what is currently required by the code nor are the code requirements made more stringent.

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

No impact to health, safety or welfare

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

Will not increase the cost of construction

This proposal will not increase the cost of construction because no additional labor, materials, equipment, appliances or devices are mandated beyond what is currently required by the code nor are the code requirements made more stringent.

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

Will not increase the cost of construction

This proposal will not increase the cost of construction because no additional labor, materials, equipment, appliances or devices are mandated beyond what is currently required by the code nor are the code requirements made more stringent.

Does not degrade the effectiveness of the code

Improves clarity in code

602.1 General. Supply, return, exhaust, relief and ventilation air plenums shall be limited to uninhabited crawl spaces, areas above a ceiling or below the floor, attic spaces ~~and~~, mechanical equipment **rooms** andthe framing cavities addressed in Section 602.3.Plenums shall be limited to one fire area. Air systems shall be ducted from the boundary of the fire area served directly to the air-handling equipment. Fuel-fired appliances shall not be installed within aplenum.

M7343

Date Submitted	11/20/2018	**Section**	602.2.1	**Proponent**	James Bickford
Chapter	6	**Affects HVHZ**	No	**Attachments**	No

TAC Recommendation No Affirmative Recommendation
Commission Action Pending Review

Comments

General Comments **No** **Alternate Language** **No**

Related Modifications

Summary of Modification

Modification of text for Section 602.2.1 “Materials within plenums.” Concerning material installation within a plenum that should be listed for the application.

Rationale

There is a misconception that any material listed for plenum use such as ordinary insulation can be used to cover PVC pipe so it can be installed in a plenum. There are specific products which have been specifically designed and tested for specific applications

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

Will improve enforcement by clarifying section

Impact to building and property owners relative to cost of compliance with code

Will increase the cost of construction

This will prevent the errors in the field as the construction community will not have to spend additional time and money removing the improper insulation and replacing with the correct material

Impact to industry relative to the cost of compliance with code

Will increase the cost of construction

This will prevent the errors in the field as the construction community will not have to spend additional time and money removing the improper insulation and replacing with the correct material

Impact to small business relative to the cost of compliance with code

Will increase the cost of construction

This will prevent the errors in the field as the construction community will not have to spend additional time and money removing the improper insulation and replacing with the correct material

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

Improves safety by assuring proper materials are used.

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

Strengthens code

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

Does not descriminate

Does not degrade the effectiveness of the code

Improves effectiveness of the code

602.2.1 Materials within plenums. Except as required by Sections 602.2.1.1 through 602.2.1.7, materials within plenums shall be noncombustible or shall be listed and labeled as having a flame spread index of not more than 25 and a smoke-developed index of not more than 50 when tested in accordance with ASTM E 84 or UL723.

Exceptions:

1. Rigid and flexible ducts and connectors shall conform to Section603.
2. Duct coverings, linings, tape and connectors shall conform to Sections 603 and 604.
3. This section shall not apply to materials exposed within plenums in one- and two-family dwellings.
4. This section shall not apply to smoke detectors.
5. Combustible materials fully enclosed within one of the following:
   5.1 Continuous noncombustible raceways or enclosures.
   5.2 Approved gypsum board assemblies.
   5.3 Materials listed and labeled for installation within a plenum and listed for the application.
6. Materials in Group H, Division 5 fabrication areas and the areas above and below the fabrication area that share a common air recirculation path with the fabrication area.

M7393

Date Submitted	11/21/2018	**Section**	603.9	**Proponent**	James Bickford
Chapter	6	**Affects HVHZ**	No	**Attachments**	No

TAC Recommendation No Affirmative Recommendation
Commission Action Pending Review

Comments

General Comments **No** **Alternate Language** **No**

Related Modifications

Summary of Modification

This proposal will reduce construction cost and still reduce energy loss that would occur due to duct leakage outside conditioned space. Low pressure longitudinal seam duct leakage is very limited and the small amount of leakage within conditioned space is still useful energy.

Rationale

This proposal will reduce construction cost and still reduce energy loss that would occur due to duct leakage outside conditioned space. Low pressure longitudinal seam duct leakage is very limited and the small amount of leakage within conditioned space is still useful energy.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

Clarifies code

Impact to building and property owners relative to cost of compliance with code

This proposal will reduce construction cost and still reduce energy loss that would occur due to duct leakage outside conditioned space. Low pressure longitudinal seam duct leakage is very limited and the small amount of leakage within conditioned space is still useful energy.

Impact to industry relative to the cost of compliance with code

This proposal will reduce construction cost and still reduce energy loss that would occur due to duct leakage outside conditioned space. Low pressure longitudinal seam duct leakage is very limited and the small amount of leakage within conditioned space is still useful energy.

Impact to small business relative to the cost of compliance with code

This proposal will reduce construction cost and still reduce energy loss that would occur due to duct leakage outside conditioned space. Low pressure longitudinal seam duct leakage is very limited and the small amount of leakage within conditioned space is still useful energy.

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

This proposal will reduce construction cost and still reduce energy loss that would occur due to duct leakage outside conditioned space. Low pressure longitudinal seam duct leakage is very limited and the small amount of leakage within conditioned space is still useful energy.

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

Will reduce energy loss that would occur due to duct leakage outside conditioned space. Low pressure longitudinal seam duct leakage is very limited and the small amount of leakage within conditioned space is still useful energy.

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

Does not discriminate

Does not degrade the effectiveness of the code

This proposal will reduce construction cost and still reduce energy loss that would occur due to duct leakage outside conditioned space. Low pressure longitudinal seam duct leakage is very limited and the small amount of leakage within conditioned space is still useful energy.

603.9Joints, seams and connections.

All longitudinal and transverse joints, seams and connections in metallic and nonmetallic ducts shall be constructed as specified in SMACNA *HVAC Duct Construction Standards—Metal and Flexible* and NAIMA *Fibrous Glass Duct Construction Standards*. All joints, longitudinal and transverse seams and connections in ductwork shall be securely fastened and sealed with welds, gaskets, mastics (adhesives), mastic-plus-embedded-fabric systems, liquid sealants or tapes. Tapes and mastics used to seal fibrous glass ductwork shall be listed and labeled in accordance with UL 181A and shall be marked “181 A-P” for pressure-sensitive tape, “181 A-M” for mastic or “181 A-H” for heat-sensitive tape. Tapes and mastics used to seal metallic and flexible air ducts and flexible air connectors shall comply with UL 181B and shall be marked “181 B-FX” for pressure-sensitive tape or “181 B-M” for mastic. Duct connections to flanges of air distribution system equipment shall be sealed and mechanically fastened. Mechanical fasteners for use with flexible nonmetallic air ducts shall comply with UL 181B and shall be marked “181 B-C.” Closure systems used to seal all ductwork shall be installed in accordance with the manufacturer's instructions.

Exception: For ducts having a static pressure classification of less than 2 inches of water column (500 Pa), additional closure systems shall not be required for continuously welded joints and seams and locking-type joints and seams of other than the snap-lock and buttonlock types <u>for ducts that are</u> <u>located outside of conditioned spaces</u>.

M8322

Date Submitted	12/15/2018	**Section**	601.5	**Proponent**	Joseph Lstiburek
Chapter	6	**Affects HVHZ**	No	**Attachments**	No
TAC Recommendation	No Affirmative Recommendation				
Commission Action	Pending Review				

Comments

General Comments **No** **Alternate Language** **No**

Related Modifications

Summary of Modification

Allows return air to be taken from a boiler room, furnace room or mechanical room warming the room reducing relative humidity and mold.

Rationale

Air conditioners and supply plenums located in mechanical rooms lead to these rooms becoming cold resulting in mold and sweating of cold surfaces. Allowing some return air to be pulled from such rooms draws warm air into the rooms from common areas warming the rooms reducing relative humidity.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

Reduces mold and indoor air quality problems.

Impact to building and property owners relative to cost of compliance with code

Reduces mold and indoor air quality problems.

Impact to industry relative to the cost of compliance with code

Adds less than $100 to the cost of compliance. The added cost is a 4 inch grille on the return and a jump duct or transfer grille from the common area to the room.

Impact to small business relative to the cost of compliance with code

Adds less than $100 to the cost of compliance. The added cost is a 4 inch grille on the return and a jump duct or transfer grille from the common area to the room.

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

Reduces mold and indoor air quality problems.

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

Reduces mold and indoor air quality problems.

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

Has no impact on other materials, products, methods or systems.

Does not degrade the effectiveness of the code

Improves the effectiveness of the code by reducing mold and indoor air quality problems.

1st Comment Period History

M8322-G1

Proponent pete quintela **Submitted** 1/14/2019 **Attachments** No

Comment:

Proposed mod is in conflict with FMC 2018, Section 601.5, item #2

1st Comment Period History

M8322-G2

Proponent pete quintela **Submitted** 1/16/2019 **Attachments** No

Comment:

Correction to my previous comment, change FMC 2018 to FMC 2017

601.5
Return air openings.
Return air openings for heating, ventilation and air-conditioning systems shall comply with all of the following:

7. Return air shall not be taken from a closet, bathroom, toilet room, kitchen, garage, boiler room, furnace room or unconditioned attic.

Exceptions:

3. Taking return air from a boiler room, furnace room or mechanical room is not prohibited where such return air taken from boiler rooms, furnace rooms or mechanical rooms shall serve only the boiler rooms, furnace rooms or mechanical rooms and may be taken from boiler rooms, furnace rooms or mechanical rooms that have no dedicated supply duct. Where return air is taken from a boiler room, furnace room or mechanical room combustion appliances other than sealed combustion appliances shall not be allowed within the boiler room, furnace room or mechanical room.Where return air is taken from a boiler room, furnace room or mechanical room the pressure differential across the boiler room, furnace room or mechanical room door shall be limited to 0.01 inch WC (2.5 pascals) or less by undercutting the door, or installing a louvered door or transfer grille, or by some other means.

M7440

Date Submitted	11/26/2018	**Section**	1104.2.2	**Proponent**	James Bickford
Chapter	11	**Affects HVHZ**	No	**Attachments**	No

TAC Recommendation No Affirmative Recommendation
Commission Action Pending Review

Comments

General Comments **No** **Alternate Language** **No**

Related Modifications

Summary of Modification

Revises Section 1104.2.2 "Industrial occupancies and refrigerated rooms." The proposal clarifies that Section 1104.2.2 only applies when a machinery room is otherwise required.

Rationale

The proposal clarifies that Section 1104.2.2 only applies when a machinery room is otherwise required.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

Will assist enforcement by clarifying code

Impact to building and property owners relative to cost of compliance with code

Will not increase the cost of construction
The proposal only clarifies the intended application of the current provisions.

Impact to industry relative to the cost of compliance with code

Will not increase the cost of construction
The proposal only clarifies the intended application of the current provisions.

Impact to small business relative to the cost of compliance with code

Will not increase the cost of construction
The proposal only clarifies the intended application of the current provisions.

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

Protects health, safety and welfare by clarifying code.

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

The proposal only clarifies the intended application of the current provisions.

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

The proposal only clarifies the intended application of the current provisions.

Does not degrade the effectiveness of the code

The proposal only clarifies the intended application of the current provisions.

1104.2.2 Industrial occupancies and refrigerated rooms. This section applies only to industrial occupancies and refrigerated rooms for manufacturing, food and beverage preparation, meat cutting, other processes and storage. ~~Machinery rooms are~~ Where a machinery room would otherwise be required by Section 1104.2, a machinery room shall not be required where all of the following conditions are met:

1. 1.The space containing the machinery is separated from other occupancies by tight construction with tight-fitting doors.
2. 2.Access is restricted to authorized personnel.
3. 3.The floor area per occupant is not less than 100 square feet (9.3 m^2) where machinery is located on floor levels with exits more than 6.6 feet (2012 mm) above the ground. Where provided with egress directly to the outdoors or into *approved* building exits, the minimum floor area shall not apply.
4. 4.Refrigerant detectors are installed as required for machinery rooms in accordance with Section 1105.3.
5. 5.Surfaces having temperatures exceeding 800°F (427°C) and open flames are not present where any Group A2, B2, A3 or B3 refrigerant is used (see Section 1104.3.4).
6. 6.All electrical *equipment* and appliances conform to Class 1, Division 2, *hazardous location* classification requirements of NFPA 70 where the quantity of any Group A2, B2, A3 or B3 refrigerant, other than ammonia, in a single independent circuit would exceed 25 percent of the lower flammability limit (LFL) upon release to the space.
7. 7.All refrigerant-containing parts in systems exceeding 100 horsepower (hp) (74.6 kW) drive power, except evaporators used for refrigeration or dehumidification; condensers used for heating; control and pressure relief valves for either; and connecting piping, shall be located either outdoors or in a *machinery room*.

M7453

Date Submitted	11/26/2018	**Section**	1104.2.2	**Proponent**	James Bickford
Chapter	11	**Affects HVHZ**	No	**Attachments**	No

TAC Recommendation No Affirmative Recommendation
Commission Action Pending Review

Comments

General Comments **No** **Alternate Language** **No**

Related Modifications

Summary of Modification

Deletes item from Section 1104.2.2 “Industrial occupancies and refrigerated rooms.” The section proposed for deletion is archaic.

Rationale

The section proposed for deletion is archaic, makes no sense, and doesn't typically apply because the second sentence largely negates the first.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

None, Deletes unnecessary language.

Impact to building and property owners relative to cost of compliance with code

None

Impact to industry relative to the cost of compliance with code

None

Impact to small business relative to the cost of compliance with code

None

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

The proposal is unlikely to impact the health, safety, and welfare because the deleted text is probably never applied anyway.

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

The proposal will not impact products methods or systems of construction because the deleted text is probably never applied anyway.

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

The proposal does not discriminate against materials and the deleted text is probably never applied anyway.

Does not degrade the effectiveness of the code

The proposal will not degrade the code because the deleted text is probably never applied anyway.

Revise as follows:

1104.2.2 Industrial occupancies and refrigerated rooms.

This section applies only to industrial occupancies and refrigerated rooms for manufacturing, food and beverage preparation, meat cutting, other processes and storage. Machinery rooms are not required where all of the following conditions are met:

1. 1.The space containing the machinery is separated from other occupancies by tight construction with tight-fitting doors.
2. 2.Access is restricted to authorized personnel.
3. ~~3.The floor area per occupant is not less than 100 square feet (9.3 m²) where machinery is located on floor levels with exits more than 6.6 feet (2012 mm) above the ground. Where provided with egress directly to the outdoors or into *approved* building exits, the minimum floor area shall not apply.~~
4. ~~4.~~3. Refrigerant detectors are installed as required for machinery rooms in accordance with Section 1105.3.
5. ~~5.~~4.Surfaces having temperatures exceeding 800°F (427°C) and open flames are not present where any Group A2, B2, A3 or B3 refrigerant is used (see Section 1104.3.4).
6. ~~6.~~5.All electrical *equipment* and appliances conform to Class 1, Division 2, *hazardous location* classification requirements of NFPA 70 where the quantity of any Group A2, B2, A3 or B3 refrigerant, other than ammonia, in a single independent circuit would exceed 25 percent of the lower flammability limit (LFL) upon release to the space.
7. ~~7.~~6.All refrigerant-containing parts in systems exceeding 100 horsepower (hp) (74.6 kW) drive power, except evaporators used for refrigeration or dehumidification; condensers used for heating; control and pressure relief valves for either; and connecting piping, shall be located either outdoors or in a *machinery room*.

M7488

Date Submitted	11/28/2018	**Section**	1104.2.2	**Proponent**	James Bickford
Chapter	11	**Affects HVHZ**	No	**Attachments**	No

TAC Recommendation No Affirmative Recommendation
Commission Action Pending Review

Comments

General Comments **No**

Alternate Language **No**

Related Modifications

Summary of Modification

Adds exceptions to Section 1104.2.2 (4) “Industrial occupancies and refrigerated rooms.”

Rationale

The proposed exceptions are derived from IIAR 2. In areas that only contain fixed piping, there are no expected leak sources, so detection is unnecessary regardless of the refrigerant type.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

The proposed exceptions are optional and will not impact enforcement

Impact to building and property owners relative to cost of compliance with code

Will not increase the cost of construction

The proposed exceptions are optional. Therefore the will never increase the cost of construction. The cost of construction may decrease depending on whether the exceptions provide a more cost effective option for leak detection.

Impact to industry relative to the cost of compliance with code

Will not increase the cost of construction

The proposed exceptions are optional. Therefore the will never increase the cost of construction. The cost of construction may decrease depending on whether the exceptions provide a more cost effective option for leak detection.

Impact to small business relative to the cost of compliance with code

Will not increase the cost of construction

The proposed exceptions are optional. Therefore the will never increase the cost of construction. The cost of construction may decrease depending on whether the exceptions provide a more cost effective option for leak detection.

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

Protects occupants and clarifies when detectors are necessary.

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

The proposed exceptions are optional and provides cost effective way of providing detectors.

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

The proposed exceptions are optional and provides cost effective way of providing detectors.

Does not degrade the effectiveness of the code

The proposed exceptions are optional and provides cost effective way of providing detectors.

1104.2.2 Industrial occupancies and refrigerated rooms. This section applies only to industrial occupancies and refrigerated rooms for manufacturing, food and beverage preparation, meat cutting, other processes and storage. Machinery rooms are not required where all of the following conditions are met:

1. The space containing the machinery is separated from other occupancies by tight construction with tight-fitting doors.

2. Access is restricted to authorized personnel.

3. The floor area per occupant is not less than 100 square feet (9.3 m2) where machinery is located on floor levels with exits more than 6.6 feet (2012 mm) above the ground. Where provided with egress directly to the outdoors or into approved building exits, the minimum floor area shall not apply.

4. Refrigerant detectors are installed as required for machinery rooms in accordance with Section 1105.3.

Exceptions:

1. Refrigerant detectors are not required in unoccupied areas that contain only continuous piping that does not include valves, valve assemblies, equipment, or equipment connections.

2. Where approved alternatives are provided, refrigerant detectors for ammonia refrigeration are not required for rooms or areas that are always occupied, and for rooms or areas that have high humidity or other harsh environmental conditions that are incompatible with detection devices.

5. Surfaces having temperatures exceeding 800°F (427°C) and open flames are not present where any Group A2, B2, A3 or B3 refrigerant is used (see Section 1104.3.4).

6. All electrical equipment and appliances conform to Class 1, Division 2, hazardous location classification requirements of NFPA 70 where the quantity of any Group A2, B2, A3 or B3 refrigerant, other than ammonia, in a single independent circuit would exceed 25 percent of the lower flammability limit (LFL) upon release to the space.

7. All refrigerant-containing parts in systems exceeding 100 horsepower (hp) (74.6 kW) drive power, except evaporators used for refrigeration or dehumidification; condensers used for heating; control and pressure relief valves for either; and connecting piping, shall be located either outdoors or in a machinery room.

M7489

Date Submitted	11/28/2018	**Section**	202	**Proponent**	James Bickford
Chapter	11	**Affects HVHZ**	No	**Attachments**	No

TAC Recommendation No Affirmative Recommendation
Commission Action Pending Review

Comments

General Comments **No** **Alternate Language** **No**

Related Modifications

1104.2.2

Summary of Modification

Deletes definition in "REFRIGERATED ROOM OR SPACE." Modifies Section 1104.2.2 "Industrial Occupancies and refrigerated rooms."

Rationale

The definition that is proposed for deletion only applies to Section 1104.2.2, and it makes more sense to incorporate the criteria of the definition into the section than to have them remotely located in Chapter 2

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

None, requirement remain the same.

Impact to building and property owners relative to cost of compliance with code

Will not increase the cost of construction The proposal is simply a clean up of code text and a correlation of the IMC to the IBC. It will not increase the cost of construction.

Impact to industry relative to the cost of compliance with code

Will not increase the cost of construction The proposal is simply a clean up of code text and a correlation of the IMC to the IBC. It will not increase the cost of construction.

Impact to small business relative to the cost of compliance with code

Will not increase the cost of construction The proposal is simply a clean up of code text and a correlation of the IMC to the IBC. It will not increase the cost of construction.

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

None, is only a text clean up.

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

Strengthens code by adding clarity.

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

Does not discriminate.

Does not degrade the effectiveness of the code

Improves effectiveness of code by adding clarity.

Section 202

Delete without substitution:

~~REFRIGERATED ROOM OR SPACE. A room or space in which an evaporator or brine coil is located for the purpose of reducing or controlling the temperature within the room or space to below 68ºF (20ºC).~~

Revise as follows:

1104.2.2 Industrial occupancies and refrigerated rooms. This section applies only to rooms and spaces that are within industrial occupancies, that contain a refrigerant evaporator, that are maintained at temperatures below 68°F (20°C) and ~~refrigerated rooms~~ that are used for manufacturing, food and beverage preparation, meat cutting, other processes and storage.

THE REMAINDER OF THIS SECTION REMAINS UNCHANGED, NOT SHOWN FOR BREVITY.

M7491

Date Submitted	11/28/2018	**Section**	1105.6.1.1	**Proponent**	James Bickford
Chapter	11	**Affects HVHZ**	No	**Attachments**	No

TAC Recommendation No Affirmative Recommendation
Commission Action Pending Review

Comments

General Comments **No** **Alternate Language** **No**

Related Modifications

Summary of Modification

Adds new Section 1105.6.1.1 "Indoor exhaust opening location."

Rationale

Although the code addresses openings when equipment is located outdoors, it is silent where dealing with exhaust duct opening locations inside the machinery room.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

None, no new requirements are added.

Impact to building and property owners relative to cost of compliance with code

Will not increase the cost of construction There will be no additional cost as this in only an editorial modification and clarification. This proposal contains no new requirements.

Impact to industry relative to the cost of compliance with code

Will not increase the cost of construction There will be no additional cost as this in only an editorial modification and clarification. This proposal contains no new requirements.

Impact to small business relative to the cost of compliance with code

Will not increase the cost of construction There will be no additional cost as this in only an editorial modification and clarification. This proposal contains no new requirements.

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

Adds safety by providing guidance on exhaust locations.

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

Provides guidance for location of openings in the machinery room.

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

This proposal contains no new requirements.

Does not degrade the effectiveness of the code

This proposal contains no new requirements.

Add new section as follows:

1105.6.1.1 Indoor exhaust opening location. Indoor mechanical exhaust intake openings shall be located where refrigerant leakage is likely to concentrate based on the refrigerant's relative density to air, the location of the air current paths and refrigerating machinery location.

M7494

Date Submitted	11/28/2018	**Section**	1107.5.3	**Proponent**	James Bickford
Chapter	11	**Affects HVHZ**	No	**Attachments**	No

TAC Recommendation No Affirmative Recommendation
Commission Action Pending Review

Comments

General Comments **No** **Alternate Language** **No**

Related Modifications

Summary of Modification

Modifies Section 1107.5.3 “Copper tube.” Modification adds press-connect joints to mechanical joints to 1107.5.3

Rationale

Press-connect joints and fittings specifically manufactured for refrigerant pipe and tube connections (including soft annealed copper) have been tested by Underwriters Laboratories (UL) on sizes larger than 7/8" to meet UL 207. The term was changed to match the terminology used in the industry and the ASTM standard from press joint to press-connect joint.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

Improves enforcement by adding reference to technology already in use.

Impact to building and property owners relative to cost of compliance with code

Will not increase the cost of construction This new technology has great potential to save construction costs by drastically reducing labor costs as well as potential damage caused by typical brazing and soldering flames.

Impact to industry relative to the cost of compliance with code

Will not increase the cost of construction This new technology has great potential to save construction costs by drastically reducing labor costs as well as potential damage caused by typical brazing and soldering flames.

Impact to small business relative to the cost of compliance with code

Will not increase the cost of construction This new technology has great potential to save construction costs by drastically reducing labor costs as well as potential damage caused by typical brazing and soldering flames.

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

Has no impact on health, safety or welfare.

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

This new technology reduces the potential of damage caused by typical brazing and soldering flames.

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

This new technology reduces the potential of damage caused by typical brazing and soldering flames. Does not discriminate against other materials.

Does not degrade the effectiveness of the code

This new technology reduces the potential of damage caused by typical brazing and soldering flames.

1107.5.3 Copper tube.

Copper tube used for refrigerant piping erected on the premises shall be seamless copper tube of Type ACR (hard or annealed) complying with ASTM B280. Where *approved*, copper tube for refrigerant piping erected on the premises shall be seamless copper tube of Type K, L or M (drawn or annealed) in accordance with ASTM B88. Annealed temper copper tube shall not be used in sizes larger than a 2-inch (51 mm) nominal size. Mechanical joints other than press-connect joints, shall not be used on annealed temper copper tube in sizes larger than $^7/_8$-inch (22.2 mm) OD size.

M8013

Date Submitted	12/12/2018	**Section**	1209.5	**Proponent**	James Bickford
Chapter	12	**Affects HVHZ**	No	**Attachments**	No

TAC Recommendation No Affirmative Recommendation
Commission Action Pending Review

Comments

General Comments **No** **Alternate Language** **No**

Related Modifications

1209.5.1, 1209.5.2

Summary of Modification

Modifies text of Section 1209.5 “Thermal barrier required.” Deleted sections 1209.5.1 and 1209.5.2.

Rationale

Insulation R-values should be located in the Florida Energy Code not the FMC

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

Design professionals, code officials, contractors, developers, virtually all involved in the building process look to the Florida Energy Code for specific thermal performance values.

Impact to building and property owners relative to cost of compliance with code

Will not increase the cost of construction

Impact to industry relative to the cost of compliance with code

Will not increase the cost of construction

Impact to small business relative to the cost of compliance with code

Will not increase the cost of construction

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

Has no impact on health, safety or welfare of the general public.

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

Strengthens code by making R values easier to find

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

There is no increase in the R-value of the insulation or the installation labor.

Does not degrade the effectiveness of the code

There is no increase in the R-value of the insulation or the installation labor.

1209.5 Thermal barrier required.

Radiant floor heating systems shall be provided with a thermal barrier in accordance with Sections 1209.5.1 ~~through 1209.5.4.~~ and 1209.5.2. Insulation R-values for slab-ongrade and suspended floor installation shall be in accordance with the International Energy Conservation Code.

Exception: Insulation shall not be required in engineered systems where it can be demonstrated that the insulation will decrease the efficiency or have a negative effect on the installation.

1209.5.1 Slab-on-grade installation.

Radiant piping utilized in slab-on-grade applications shall be provided with insulating materials installed beneath the piping having a minimum R-value of 5.

1209.5.2 Suspended floor installation.

In suspended floor applications, insulation shall be installed in the joist bay cavity serving the heating space above and shall consist of materials having a minimum *R*-value of 11.

~~**1209.5.3 Thermal break required.**~~

~~A thermal break shall be provided consisting of asphalt expansion joint materials or similar insulating materials at a point where a heated slab meets a foundation wall or other conductive slab.~~

~~**1209.5.4 Thermal barrier material marking.**~~

~~Insulating materials utilized in thermal barriers shall be installed such that the manufacturer's *R*-value mark is readily observable upon inspection.~~

M7113

Date Submitted	9/15/2016	**Section**	1	**Proponent**	Michael Steele
Chapter	15	**Affects HVHZ**	Yes	**Attachments**	Yes

TAC Recommendation No Affirmative Recommendation
Commission Action Pending Review

Comments

General Comments **No** **Alternate Language** **No**

Related Modifications

Summary of Modification

The shown reference year of 2008 for AMCA 550 is incorrect.

Rationale

(Originally this modification was listed for the "Building" section of FBC, but was supposed to be in the "Mechanical" section of FBC.)

AMCA 550 was not an official ANSI/AMCA Standard until 2009 per AMCA. AMCA 550 was finalized by AMCA in 2008, and was then was submitted to ANSI. By the time it became adopted by ANSI, the year was 2009. Therefore, the standard became ANSI/AMCA 550 (2009).

Note that ANSI/AMCA 550-09 has since been updated from year 2009 to 2015, and then again to 2015 (Rev 09-18), a September 18th revision date, to correct a wind speed calibration procedure that the test labs could not follow in the original 2015 revision.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

none

Impact to building and property owners relative to cost of compliance with code

none

Impact to industry relative to the cost of compliance with code

No longer have to explain why a product cannot be tested to the 2008 version of AMCA 550.

Impact to small business relative to the cost of compliance with code

None, manufactures are already testing products to newer revisions of the test standard without additional cost to the customers.

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

The ANSI/AMCA 550-09 or ANSI/AMCA 550-15 or ANSI/AMCA 550-15 (Rev. 09-18) standard provides a way for a louver to be rated for high velocity wind driven rain resistance by helping to prevent wind driven rain from entering intake/exhaust ducts or openings of a building during a hurricane type event.

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

Strengthens the code as the code would no longer reference a standard year that products are not being tested to.

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

Change does not discriminate.

Does not degrade the effectiveness of the code

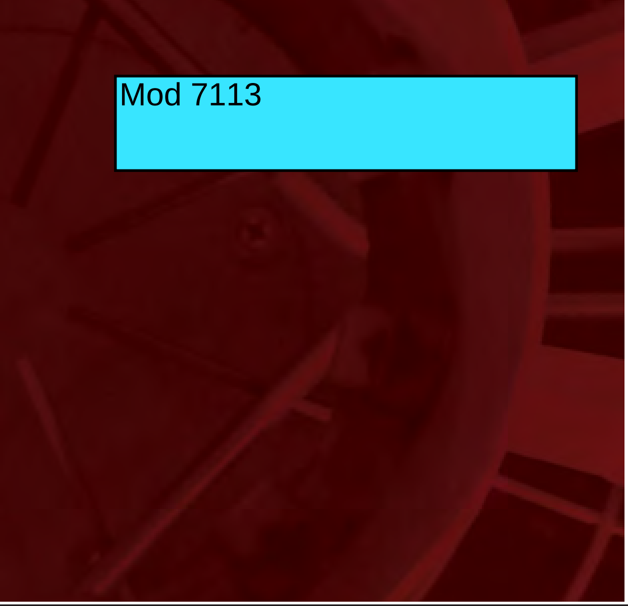
Change does not degrade code.

Under the AMCA Standard reference number section: 550-0~~8~~9

Or instead update to the following per the last note in this modification's Rationale section: 550-~~08~~15 (Rev. 09-18)

Mod 7113

STANDARD



ANSI/AMCA Standard 550-15 (Rev. 09-18)

Test Method for High Velocity Wind Driven Rain Resistant Louvers

An American National Standard
Approved by ANSI on September 20, 2018

Air Movement and Control Association International

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ANSI/AMCA Standard 550-15 (Rev. 09-18)

Test Method for High Velocity Wind Drive Rain Resistant Louvers

Air Movement and Control Association International
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Arlington Heights, Illinois
60004

AMCA Standards

Authority ANSI/AMCA Standard 550-15 (Rev. 09-18) was adopted by the membership of the Air Movement and Control

Association International Inc. on June 29, 2018. It was approved by the American National Standards Institute on September 20, 2018

Objections The Air Movement and Control Association (AMCA) International Inc. will consider and take action upon all written complaints regarding its standards, certification programs or interpretations thereof. For information on procedures for submitting and handling complaints, write to

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M7645

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Date Submitted	12/3/2018	**Section**	324	**Proponent**	John Hall
Chapter	3	**Affects HVHZ**	No	**Attachments**	Yes

TAC Recommendation No Affirmative Recommendation
Commission Action Pending Review

Comments

General Comments **No** **Alternate Language** **No**

Related Modifications

The location and numbering of this modification will be dependent upon any action taken on modification #7475.

Summary of Modification

The modification provides for solar ready features to facilitate the instalation of solar PV and solar thermal systems without resort to destructive methods.

Rationale

Solar photovoltaic and solar thermal systems are becoming more cost competitive in the marketplace. Adoption of this technology has many societal benefits. A serious hindrance to the adoption of solar technology is the destructive means required to install them on existing structures. This mod seeks to overcome this hindrance.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

There will be no cost impact relative to enforcement of the code due to this proposed modification. The inspection activity will be performed during already required inspections that are regularly scheduled.

Impact to building and property owners relative to cost of compliance with code

There will be a cost impact to building and property owners for compliance. The requirements are minimal and the associated cost is negligible.

Impact to industry relative to the cost of compliance with code

There will be no cost impact to industry for compliance. The modification is only applicable to one- and two-family dwellings and townhouses.

Impact to small business relative to the cost of compliance with code

There will be no cost impact to small business for compliance. The modification is only applicable to one- and two-family dwellings and townhouses.

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

The proposed modification has a reasonable and substantial connection with the health, safety, and welfare of the general public by fostering adoption of solar technology that will reduce harmful emissions from use of fossil fuels.

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

The proposed modification improves the code by making provision for non-destructive installation of solar systems on existing structures.

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

The proposed modification does not discriminate against any materials, products, methods, or systems of construction as none are specified. The modification allows use of any existing code approved methods and materials for compliance.

Does not degrade the effectiveness of the code

The proposed modification does not degrade the effectiveness of the code. The implementation of the code is enhanced through the provision of features that simplify addition of solar systems to existing structures.

1st Comment Period History

M7645-G1

Proponent Stevie Freeman-Monte **Submitted** 1/29/2019 **Attachments** No

Comment:

I support this proposed code modification.

SECTION 324

SOLAR ENERGY SYSTEMS

R324.1 General. Solar energy systems shall comply with the provisions of this section.

R324.2 Solar thermal systems. Solar thermal systems shall be designed and installed in accordance with Chapter 23 and the *Florida Fire Prevention Code.*

R324.3 Photovoltaic systems. Photovoltaic systems shall be designed and installed in accordance with Sections R324.3.1 through R324.7.1, NFPA 70 and the manufacturer's installation instructions.

R324.3.1 Equipment listings. Photovoltaic panels and modules shall be listed and labeled in accordance with UL 1703. Inverters shall be *listed* and *labeled* in accordance with UL 1741. Systems connected to the utility grid shall use inverters *listed* for utility interaction.

R324.4 Rooftop-mounted photovoltaic systems. Rooftop-mounted *photovoltaic panel systems* installed on or above the roof covering shall be designed and installed in accordance with this section.

R324.4.1 Structural requirements. Rooftop-mounted *photovoltaic panel systems* shall be designed to structurally support the system and withstand applicable gravity loads in accordance with Chapter 3. The roof on which these systems are installed shall be designed and constructed to support loads imposed by such systems in accordance with Chapter 8.

R324.5 Building-integrated photovoltaic systems. Building-integrated photovoltaic systems that serve as roof coverings shall be designed and installed in accordance with Section R905.

R324.5.1 Photovoltaic shingles. Photovoltaic shingles shall comply with Section R905.16.

R324.5.2 Fire Classification. *Building-integrated photovoltaic systems* shall have a fire classification in accordance with Section R902.3.

R324.6 Ground-mounted photovoltaic systems. Groundmounted photovoltaic systems shall be designed and installed in accordance with Section R301.

R324.6.1 Fire separation distances.

Ground-mounted photovoltaic systems shall be subject to the *fire separation distance* requirements determined by the local *jurisdiction*.

<u>**R324.7 Solar-ready zone.** New detached one- and two-family dwellings, and townhouses with not less than 600 square feet (55.74 m2) of roof area oriented between 90 degrees and 270 degrees of true north shall comply with Sections R324.9 through R324.17.</u>

<u>**Exceptions:**</u>

New residential buildings with a permanently installed on-site renewable energy system.

A building where all areas of the roof that would otherwise meet the requirements of Section R324.8 are in full or partial shade for more than 70 percent of daylight hours annually.

Solar-ready zone. A section or sections of the roof or building overhang designated and reserved for the future installation of a solar photovoltaic or solar thermal system.

R324.7.1 Construction document requirements for solar ready zone. Construction documents shall indicate the solar-ready zone.

R324.7.2 Solar-ready zone area. The total solar ready zone area shall be not less than 300 square feet (27.87m2) exclusive of mandatory access or set back areas as required by the *Florida Fire Prevention Code*. New townhouses three stories or less in height above grade plane shall have a solar-ready zone area of not less than 150 square feet (13.94 m2). The solar-ready zone shall be composed of areas not less than 5 feet (1524 mm) in width and not less than 80 square feet (7.44 m2) exclusive of access or set back areas as required by the *Florida Fire Prevention Code*.

R324.7.3 Obstructions. Solar-ready zones shall be free from obstructions, including but not limited to vents, chimneys, and roof-mounted equipment.

R324.7.4 Shading. The solar-ready zone shall be set back from any existing or new, permanently affixed object on the building or site that is located south, east or west of the solar zone a distance not less than two times the object's height above the nearest point on the roof surface. Such objects include, but are not limited to, taller portions of the building itself, parapets, chimneys, antennas, signage, rooftop equipment, trees and roof plantings.

R324.7.5 Capped roof penetration sleeve. A capped roof penetration sleeve shall be provided adjacent to a solar-ready zone. The capped roof penetration sleeve shall be sized to accommodate the future photovoltaic system conduit, but shall have an inside diameter of not less than 11/4 inches (32 mm).

R324.7.6 Roof load documentation. The structural design loads for roof dead load and roof live load shall be clearly indicated on the construction documents.

R324.7.7 Interconnection pathway. Construction documents shall indicate pathways for routing of conduit or plumbing from the solar-ready zone to the electrical service panel or service hot water system.

R324.7.8 Electrical service reserved space. The main electrical service panel shall have a reserved space to allow installation of a dual pole circuit breaker for future solar electric installation and shall be labeled "For Future Solar Electric." The reserved space shall be positioned at the opposite (load) end from the input feeder location or main circuit breaker location.

> **Exception.** A listed enclosure on the supply side of the electrical service main disconnecting means providing access for future interconnection of a solar photovoltaic power production source shall be permitted. The listed enclosure shall be labeled "For Future Solar Electric." The label shall comply with NFPA 70 110.21(B).

R324.7.9 Construction documentation certificate. A permanent certificate, indicating the solar-ready zone and other requirements of this section, shall be posted near the electrical distribution panel, water heater or other conspicuous location by the builder or registered design professional.

Fiscal Impact Assumptions Mod 7645

1. Electrical inspections will be required during the course of construction of a new dwelling. The inspections required by this modification will be performed during the regularly scheduled rough inspection.
2. The modification will result in negligible cost to the owner. The modification requires only three physical items to be installed, a capped roof penetration sleeve of a minimum inside diameter of 1.25 inches, a two pole space in the electrical panel, and labels indicating the location of the solar ready roof zone and the electrical panel space or supply side enclosure if provided.
3. The space in the electrical panel can be substituted with a listed enclosure on the supply side of the service main disconnecting means. This option would eliminate the need for additional space in the electrical panel.
4. All remaining requirements are for location of items to allow clear space on the roof for the system.

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List of abbreviations:

IRR = Internal rate of return

PPA = Power purchase agreement

PV = (Solar) photovoltaics

TGC = tradable green certificates

TIS = Technological innovation system

TPO = Third-party ownership

Keywords: Solar photovoltaics (PV), renewable energy, sustainability transitions, technology deployment, diffusion of innovations, barriers, drivers, space, technological innovation system (TIS), technology adoption, business model, peer effects

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Abstract

In order to support a sustainability transition in the energy sector, actors need knowledge about barriers and drivers to the deployment of clean energy technologies. Solar photovoltaics (PV) is a renewable energy technology that is technically mature and on the verge of becoming economically competitive in numerous regions around the world. Not least in the residential segment, PV has considerable potential. Even after residential PV has reached economic competitiveness, however, the technology might still face important barriers in the sociotechnical system in which it is to be deployed.

This thesis aims at adding knowledge about barriers and drivers to the deployment of residential PV systems. The research takes a sociotechnical systems perspective and demonstrates how the *technological innovation systems* (TIS) framework can be amended by the *business models* and the *diffusion of innovations* frameworks to study the deployment of a mature technology in a catching-up market, treating technology development and production as a 'black box'. The research is largely based on case studies and uses various modes of data collection and analysis. The bulk of the research was performed in Swedish settings on the national and local levels, although the United States, Germany and Japan were also studied. Studying these different contexts, the thesis builds knowledge about barriers and drivers on different spatial scales. The researched focused on the period between 2009 and 2014.

The results highlight various barriers and drivers in the studied contexts. On the national level, the Swedish sociotechnical system for PV deployment has been immature and infested by various institutional barriers. Swedish subsidies for PV deployment have been flawed with uncertainties, complexities and discontinuations, and there have been important uncertainties regarding the future development of the institutional set-up. The results also demonstrate how barriers in different national contexts have been decisive for what kinds of business models for PV deployment that have been viable. On the local level in Sweden, the results show how actors such as local electric utilities and private individuals have influenced homeowners to adopt PV through information dissemination and social influence (peer effects). The results can inform policymakers, firms and other actors as to how to support PV deployment.

Populärvetenskaplig sammanfattning

Klimatförändringarna är en av vår tids största utmaningar. För att utsläppen av koldioxid ska minska behöver teknologier för förnybar energi snabbt ersätta energi baserad på fossila bränslen. För att olika aktörer – såsom lagstiftare, företag, ideella organisationer och privatpersoner – ska kunna stödja en sådan omställning behövs kunskap om olika hinder och drivkrafter som motverkar respektive främjar (eller skulle kunna främja) spridningen av teknologi för förnybar energi.

Denna avhandling handlar om spridning av *solceller*. Avhandlingens mål är att identifiera och utvärdera hinder och drivkrafter som påverkar hur mycket solceller som installeras. Fokus ligger främst på solcellsanläggningar för privatpersoner i Sverige, vilket i regel innebär solceller placerade på villatak. Trots Sveriges geografiska läge på förhållandevis solfattiga breddgrader finns god potential för användning av solceller även i Sverige. Avhandlingen tar ett sociotekniskt systemperspektiv och analyserar samtida hinder och drivkrafter relaterade till regelverk, styrmedel, affärsmodeller, social påverkan och ekonomi. En rad fallstudier genomfördes, och data samlades in genom bland annat enkäter och intervjuer med nyckelaktörer. Genom fallstudier fokuserade på såväl det nationella som det lokala planet bygger avhandlingen kunskap om hinder och drivkrafter på olika geografiska nivåer.

Arbetet genomfördes som fyra delstudier, vilka har publicerats (eller ska publiceras) i vetenskapliga tidskrifter. Den första delstudien tog ett helhetsperspektiv på hinder och drivkrafter på nationell nivå i Sverige. Analysen återger ett underutvecklat sociotekniskt system för byggnadsanknutna solceller i Sverige och pekar på en rad problem vad gäller den institutionella stabiliteten. Brister i de ekonomiska styrmedlen har medfört osäkerheter och försämrad investeringsvilja inom installatörsbranschen samt en lång kö för privatpersoner att få ansökningar om bidrag beviljade. Stora osäkerheter har rått vad gäller den framtida utformningen av styrmedel och skatteregler. I vissa fall har det varit oklart hur befintliga regler ska tillämpas då dessa inte varit anpassade för mikroproduktion av elektricitet utan utvecklats för centraliserad storskalig elproduktion.

I den andra delstudien analyserades olika typer av affärsmodeller som nått framgång på tre stora solcellsmarknader (USA, Tyskland och Japan). En affärsmodell är det sätt på vilket företag skapar värde åt sig själva och sina kunder. Studien gick ut på att identifiera faktorer som skiljer sig åt mellan marknaderna och som skulle kunna förklara varför en viss affärsmodell nått framgång på en marknad men inte på en annan. De studerade marknaderna skiljer sig åt markant vad gäller vilka typer av affärsmodeller som nått framgång. Till exempel har leasing av solcellssystem varit mycket populärt i USA men nästintill obefintligt i Tyskland och Japan. Resultaten visade på att faktorer som husägares tillgång till kapital, sparkvoter, flyttmönster, egenskaper hos den nationella byggsektorn samt utformning av bidragssystem kan ha ett stort förklaringsvärde. Resultaten kan användas för att stödja spridning av solceller i Sverige och annorstädes, t.ex. genom att informera lagstiftare om hur institutionella hinder mot vissa typer av affärsmodeller kan avlägsnas, eller genom att informera entreprenörer om hur affärsmodeller kan anpassas för olika nationella kontexter.

Den tredje delstudien gick ut på att förklara skillnader i antalet solcellsinstallationer per capita mellan svenska kommuner. Intervjuer med lokala aktörer samt en enkät skickad till personer som skaffat solceller användes för att identifiera lokala faktorer i fem kommuner med särskilt hög solcellstäthet (antal installationer per capita). Resultaten pekar på att den troligen enskilt viktigaste förklaringen till den höga solcellstätheten i de studerade kommunerna är att lokala aktörer aktivt främjat solceller. Framförallt verkar lokala elnätsbolag som marknadsfört och spridit information kring solceller ha haft en stor effekt.

Den fjärde delstudien handlade om social påverkan mellan privatpersoner. En rad utländska studier har tidigare visat att varje ny solcellsinstallation ökar sannolikheten för ytterligare installationer i dess absoluta närhet, vilket indikerar att grannar påverkar varandra att skaffa solceller. Kunskapen om *hur* denna påverkan gått till har dock varit låg. En enkät skickades till solcellsägare, och uppföljande intervjuer genomfördes med utvalda respondenter. Resultaten tydde på att påverkan främst skett genom förhållandevis nära sociala nätverk (mellan släkt och vänner snarare än mellan grannar utan någon närmare relation), samt att den information som förmedlats och som ansetts viktig främst varit en *bekräftelse* på att anläggningen är enkel att använda, levererar elektricitet som förväntat och är driftsäker, samt att inga obehagliga överraskningar är att vänta. Kontakt mellan privatpersoner har således fungerat som ett komplement till professionell rådgivning, där solcellsägande privatpersoner förmedlat en trygghet som ökat deltagarnas benägenhet att skaffa solceller trots att de saknat proffsens detaljkunskaper.

I sin helhet visar avhandlingen på en rad viktiga hinder och drivkrafter för spridning av solceller. Dessa hinder och drivkrafter kopplar till såväl nationella styrmedel och regelverk som till lokala informationsinsatser och social påverkan. Genom att öka kunskaperna om hinder och drivkrafter på olika geografiska nivåer bidrar avhandlingen till bättre förutsättningar för olika aktörer att underlätta spridning av solceller.

List of papers

This thesis is based on the following four research papers (articles). The full papers can be found at the end of the thesis.

Paper 1:

Palm, A., 2015. An emerging innovation system for deployment of building-sited solar photovoltaics in Sweden. Environmental Innovation and Societal Transitions 15, 140-157.

Paper 2:

Strupeit, L., Palm, A., 2016. Overcoming barriers to renewable energy diffusion: business models for customer-sited solar photovoltaics in Japan, Germany and the United States. Journal of Cleaner Production 123, 124-136.

This paper was produced by my colleague Lars Strupeit and me in close collaboration. As regards research design, the credit goes mainly to Lars. Data collection was split between us, with me responsible for one case (Japan) and Lars for the other two cases. The literature review, data analysis and writing were performed by the two of us in close collaboration.

Paper 3:

Palm, A., 2016. Local factors driving the diffusion of solar photovoltaics in Sweden: A case study of five municipalities in an early market. Energy Research & Social Science 14, 1-12.

Paper 4:

Palm, A., 2016. Peer effects in residential solar photovoltaics adoption – a mixed methods study of Swedish users. Submitted to Energy Research & Social Science.

Content

1. Introduction

To cope with the challenge of climate change, the need for a transition to a low-carbon energy system is urgent (IPCC, 2014). Such a transition is likely to not only involve the introduction of new energy technologies, but also changes of a more social character, involving institutions, consumption behaviour, knowledge and business models (Geels, 2002; Grübler, 2003; IPCC, 2014; Kemp et al., 1998). Sociotechnical transitions of this kind have occurred several times throughout history in different sectors, but they normally take decades (Grübler, 1996), not only because of the time required to develop and refine new technological artefacts, but also because of various barriers in the sociotechnical environment in which the technology is to be deployed. Not least in the energy sector, such barriers are often severe (Unruh, 2000).

Common barriers to the dissemination of new technology include high costs, technical flaws and poor compatibility with existing infrastructure (Geels, 2002; Grübler, 1996; Kemp et al., 1998). Key reasons that new technology tends to be expensive are that production typically takes place on a relatively small scale, and that processes of learning regarding efficient production are yet to occur (Grübler, 2003; Kemp and Soete, 1992). Long periods of experimentation and learning are typically required to bring down costs and refine the performance of a new technology (Grübler, 2012; Kemp and Soete, 1992; Rosenberg, 1994).

Even after a new technology has reached economic and technical competitiveness, important barriers of a more social character typically remain, obstructing deployment of the technology. Organisational and institutional support for new energy technologies is often lacking, while existing (competing) technologies have built up such support over a long period (Bergek et al., 2008a; Geels, 2002; Grübler, 2012; Hekkert et al., 2007; Unruh, 2000). Existing institutions are often poorly aligned to new, radical innovations as the institutions were often adapted for another technological regime, and incumbent companies with vested interests in preserving the status quo will often use their (superior) financial resources and networks to hold new competitors back, e.g. through lobbying (Unruh, 2000). Besides, consumers tend to be somewhat suspicious of new technologies, and complexities and uncertainties (perceived or real, technical or institutional) can often deter potential adopters (Kemp et al., 1998; Rogers, 1983).

There is also an important spatial dimension to the dissemination of innovations. Understanding the preconditions for a transition requires an understanding of how different phenomena relate to geographical places and scales (Coenen et al., 2012; Hansen and Coenen, 2015). The spatial dimension of sustainability transitions has, nevertheless, remained underexplored (Coenen et al., 2012; Hansen and Coenen, 2015). For example, local aspects related to consumers and market formation have only been sporadically considered in the transitions literature (Hansen and Coenen, 2015).

There are various strategies that different actors can use to facilitate a transition. Various policy interventions can be used, based on economic instruments, regulatory approaches or information dissemination (IPCC, 2014). Firms can develop innovative business models that fit certain characteristics of a new technology (Bocken et al., 2014; Boons and Lüdeke-Freund, 2013). Information campaigns and lobbying can be run by non-profit organisations or others. Individuals can influence each other through social networks. Such activities can make a new technology disseminate more quickly. To enable different actors to facilitate a transition in an informed manner, a thorough understanding of the sociotechnical system in which the technology is to be deployed is needed.

This thesis is about the deployment of one specific renewable energy technology, namely *solar photovoltaics* (PV). The aim is to identify and assess *barriers* and *drivers* that obstruct and facilitate PV deployment. The thesis takes the *spatial* dimension into consideration, recognising that geographical place and scale might matter in different ways for different barriers and drivers. The scope is limited to the residential sector, i.e. to PV systems situated on the premises of private homeowners. Only grid-connected applications are considered. The thesis adopts a systemic, sociotechnical view of technology deployment, recognising that deployment depends on an interplay between aspects such as institutions, perceptions, social influence, economy infrastructure and artefacts (Bergek et al., 2008a; Geels, 2002; Grübler, 2003; Hekkert et al., 2007; Hughes, 1993; Markard et al., 2012; Unruh, 2000).

The research behind the thesis has been presented to the research community in four papers. Three of them have been published in different peer-reviewed academic journals, and the fourth is under revision. The papers are summarised one by one in section 3, and the full papers are provided as appendices.

Box 1. Background: PV technology

What is a PV system?

A PV system consists of a number of PV modules and any necessary mounting device, wiring, power inverters etc. Each module consists of a series of solar cells encapsulated into a weather-resistant shell with a transparent surface. PV systems take advantage of the photovoltaic effect, which occurs as the semiconductive material of solar cells is exposed to sunlight.

PV development and dissemination: a brief history

After its invention in the mid-1900s, PV technology found its first significant commercial market in the space industry, where the then high cost of PV was of minor concern. Subsequent niche markets include pocket calculators, early mobile phones, remote transmission stations, parking meters and holiday cottages. As a result of cost reductions and subsidies, the residential rooftop segment gained relevance in the 1990s. Global PV installations came to be dominated by a handful of countries with ambitious subsidy schemes, including Japan, Germany and the United States. In the most recent years, the global PV market has become increasingly geographically diverse.

Technical benefits and challenges of PV

Rooftop PV systems allow adopters to produce and use their own electricity. As the production is close to the user, transmission losses are kept at a minimum. PV technology is highly modular, and PV can feasibly be applied on vastly different scales (from pocket calculators to ground-mounted solar parks). A challenge of PV is intermittency (electricity is produced only when the sun shines), and an increasing share of PV in the power systems might eventually increase the need for load management.

The efficiency of most commercial PV modules in converting solar energy into electricity is around 15%, a figure that has gradually increased from around 6% in the earliest years of PV technology. This figure might not appear too impressive at first glance, but, considering the large amounts of solar energy entering the Earth, it is more than enough from a technical perspective. The global technical potential for electricity generation is several times larger for PV than for biomass or wind power (de Vries et al., 2007).

Although solar cells can be made from a variety of different materials, the world market has been dominated by cells made of silicon, which is the Earth's second most abundant element. The lifecycle greenhouse gas emissions and other externalities of PV systems are normally small in comparison to fossil fuel based electricity generation systems. The energy payback time of silicon-based PV systems under average United States and Southern European conditions is typically around two to three years (Fthenakis and Kim, 2011), and the lifetime of PV modules can be assumed to be 25 years or more (Bazilian et al., 2013).

1.1. PV deployment: barriers, drivers and space – previous knowledge and gaps in the literature

1.1.1. Barriers and drivers to PV deployment

Residential PV deployment faces substantial challenges, including issues that are general to the deployment of new technologies as well as issues that are more specific to PV, the electricity system and the built environment. While barriers are present throughout the PV value chain, this thesis focuses on barriers at work in the *deployment* phase. Deployment is defined here as the process of putting the technology into use, involving activities occurring at and around the very end of the value chain (see section 1.3 for a more detailed definition).

From a purely technical point of view, PV has been a rather mature technology for decades, performing well in various applications (Jacobsson et al., 2004). However, PV is a radical innovation in the context of national electricity systems and the built environment (Awerbuch, 2000; Schleicher-Tappeser, 2012). Compared to established electricity generation technologies, PV is a disruptive technology as it (a) can be distributed at many points in the electrical grid rather than concentrated to a few large plants, (b) can be located at the user side of the electricity meter, and (c) produces electricity intermittently (only when the sun shines). As a radical technology that requires compatibility with other systems, PV can be expected to face substantial challenges regarding compatibility with existing institutions, practices and infrastructures when deployed in a new context (cf. Kemp et al., 1998). Although there is a fair amount of literature on barriers and drivers to PV deployment, there are various relevant research gaps, of which this thesis addresses a few.

Historically, high costs of PV-generated electricity compared to electricity bought from the grid have been a dominant barrier to residential PV and other grid-connected PV applications (Arvizu et al., 2011; Jacobsson et al., 2004). Only recently have costs of PV technology become low enough for PV to compete in grid-connected applications without subsidies. These cost reductions have largely been the result of learning and economies of scale in the production of solar cells, including input materials (Candelise et al., 2013; de La Tour et al., 2013; Jacobsson et al., 2004; Neij, 2008; Nemet, 2006; Zheng and Kammen, 2014). However, this thesis mainly studies a context (Sweden) in which limited economic profitability has remained a substantial barrier.

To overcome the cost barrier, subsidies to deployment have been a common strategy and an important driver. However, not only the sheer size of subsidies is important, but also various other design aspects. For example, the remuneration can be based on the electricity production, total cost or installed capacity of a PV system, creating somewhat different incentive structures (Haas, 2003). Regardless of which strategy is chosen, the literature stresses the importance of keeping subsidies predictable (to reduce uncertainty), user-friendly (to reduce complexity) and dynamic (to be adaptable to external changes). It is crucial to keep the economic profitability (measured for example as the *internal rate of return*, IRR) of investing in a PV system predictable. Remuneration levels should thus be continuously monitored and adapted to changing prices of PV systems (Haas, 2004, 2003; Sandén, 2005). Throughout Europe, insufficient guarantees regarding the continuation of subsidies have been a common problem (Dusonchet and Telaretti, 2010). The potential of subsidies for PV adoption to drive down costs of PV technology has also been stressed, as the subsidies provide the industry with a market in which it can sell its products and thus learn how to produce and deploy PV more efficiently (Jacobsson et al., 2004; Sandén, 2005). There has, however, been a large variation in how subsidies for PV deployment have actually been designed.

An economic barrier that is particularly tangible for PV is the relatively high *upfront* cost. That is, the total lifecycle cost of PV systems is typically highly concentrated to the initial investment. The 'fuel' is free and maintenance costs are low, and although a PV system might be a beneficial long-term investment, prospective adopters might not be able to purchase a PV system due to difficulties in raising the necessary capital (Rosoff and Sinclair, 2009; Yang, 2010). This issue can also deter potential adopters that use a high (explicit or implicit) discount rate.

As costs of PV systems have decreased over time, other barriers than poor economic profitability have gained in relative importance. For example, various complexities and uncertainties (institutional, financial, technical) will often deter potential PV adopters (Karteris and Papadopoulos, 2012; Rai et al., 2016; Rosoff and Sinclair, 2009; Shih and Chou, 2011; Simpson and Clifton, 2015). Examples of specific institutional barriers to PV deployment that have been pinpointed in the literature are a lack of reliable installer certification and standards for technical components and grid-connection (Shrimali and Jenner, 2013; Simpson and Clifton, 2015; Zhang et al., 2015), and long turnaround times and high fees in permitting (Dong and Wiser, 2013; Li and Yi, 2014). Incumbent actors in the electricity sector that have seen their revenues being threatened by the dissemination of residential PV have often tried to influence institutions to counteract PV dissemination, with some (albeit limited) success (Hess, 2016).

Barriers to PV deployment may often be rooted in the electricity and housing systems. Barriers to new technologies tend to be most severe for "systemic technologies that require change in the outside world" (Kemp et al., 1998). For PV to achieve compatibility with buildings and electricity systems, technical and institutional change in these systems might be required. Housing and energy are also typically highly regulated, meaning that various legislative barriers might be present (cf. Unruh, 2000). Systems for electricity generation and distribution can be understood as 'large technical systems' of high complexity and inertia (Hughes, 1993). In such systems, existing institutions and infrastructures often interact to obstruct the deployment of new technologies. Legislation and other institutions in the electricity sector have typically been adapted for a technological regime (cf. Geels, 2002) of centralised large-scale facilities (Unruh, 2000). Current energy systems can be understood as being in a state of 'carbon lock-in' caused by "technological and institutional co-evolution driven by path-dependent increasing returns to scale" (Unruh, 2000), impeding radical innovation in the energy sector and conserving the status quo. Furthermore, technological change is typically slower in sectors of long-lived structures (Grübler, 1996). Only rarely does new energy technology replace existing technology through the premature retiring of existing capital stock; thus, the longevity of plants and infrastructures in incumbent energy systems holds back the dissemination of new energy technologies (Grübler, 2012).

In understanding barriers and drivers to PV deployment, it is important to understand the motives for adopting a residential PV system. In developed countries, motives have mainly related to electricity bill savings, reduced environmental impact, energy independence and a general interest in new technology (Rai et al., 2016; Schelly, 2014; Zhai and Williams, 2012). In markets where PV adoption has been a poor economic investment, concern for the environment and an interest in the technology have often been important driving forces for those few adopting PV (e.g. Palm and Tengvard, 2011).

It is recognised that business model innovation (the development of new business models or the adaptation of existing ones) could serve to overcome certain barriers to PV deployment. For example, third-party ownership (TPO) business models can address the high upfront cost of PV systems, bureaucratic hassle and concerns related to operation and maintenance (Overholm, 2015). Research on how different business models for PV deployment relate to different contextual factors has, however, been scarce.

1.1.2. The spatial dimension of PV deployment

Barriers and drivers to PV deployment can be rooted in different places and extend over different geographical scales. The production of PV system components has mainly taken place in other parts of the world than where the technology has been deployed (Huang et al., 2016; Quitzow, 2015), and the part of the value chain where development and production occur has been more global by nature than have processes of deployment. Processes occurring 'upstream' in the PV value chain, such as silicon purification and wafer production, are technologically advanced and take place in a global arena. In this part of the value chain, skilled staff has been recruited from around the world and production equipment and produced goods have been traded internationally (de la Tour et al., 2011; Huang et al., 2016). The development of institutions governing the global PV industry has been shaped by an interplay between governments and firms across national borders (Bohnsack et al., 2016). Although the actual production of PV system components and input materials has been concentrated to certain places, the sociotechnical system for the generation of PV system components has thus been rather global by nature. At the subsequent steps down the value chain too, solar cells and modules are traded globally nearly as commodities. As a consequence, cost reduction and technological improvements of PV system components have been globally pervasive, thus directly reducing barriers to PV deployment around the world.

PV deployment is an inherently more local process. Installations must be performed on-site, and the geographical focus of the actors involved typically range from the local to the national scale. Deployment in any given place is typically strongly dependent on formal institutions applying to a limited geographical area (Dewald and Fromhold-Eisebith, 2015; Quitzow, 2015), including subsidies, tax rules, building permits and rules for grid-connection.

The cost and technical performance of PV technology have thus been determined to a great extent by factors beyond the deployment context, operating at other geographical places and scales.

Although PV system installation is in itself a rather straightforward procedure, PV deployment is a complex and systemic procedure involving interaction between various actors, institutions and artefacts (Quitzow, 2015). PV deployment and production could indeed be understood as being different sociotechnical systems with different spatial characteristics, interconnected through certain linkages (cf. Bergek et al., 2015; Markard et al., 2015; Quitzow, 2015; Sandén et al., 2008). For small national deployment markets, the global PV industry could be seen as an ‘external force’ (cf. Sandén et al., 2008). Deployment could thus be characterised as taking place in sociotechnical ‘sub-systems’ (national or regional PV markets) to a global sociotechnical system for PV technology. The geographical reach of these sub-systems is presumably defined to a great extent by national borders, as the nation state is a natural upholder and enforcer of formal institutions. Although the aggregate of these sub-systems is what fuels (and is fuelled by) the global production system for PV system components, the individual sub-systems are often too small to substantially influence the global system (a counterexample is the domination of the German PV market on global demand in the early 2000s (Quitzow, 2015)).

Conventional methods for analysing technological transitions have suffered from a lack of attention to geographical aspects of the kinds described above (Coenen et al., 2012; Raven et al., 2012). The most widely used sociotechnical system approaches to understanding sustainability transitions are *technological innovation systems* (TIS) and the *multi-level perspective* (MLP) (Coenen et al., 2012; Coenen and Díaz López, 2010; Markard et al., 2012; Markard and Truffer, 2008; Weber and Rohracher, 2012). These approaches have been developed and conventionally applied to consider processes of technology development and deployment together as belonging to one and the same system. However, neither of them has been very explicit on how to deal with spatial division of labour of the kind occurring in the PV value chain (Coenen et al., 2012), although some development has occurred in this regard in parallel to the work with this thesis (Hansen and Coenen, 2015).

As stated, PV technology is mature regarding technical performance, and is reaching cost competitiveness in an increasing number of regions. Meanwhile, there are numerous potential national and regional markets around the world where PV penetration is (still) very low. These markets can be seen as potential catching-up markets, into which PV technology could be imported and deployed relatively swiftly if their internal barriers to deployment are not too severe. The potential global aggregate for PV uptake in such markets is huge, and it is thus important to understand barriers and drivers to deployment in these markets. Research on barriers and drivers to PV deployment in catching-up markets has, however, been scarce.

Various factors of a more local nature have been found to influence PV adoption rates, such as local variations in solar insolation, electricity prices (Kwan, 2012) and rules and procedures for permits, grants and grid-connection (Brudermann et al., 2013; Dong and Wiser, 2013). There is also some evidence that local organisations can overcome barriers to deployment by promoting PV through campaigns, information provision, lobbying or demonstration projects (Brudermann et al., 2013; Dewald and Truffer, 2012; Noll et al., 2014; Owen et al., 2014). As argued by Noll et al. (2014), such local initiatives are likely to have the largest impact on PV adoption rates if residential PV adoption is neither highly profitable nor clearly unprofitable. As financial aspects are neither the dominant driver nor a major barrier in such situations, the argument goes, there is more opportunity for information campaigns or seminars to make a relative difference in driving adoption rates. However, the understanding of what factors can explain local variation in PV adoption rates has been limited.

A driver with an often inherently large local component is social influence between peers, also referred to as *peer effects*. Positive word of mouth often plays an important role in overcoming barriers to the diffusion of innovations (Rogers, 1983). This is particularly true in situations where the support of a strong brand or strong marketing resources are lacking, which is often the case for small companies marketing radical innovations (Mazzarol, 2011). A number of recent studies have attempted to quantify local peer effects in terms of increased probability of additional nearby PV adoptions following previous adoptions (Bollinger and Gillingham, 2012; Graziano and Atkinson, 2014; Graziano and Gillingham, 2014; Müller and Rode, 2013; Rai and Robinson, 2013; L.-L. Richter, 2013; Rode and Weber, 2013). The results indicate that peer effects are stronger down to the zip code or street level (e.g. Bollinger and Gillingham, 2012). Some early attempts have also been made to separate *active* (through direct interpersonal contact) and *passive* (through passively observing PV systems) peer effects, although the results have remained rather inconclusive (e.g. Rai and Robinson, 2013). Pre-existing research on peer effects in PV adoption has focused on estimating the sheer magnitude of the effects, and the qualitative perspective has been lacking. The actual mechanisms underlying the peer effects have thus remained poorly understood.

There is some evidence that local organisations can take advantage of peer effects to reduce barriers to adoption. The findings of Noll et al. (2014) suggest that local non-profit organisations promoting residential PV in the U.S. have managed to leverage the impact of their activities through peer effects by engaging local individuals. A better understanding of how peer effects actually work could potentially inform organisations in how to exploit peer effects to boost PV uptake.

1.2. Objective

The objective of this thesis is to advance the knowledge on *the deployment of residential PV systems*. More specifically, the thesis aims at identifying and assessing *barriers* and *drivers* that obstruct or facilitate PV deployment in different geographical settings, taking the spatial dimension into account. Barriers include any factors in the sociotechnical system surrounding PV deployment that obstruct the deployment process, thus reducing the rate of PV adoptions. Correspondingly, drivers are sociotechnical factors that facilitate PV deployment, thus increasing adoption rates. Such barriers and drivers may relate to for example institutions, firms, economy, human behaviour, infrastructure or technology. Studying different national and local contexts, the thesis aims at building knowledge on barriers and drivers on different spatial scales. The thesis aims at answering four different research questions, one for each paper:

- RQ1 (paper 1): What barriers are present in the Swedish sociotechnical system for residential PV deployment?

- RQ2 (paper 2): How have different kinds of business models been successfully designed by firms to overcome country-specific barriers to residential PV deployment in different national contexts?
- RQ3 (paper 3): What local factors can explain geographically uneven adoption rates (as measured on the municipal level) of residential PV systems within Sweden?
- RQ4 (paper 4): How has social influence between peers (peer effects) reduced barriers to PV adoption among Swedish homeowners?

The thesis is largely based on case study methodology. Important modes of data collection were interviews and surveys, although data were gathered in various other ways as well. Both qualitative and quantitative methods were used.

The target audience includes actors that might have an interest in stimulating PV dissemination. These include policymakers, firms and non-profit organisations.

1.3. Scope

This thesis focuses on a particular part of the PV value chain, namely on *deployment*. Deployment is defined here as the process of putting the technology into use, and involves various activities taking place at and around the very end of the PV value chain, such as PV system marketing, sales, installation and adoption decision making among (potential) users. Deployment is thus the last set of processes in a series of events that lead to a PV system being commissioned. Processes taking place further upstream in the value chain, such as technology production and development, are outside the scope.

Although the terms 'deployment' and 'dissemination' are often used interchangeably, 'deployment' is in this thesis used to signal that it is activities at the end of the value chain that are alluded to. The term 'dissemination' is used here to describe the increased uptake of an innovation (e.g. the number of PV systems per capita) without alluding to any particular part(s) of the value chain. Dissemination is thus regarded here as an outcome of the combination of technology development, production and deployment.

With a focus on deployment, there is little reason to delimit the scope to PV systems based on any particular kind of solar cells. Although crystalline silicon solar cells dominate PV markets worldwide, other kinds of solar cells are in principle not excluded from the analysis. Other cell types can be produced with very different methods using different materials, but once encapsulated into modules they can typically be treated more or less as equivalents for residential applications. The deployment focus thus allows the researcher to regard PV modules as 'black boxes' converting sunlight into electricity regardless of the characteristics of its internal processes.

As regards different applications, the focus is on the *residential* segment, i.e. on systems situated in connection to and providing electricity to a particular household. Thus, larger ground-mounted installations, industrial applications and most applications on multi-family dwellings are not considered. Although people renting their homes are in principle not excluded, the current state of affairs in PV markets around the world (including the studied contexts) implies that the adopter category of interest is that of private homeowners.

Regarding *geography*, most of the research focused on Sweden, either the whole country (paper 1) or more local entities (papers 3 and 4). Only in paper 2 was the focus on markets outside Sweden, namely Germany, Japan and the United States. Paper 2 does, nevertheless, provide important lessons for Swedish actors regarding the future development of the Swedish market as this paper studies more developed markets. Papers 3 and 4 differ from the other papers in that they have a *local* focus. All research was conducted in developed countries only. Practically all households in the studied contexts are connected to the electrical grid, and the thesis thus considers grid-connected PV applications only.

Sweden was chosen as the main setting for three key reasons. First, residential PV as an investment in Sweden has been neither clearly unprofitable nor very profitable in recent years. When PV adoption offers limited (but not too poor) prospects of economic gains, various non-economic factors are presumably more likely to have a relatively high impact on adoption rates (cf. Noll et al., 2014), which makes such factors more easily observable. This makes Sweden a potentially fruitful case for studying non-economic barriers to deployment. Second, there has been a lack of research on barriers to PV deployment in catching-up markets. The aggregate of (potential) catching-up PV markets around the world offers a huge potential for PV uptake, and understanding barriers in such contexts is thus of utmost importance. Third, data for Sweden were relatively accessible as the researcher was based there and is a native speaker of the language. Paper 2 went outside the Swedish context because there was not enough empirical data to be found on the topic of interest (business models for PV deployment) within Sweden. A better understanding of business models can nevertheless be useful to support PV deployment in Sweden and other catching-up markets.

Regarding *time*, the research focuses mainly on phenomena that occurred between 2009 (when a subsidy for residential PV was launched in Sweden) and 2014. During that period and up until the time of writing this chapeau (late 2016), the studied PV markets, as well as other PV markets around the world and the global PV industry, have developed substantially. There is, nevertheless, little reason to believe that the findings of this thesis (with perhaps some minor exceptions) are less relevant at the time of finishing the thesis than a few years earlier. First, as observed by the researcher, most of the barriers to deployment in Sweden identified throughout the research remain at the time of finishing the thesis and are thus still relevant targets for policy. Second, even if the studied contexts have changed, there are numerous markets around the world that will likely face challenges similar to those encountered in the studied cases, and that can learn important lessons from them.

All papers except paper 4 adopt a systemic perspective in their respective context, considering a variety of interacting factors in PV deployment. Paper 4, being narrower in scope, focuses exclusively on social influence between peers in PV adoption.

1.4. Limitations

Some limitations of this thesis need to be recognised. First, the generalisability (external validity) of the findings is limited by the fact that the bulk of the research was focused on the Swedish context. Generalisability might be largest to similar cases, e.g. to developed countries with PV markets that are in an early stage of development and where the economic profitability of adopting a PV system is limited.

Second, the perspectives of all relevant actors are not always present. Due to restrictions in time available to the researcher, primary data could not be collected through interviews or surveys for all actors but were collected only from actors that were deemed the most relevant. In paper 1, the actors interviewed were general experts, installers and electricity companies, while primary data were not gathered for adopters and policymakers. In paper 2, primary data were obtained from companies using the business models of interest and from industry experts, but not from the companies' customers or from companies using other business models. Also in paper 3, a deeper understanding could possibly have been obtained through interviews with adopters that responded to the survey.

Third, the number of cases in the comparative case studies (papers 2 and 3) was constrained by limitations in the amount of time available to the researcher rather than by theoretical saturation (cf. Glaser and Strauss, 1967). With more cases added, the internal and external validity could have been increased, and additional insights could potentially have been reached.

Fourth, data could have been gathered to support more elaborate statistical analyses. For paper 3, data could have been collected to perform statistical analyses comparing a larger number of municipalities with regard to how various aspects correlate with PV adoption rates. For paper 4, a larger sample with secured representativeness would have made more elaborate statistical analyses possible.

2. Methodology

This section starts with a description of three theoretical frameworks that were used to guide the research. Then, the overall research design, which is based on case studies and various methods for data collection and analysis, is presented. Lastly, the interdisciplinary nature of the research is discussed briefly.

2.1. Theoretical frameworks

The research conducted for this thesis was guided by a variety of theoretical frameworks and concepts. However, three theoretical frameworks were particularly important. The rationale for choosing these frameworks is described below, after which the frameworks are outlined one by one.

As the thesis aims at identifying barriers and drivers throughout sociotechnical systems for PV deployment, the theoretical framework, or set of frameworks, used must reflect the 'whole' system. There are existing frameworks that fit this purpose quite well. In particular, the *technological innovation systems* (TIS) framework (e.g. Bergek et al., 2008a; Hekkert et al., 2007) and the *multi-level perspective* (MLP) (e.g. Geels, 2002) have been developed to analyse the development and deployment of new technologies from a sociotechnical systems perspective. These two frameworks have become dominant as analytical tools to understand (various barriers and drivers to) sustainability transitions, and, even though they have been developed rather independently of each other, they are largely focused on the same real-world phenomena and share several key concepts (Coenen et al., 2012; Markard and Truffer, 2008). Although these frameworks were not developed for any particular technology or sector, they have very often been applied to renewable technologies in the energy sector (Markard et al., 2012; Markard and Truffer, 2008).

Yet, there are differences between these two frameworks. The TIS framework is apt for studying barriers and drivers at different stages of a technology's development (Bergek et al., 2015, 2008a; Markard et al., 2012), while the MLP framework is relatively more focused on niche applications *or* regimes and less so on intermediate stages of development (Markard and Truffer, 2008). The MLP framework is more apt to explain broader transformative changes than the TIS framework, which is more focused on technology-specific matters (Markard et al., 2015; Weber and Rohracher, 2012). These differences hint that the TIS framework might be a more appropriate choice for the purpose of studying the deployment of a mature technology (PV) in an application that is not to be considered a niche (the residential application) but that has become mainstream in other geographical contexts and is expected to become mainstream also in the country or region of interest. Thus, the thesis uses the TIS framework as a starting point to analyse barriers to PV deployment (paper 1).

The wide scope of the TIS framework implies that it is not as detailed in all parts of the studied sociotechnical system. To further understand barriers and drivers to PV deployment, papers 2-4 analyse specific parts of the deployment systems. The research designs of papers 2-4 thus required the identification of the most relevant parts of these systems, as well as the identification or construction of theoretical frameworks that zoomed in on these parts.

Ideally, the TIS framework would provide adequate guidance to other frameworks that could be applied when studying certain phenomena in greater depth. This is the case for some phenomena that are within the scope of the TIS framework; for example, the TIS framework assigns significant importance to institutions, and accordingly the TIS literature refers to central literature on institutional theory, particularly to literature that deals with relationships between institutions and technological change. However, when it comes to other phenomena that occur in the TIS framework, such as the different actors involved in technology deployment and some of the 'functions' (key processes), the TIS literature does not connect as well to other literature streams. Neither does it provide guidance to any subsystems that might be analysed.

A useful analysis has, nevertheless, been performed by Foxon (2011), who identified a set of key coevolving systems relevant when analysing sustainability transitions, namely *ecosystems*, *technologies*, *institutions*, *business strategies* and *user practices*. Of these systems, *ecosystems* are regarded as external in this thesis. Also *technologies* are largely regarded as an external force, as the focus is on the deployment of artefacts that are in themselves technically mature and imported from another system. *Institutions* are crucial to a systemic analysis of barriers to deployment but are, as stated, quite well covered by the TIS framework, and paper 1 accordingly provides a thorough institutional analysis. Thus, potential areas for further studies remaining after the completion of paper 1 are *business strategies* and *user practices*. Business strategies have also been identified as crucial in bringing sustainable products to the market within the *business models* literature (Bocken et al., 2014; Boons and Lüdeke-Freund, 2013; Mont et al., 2006; Reim et al., 2015; Tukker, 2004). Furthermore, Schot et al. (2016) have made a strong case for dealing in greater depth with the role of users in the technological transitions literature.

Suitable frameworks for studying business strategies and user practices are the *business models framework* (Amit and Zott, 2001; Shafer et al., 2005) and Rogers' (1983) *diffusion of innovations* framework, respectively. Thus, these frameworks were used for papers 2-4. These frameworks fit within the scope of the TIS framework as they zoom in on real-world phenomena covered by the TIS literature. Both frameworks could be positioned relatively easily within the TIS literature as they clearly relate to core TIS concepts. What the TIS framework intends to capture by stressing the importance of firms and the function 'entrepreneurial experimentation' has a large overlap with what is described in the business models literature. The business models literature, being solely devoted to this topic, is nevertheless much more detailed on the phenomena of interest. In a similar manner, the role of users and the functions 'legitimation', 'knowledge development and diffusion' and 'market formation' of the TIS framework have a large overlap with what is dealt with in Rogers' diffusion of innovations framework.

2.1.1. Framework 1: Technological innovation systems (TIS)

The technological innovation systems (TIS) framework was developed to analyse the development, production and deployment of new technologies from a sociotechnical systems perspective (Bergek et al., 2008a; Hekkert et al., 2007). Its most common application has been to identify and assess barriers and drivers to technology dissemination in order to derive policy recommendations, often with the purpose of understanding how increased uptake of renewable energy technologies could be supported (e.g. Dewald and Truffer, 2011; Dewald and Fromhold-Eisebith, 2015; Jacobsson and Bergek, 2011; Quitzow, 2015; Sandén et al., 2008; Suurs, 2009; Suurs and Hekkert, 2009).

The TIS literature is a branch of a wider innovation systems literature, including other innovation systems approaches such as *national*, *regional* and *sectoral* innovation systems. An innovation system belonging to any of these categories can be understood as a complex system of actors and institutions involved in the development, production and deployment of new technology. Originally, the innovation systems literature focused on *national* innovation systems, which are not restricted to one particular technology but deal with the general innovative capability of a country (Lundvall, 2010). Subsequently, literature emerged on sector-specific innovation systems (Malerba, 2009) and, narrowing down, on innovation systems for specific technologies – that is, on TISs. The innovation systems literature emerged largely as a result of a frustration among certain scholars regarding how (mainstream) economics dealt with economic development; the argument was that it neglected processes of learning, institutions and technological change, and wrongfully assumed a static equilibrium (Sharif, 2006).

The rate and direction of technological change can be understood as being determined more by competition between innovation systems than between technologies (Hekkert et al., 2007). A major external force of a TIS for PV deployment is the incumbent system for electricity production, which could be understood as a sectoral innovation system, or as a sociotechnical *regime* (Geels, 2002). As stated, such incumbent systems/regimes could be expected to be locked in through various technological and institutional mechanisms, making it difficult for new and competing technologies to gain ground (Unruh, 2000).

In this thesis (paper 1), the TIS approach was used somewhat differently than in most previous TIS studies as it was applied to the *deployment* phase exclusively. Earlier TIS studies (as most other innovation system studies) have been predominantly used to study processes of development, production and deployment together as occurring in one and the same system, or they have paid less attention to deployment than to development and production (Dewald and Truffer, 2011). However, due to spatially different characteristics between different parts of the PV value chain (see section 1.1.2), a pure deployment focus was deemed the most appropriate for the present research (see also section 2.1.1.3).

In recent (post-2007/2008) TIS literature (Bergek et al., 2008a; Hekkert et al., 2007), a TIS is normally divided into one 'structural' and one 'functional' (more dynamic) part. These are outlined below, and it is briefly explained how they may relate to technology deployment. A brief account of how to think about geographical system boundaries in relation to the value chain follows, as this was an important issue in paper 1.

2.1.1.1. The structure of a TIS

The 'structure' of a TIS is normally thought of in terms of the following three categories of elements:

- *Actors*: Any organisations or individuals relevant for the development or deployment of the technology. With a deployment focus, core actors include, for example, installers and suppliers of turnkey systems and components, policymakers and (potential) adopters.
- *Networks*: Linkages between actors through which information is exchanged. In deployment, associations for installers and suppliers are frequently of high importance, as well as informal networks between adopters. Advocacy coalitions may attempt to influence policy though political networks (Bergek et al., 2008b).
- *Institutions:* Any humanly devised rules (formal or informal) affecting the development or deployment of the technology, such as laws, standards, practices or collective mind frames. For deployment, technology standards

(Ma, 2010) and popular perceptions (legitimacy) (Jacobsson and Bergek, 2004) are examples of institutions that are often important. Although institutions often facilitate deployment, pre-existing institutions may also prohibit or complicate the deployment of a new technology, often unintentionally.

While a TIS is in its early stages, the institutional set-up is usually badly aligned to the emerging technology as institutions are either not in place or are maladapted to the technology. The alignment of institutions to new technology is, however, notoriously an arduous process (Unruh, 2000), further complicated by the fact that firms "compete not only in the market but also over the nature of the institutional set-up" (Bergek et al., 2008a), a competition in which incumbent firms are often in a stronger position than the small newcomers that might represent the new technology. Furthermore, key actors might be missing or might not have gained the relevant knowledge, and networks are often lacking.

With a focus on deployment, these three categories of structural components are all likely to be as important as when the TIS framework is used to study development and deployment together. However, the deployment focus allows the researcher to focus his or her resources on those actors, networks and institutions that are the most relevant for deployment, thus creating room for a more in-depth analysis of those elements.

2.1.1.2. Functions of a TIS

Functions represent key processes that should occur in a TIS in order for the system to perform well. Functions have been described as constituting "an intermediate level between the components of a [TIS] and the performance of the system" (Jacobsson and Bergek, 2004) and as "emergent properties of the interplay between actors and institutions" (Markard and Truffer, 2008). The exact number of functions that should occur is somewhat arbitrary, and various sets of functions have been presented. The following set has (with some variation) gained recognition in the recent TIS literature (Bergek et al., 2008a; Hekkert et al., 2007):

- *Knowledge development and diffusion*, encompassing different processes of learning among key actors. As regards deployment, firms, policy makers and (potential) adopters need to gain an understanding of how to install, market, regulate, support and use the technology.
- *Guidance of the search*, capturing incentives for firms and other organisations to enter and participate in the TIS. The strength of this function is to a great extent determined by present and future *market formation* (see below) as perceived by relevant actors, not least when it comes to the deployment phase.

- *Entrepreneurial experimentation*, including various creative activities of firms. As regards deployment, innovation and variation regarding what applications and business models are employed can be important indicators of the strength of this function.
- *Market formation*, referring to activities that contribute to the creation of demand for the technology. Market formation is a crucial part of the deployment process and a prerequisite for dissemination. Barriers to market formation are often found in the institutional set-up (for example as a lack of standards or misaligned legislation) or in a poor price/performance.
- *Legitimation*, referring to changes in the social acceptance of a technology, or how good or desirable the technology is perceived to be. Legitimation through lobbying performed by activists and interest organisations was decisive for the implementation of deployment supporting schemes for PV in Germany (Bergek et al., 2008a; Jacobsson and Lauber, 2006).
- *Resource mobilisation*, reflecting the availability of human and financial capital necessary for the TIS to perform well. As regards the deployment of renewable energy technologies, the mobilisation of capital for subsidy schemes has often been crucial.

By identifying and strengthening poorly performing functions, policy interventions can facilitate the dissemination of a desirable technology (e.g. a renewable energy technology). This can be achieved by strengthening or adding drivers, or by weakening or removing barriers (Bergek et al., 2008a).

The functions have often been used to study feedback loops between production and deployment. When the TIS framework is applied to the deployment phase exclusively, such feedback loops will not be made visible. With a deployment focus, there is also a possibility that the relative importance between functions might differ from when the TIS framework is applied to a larger part of the value chain, as some functions might be more directly related to earlier stages of the value chain and others to deployment processes (e.g. 'market formation').

2.1.1.3. The spatial dimension and the case for deployment-focused TIS studies

Setting spatial system boundaries in TIS studies can be more or less complicated depending on the case at hand. While some technologies have their value chain assembled more or less entirely within one single country, others have their value chain distributed over different geographical places and scales. As stated by Hekkert et al. (2007), a technology is "hardly ever embedded in just the institutional infrastructure of a single nation or region, since – especially in modern society – the relevant knowledge base for most technologies originates from various geographical areas all over the world". The question of what part(s) of the value chain that are in focus thus has implications for the choice of spatial scope of the study.

A need for more elaborate approaches to geographical system boundary setting and spatial differentiation in TIS studies has been identified in recent publications (Binz et al., 2014; Coenen et al., 2012). The general trend towards increased global division of labour and specialisation in value chains (Antràs et al., 2012; Baldwin and Robert-Nicoud, 2014; Hummels et al., 2001; Los et al., 2015; Timmer et al., 2013) suggests that this need, if anything, will increase as technologies increasingly have their value chains distributed over different geographical places and scales. In parallel to the work with this thesis, empirical and conceptual work has been carried out by other scholars to make the TIS framework more elaborate regarding spatial differentiation (Bergek et al., 2015; Binz et al., 2014; Dewald and Fromhold-Eisebith, 2015; Gosens et al., 2015; Huang et al., 2016; Quitzow, 2015; Wieczorek et al., 2015). Empirical studies using geographically differentiated TIS approaches have been performed for PV (Dewald and Fromhold-Eisebith, 2015; Quitzow, 2015), membrane bioreactors (Binz et al., 2014) and wind power (Wieczorek et al., 2015). A spatially differentiated TIS analysis, in which deployment and production are treated as (partly) different sociotechnical systems between which linkages exist, has been proposed in recent publications (Bergek et al., 2015; Dewald and Fromhold-Eisebith, 2015; Quitzow, 2015). Such analyses could often be useful, but they are resource-intensive as the researcher has to gather and analyse data from different contexts. It is thus important that the researcher knows what to focus his or her resources on and what can be left out of the analysis. Thus, there is a case for elaborating upon whether and under what circumstances the TIS framework can be applied to deployment exclusively, treating technology development and production as a 'black box'.

PV is an example of a technology whose whole value chain does not naturally fit into one and the same geographically defined TIS. As described in section 1.1.2, the development and production of PV system components take place in a global arena, and this part of the value chain is thus better understood as pertaining to a global TIS (although it might, for pragmatic reasons, make sense to define a national TIS for these processes if the purpose is to derive policy recommendations for a particular government), while the deployment of PV is an inherently much more local activity. This can make it somewhat problematic to attempt to squeeze development, production and deployment of PV into one and the same TIS, although the TIS framework is originally intended to study all these processes together. In paper 1, this dilemma was elaborated upon, and it was demonstrated that the TIS framework is useful to study deployment separately in cases where it does not make sense to include more upstream parts of the value chain in the same TIS as deployment.

Two macro trends hint that TIS analyses focused on deployment will be increasingly needed. First, an increasing global division of labour and specialisation suggests that the production and trade of artefacts will increasingly take place in a global arena, while processes of deployment may remain more localised (which has been the case for PV, see section 1.1.2). In those cases, individual end user markets will often be small in relation to the global production system, and a pure deployment focus in TIS studies may be feasible. Second, there is an increasing availability of mature renewable energy technologies that can be deployed in new regions. This availability creates a case for more deployment-focused TIS analyses to study barriers and drivers in these catching-up markets, thus informing actors in how to facilitate a sustainability transition. Furthermore, as technologies mature, their global production systems are likely to increase in size in both absolute terms and in relation to more localised deployment systems, in which case it can be feasible to treat technology development and production as a 'black box' in relation to deployment.

2.1.2. Framework 2: Business models

In order for a technological transition to take place, not only technical but also organisational innovation is required. Not least *firms*, who are usually key actors in technology deployment, might need new strategies to overcome barriers to the deployment of radical innovations. In order to profit from a new technology, firms will often need new strategies for how to provide value for their customers and capture value for themselves – that is, new *business models* are needed. In paper 2, an analysis was made of why different kinds of business models for PV deployment have reached success in different national contexts.

A business model is, simply put, a representation of how firms create value for themselves and their customers. Customers may be private individuals, other firms or other organisations, and value may be provided in the form of services, products or a combination of both. In two widely cited papers, business models have been described as "the design of transaction content, structure, and governance so as to create value through the exploitation of business opportunities" (Amit and Zott, 2001), and the "firm's underlying core logic and strategic choices for creating and capturing value within a value network" (Shafer et al., 2005). The business models concept became prevalent around the mid-1990s in connection with the rise of the Internet (Shafer et al., 2005; Zott et al., 2011). A deployment focus is common in business model analyses, although focus can equally well be on products that are to be further processed before a finished product can be deployed.

Although there is no precise, agreed definition of a business model, the following elements are central to most definitions (M. Richter, 2013):

- *Value proposition:* the products or services offered to customers.
- *Customer interface:* the overall interaction with customers, including customer relations, customer segmentation and distribution channels.
- *Infrastructure:* the company's inner structure for value creation, including assets, know-how and partnerships.
- *Revenue model:* the relationship between the costs and revenues of the value proposition.

It is recognised in the literature that business model innovation (the development of new business models or the adaptation of existing ones) can facilitate the deployment of new technologies (Boons and Lüdeke-Freund, 2013). A new technology might not only come with some inherent attributes that call for a new or changed business model, but also the newness in itself might entail barriers that could be addressed through business model innovation. Uncertainties and incompatibilities with existing institutions could potentially be addressed through business models designed to transfer risks and transaction costs from the customer to the company, or to neutralise particular institutional barriers.

In the present thesis (paper 2), the analysis went beyond the conventional business models framework to also consider various contextual country-specific factors. This allowed the research to identify how various barriers have influenced the viability of different business models for PV deployment in different geographical contexts.

2.1.3. Framework 3: Diffusion of innovations

In the *diffusion of innovations* literature, the (potential) adopters are in focus, as well as those influencing or trying to influence their decision to adopt or reject an innovation. Thus, this framework is deployment-focused by nature, although it does not capture the full set of actors (or other factors) relevant for deployment. This section outlines the diffusion of innovations framework as presented by Rogers (1983). Rogers' framework gathers insights from a broad set of literature and has gained wide recognition. His main contribution was to put existing research together into a comprehensible yet robust package. The framework is by no means restricted to sustainability innovations or innovations in the energy sector, but is general to innovations that are or can be adopted by individuals. Elements of the diffusion of innovations framework were used throughout this thesis, particularly in papers 3 and 4.

Rogers (1983, p. 5) defined diffusion as *"the process by which an innovation is communicated through certain channels over time among the members of a social system"*. The framework focuses on processes of decision making, how different personality types relate to the inclination to adopt an innovation, and how different attributes of innovations might influence their adoption rates. Rogers used the terms 'diffusion' and 'dissemination' interchangeably. In this thesis, 'dissemination' is used as a general term for the uptake of an innovation (e.g. in terms of adoption rates), while 'diffusion' is used for processes more specifically related to communication or exchange of ideas, or to signal adherence to the work of Rogers. In this thesis, 'diffusion' differs from 'deployment' in that 'deployment' involves more aspects than just interpersonal communication (the difference between 'dissemination' and 'deployment' has been accounted for in section 1.3).

A key feature of the framework is the categorisation of potential adopters by some key characteristics and their role in diffusion processes. Rogers promotes a categorisation of potential adopters into five ideal types (although he concedes that in reality there are no sharp boundaries between these groups):

- *Innovators* are the first to adopt innovations. The innovator is venturesome and eager to try new ideas, leading him or her to seek social relationships with other like-minded outside their local peer group. Innovators are often seen upon with some suspicion by their peers, being perceived as 'too' innovative, but they can still facilitate the diffusion process by bringing new ideas into their social system.
- *Early adopters* are somewhat less innovative than innovators. They are more integrated into their local social system than innovators, and are more influential on the attitudes of their local peers. Being both relatively respected and innovative (but not *too* innovative), they are effective role models and have the highest level of *opinion leadership* (see below) among the categories.
- The *early majority* adopts innovations just slightly earlier than the average individual. This group is an important link between early and late adopters, providing interconnectedness supporting the diffusion process. Once a person belonging to this category has started contemplating adoption, his or her decision period is longer than that of earlier adopters.
- The *late majority* adopts innovations slightly later than the average individual. Adoption often comes as the result of economic necessity or social pressure. Persons in this category tend to maintain a sceptical attitude towards new ideas in general, and practically all uncertainty about the innovation must have disappeared before they choose to adopt.
- *Laggards* are the last to adopt an innovation. They are suspicious of new ideas, and their attitudes are often aligned with the practices of previous generations. Often, however, a precarious economic situation is a partial reason for the late adoption.

The decision to adopt (and keep using) an innovation is described by Rogers as an *innovation-decision process* consisting of the following five stages:

- *Knowledge,* in which awareness of the existence of the innovation and understanding of how it works are gained.
- *Persuasion*, in which a favourable or unfavourable attitude towards the innovation is formed.
- *Decision*, involving activities leading to a choice regarding whether to adopt or reject the innovation.
- *Implementation*, in which the innovation is put into use.
- *Confirmation*, in which reinforcement of an earlier adoption decision is sought, sometimes leading to a reversal of the adoption.

Innovations have different *attributes*, which are highly influential on the rate at which they diffuse in a social system. Attributes can be generalised into the following five categories, which, according to Rogers, taken together normally explain most of the variance in the rate of adoption between innovations:

- *Relative advantage* as compared to existing alternatives. In the case of residential PV, the existing alternative would for most prospective adopters be electricity from another source or another financial investment.
- *Compatibility* with for example norms, beliefs and infrastructure. As an example, residential PV benefits from a widespread belief in the perils of climate change, but may be in conflict with permitting or tax rules.
- *Complexity* as perceived by potential adopters. Although residential PV systems are typically relatively easy to acquire and use (at least from a technical point of view), potential adopters might perceive adoption and use as potentially complicated.
- *Trialability*, reflecting the possibility of testing the technology before adopting it. Residential PV suffers from low trialability, as a PV system cannot easily be installed and uninstalled for testing on a rooftop.
- *Observability*, being the extent to which members of a social system can observe the results of an adoption. While residential PV has a high observability in terms of *awareness* (neighbours will normally notice when someone has installed a rooftop PV system), lower observability of the actual results of PV adoption (production, economy, reliability) might be a disadvantage.

A key concept in papers 3 and 4 is that of ‘peer effects’, which captures social influence between peers (e.g. neighbours, co-workers or friends) in the adoption decision process. Although Rogers did not use this particular term, much of his framework is, as should be evident from the above account, dedicated to this topic. Peer effects can be *active* (occurring through direct communication between peers) or *passive* (occurring without direct communication, for example when someone observes a new PV installation in their neighbourhood) (e.g. Rai and Robinson, 2013). Peer effects have been observed in the adoption of a variety of technologies, such as menstrual cups among Nepalese adolescents (Oster and Thornton, 2009), electric vehicles (Axsen et al., 2009), information and communication technologies (e.g. Stewart, 2007), housing renovation (Helms, 2012) and various kinds of farming equipment (Rogers, 1983). Peer effects are often highly localised (Rode and Weber, 2013), and local peer effects for residential PV systems have been quantified in a number of recent studies (Bollinger and Gillingham, 2012; Graziano and Atkinson, 2014; Graziano and Gillingham, 2014; Müller and Rode, 2013; Rai and Robinson, 2013; L.-L. Richter, 2013; Rode and Weber, 2013). There has, nevertheless, been a lack of qualitative research on peer effects in PV adoption, and consequently the understanding of the underlying mechanisms of peer effects in PV adoption has remained poor. This gap was addressed in paper 4.

2.2. Research design

The research was mainly based on case studies carried out using qualitative methods. Data were collected through a variety of methods, including interviews (all papers), surveys (papers 3 and 4) and comprehensive internet searches (all papers). Both primary and secondary data (academic and non-academic) were used (secondary data were relatively more important for papers 1 and 2). In this section, the case study approach(es) adopted and the methods for data collection and analysis are outlined. (For a more detailed account of the research designs of each paper, see section 3 or the appended papers.)

2.2.1. Case studies

The thesis is largely based on *case studies*, i.e. empirical in-depth inquiries in single settings (Eisenhardt, 1989; Yin, 2009). Case studies are suitable to shed light on 'how'- or 'why'-questions regarding contemporary phenomena over which the researcher has little or no control (Yin, 2009). Case studies can be based on qualitative or quantitative methods, or a combination of both, and they normally make use of a variety of evidence, including documents, artefacts, interviews, and observations (Eisenhardt, 1989; Yin, 2009). Case studies are generalisable to theoretical propositions rather than to populations, and one of their important strengths is to explain causal links in complex situations (Yin, 2009).

Case studies can be based on one or more cases, which should be selected on the basis of their expected ability to provide useful information rather than to provide a representative sample of a larger universe (Eisenhardt, 1989; Yin, 2009). If the number of candidates for cases to study exceeds about a dozen, quantitative data should be collected about the cases and pre-defined criteria should be specified to select a smaller number (Yin, 2009). This strategy was adopted for paper 3.

For papers 1-3, a clear-cut case study approach was adopted, while paper 4 employed elements of case study methodology. Paper 1 was carried out as a single-case study to identify and assess barriers and drivers within one particular setting (Sweden as a whole). Papers 2 and 3, on the other hand, used multiple-case approaches to support generalisations by means of comparison between different settings.

2.2.2. Data collection and analysis

In line with the interdisciplinary nature of the research and with case study methodology, data were collected and analysed using a variety of sources and methods (Table 1). This allowed for knowledge to be added regarding various aspects of the posed research questions. The variety also allowed for triangulation, i.e. for increasing the internal validity of the findings using evidence derived from different datasets and methods (Richards, 2007). While papers 1 and 2 were exclusively qualitative, papers 3 and 4 used a mix of qualitative and quantitative methods. Paper 4 used a narrower set of data sources than the other papers. Both primary and secondary data were used. Primary data were collected mainly from interviews and surveys. See Table 1, section 3 or the appended papers for more detailed information on the data used for each paper.

Participants (interviewees and survey respondents) were selected through *purposeful sampling*, i.e. they were selected based on their expected ability to provide useful information rather than to achieve a representative sample of a larger population. Purposeful sampling is generally adequate in qualitative research (Maxwell, 2008).

Interviews were carried out in a semi-structured manner, meaning that a set of questions (an interview guide) was prepared in advance but was not necessarily followed strictly. Thus, any unforeseen and interesting matters surging during the interview could be addressed. In total, 59 interviews were performed. In addition, numerous shorter or less structured communications were performed with various actors, mainly through telephone or email. The main function of these shorter contacts was to guide the research towards relevant data sources or topics.

The interviews were analysed differently between the papers, mostly depending on their relative importance for the respective paper. For papers 1-3, interviews were not recorded but notes were taken during the interviews. For paper 4, in which interviews were relatively more important, not only notes were taken but the interviews were also recorded and (whenever the notes were not considered detailed enough) revisited and partly transcribed. Simple coding techniques were used to analyse the interviews, through which themes were identified and put into categories. This allowed the researcher to keep track of how many interviewees had made certain statements or expressed certain considerations. Some degree of interview coding was performed for all papers, although it was done most systematically for paper 4.

Two surveys were performed to collect data for papers 3 and 4, respectively. Questionnaires (see appendices A and B) were sent by postal mail to Swedish PV adopters. The response rates were 74-80% (which is to be regarded as high) and in total 130 valid responses were obtained. The data obtained through the surveys were used mainly for descriptive statistics and to guide the further research, although some inferential statistics were also performed.

Table 1. Data systematically collected for the four papers, by type and quantity. In addition to what is shown in this table, systematic Internet searches were important for papers 1-3, leading to the use of various secondary data.

Paper	Data		
	Type	**Actor/source**	**Quantity**
1	Interviews (duration 0.5-1 h)	PV installers	9
		Electricity companies	9
		Experts	4
2	Interviews, marketing material	Companies (Japan)	5
	Websites	Companies (U.S, Germany)	70
3	Survey questionnaire (appendix A)	Adopters	65 valid responses (80% response rate)
	Interviews (duration 0.25-0.5 h)	Local actors (e.g. PV installers, electric utilities, municipal energy advisers)	16
4	Survey questionnaire (appendix B)	PV adopters	65 valid responses (74% response rate)
	Interviews (appendix C) (duration 0.25-0.75 h)	PV adopters	16

Secondary data were collected from various sources. Documents such as industry reports, academic publications, newspaper articles and the websites of firms and other organisations were used. For papers 1-3, comprehensive Internet searches were an important tool to identify and gather data. An important data source and tool was the Swedish Energy Agency's register of applications and approvals for an investment subsidy scheme that has been available to PV adopters since 2009. The names and addresses of PV adopters obtained from this register allowed for analysis of geographical differences in PV adoption rates within Sweden, and made it possible for the researcher to contact adopters for the surveys and interviews. This register was used for papers 3 and 4.

When feasible, data were collected until theoretical saturation (Glaser and Strauss, 1967) was approached, i.e. until the marginal gain in insights obtained through additional data collection was not large enough to motivate the effort of collecting more data. There were, nevertheless, restrictions regarding the extent to which theoretical saturation could be applied (see section 1.4).

2.3. Interdisciplinarity

The research behind this thesis is *interdisciplinary* by nature. Interdisciplinarity is the combination and (partial) integration of elements from two or more academic disciplines (Boden, 1999; Klein, 2010, 1990). A broad scope alone does not necessarily imply interdisciplinarity, and neither does the mere juxtaposition of different disciplines (Klein, 1990). For interdisciplinarity to be meaningful, the strengths of different disciplines should contribute to address one and the same issue and, ideally, the disciplines should enrich each other (Boden, 1999). Although interdisciplinarity is often confused with *multidisciplinarity*, the latter term refers to the juxtaposition of disciplines without any requirements on integration (Klein, 1990). Distinctions between different branches of social science are to a large extent arbitrary and historically forged (Calhoun and Rhoten, 2010), meaning that that interdisciplinary approaches are often no more intrinsically wide-scoped or integrative than research within established disciplines.

Interdisciplinary approaches are often useful to study phenomena that are complex or that do not fit into one particular discipline (Calhoun and Rhoten, 2010; Klein, 1990; Krohn, 2010), including many policy challenges facing humanity, such as climate change and sustainability transitions in the energy sector (Bhaskar et al., 2010; Miller, 2010). The present research made use of two theoretical frameworks (TIS and business models) that are in themselves pronouncedly interdisciplinary (Pateli and Giaglis, 2007; Sharif, 2006). In addition, theories originating in sociology (the diffusion of innovations framework) were used to understand the role of adopters in PV deployment. Although these three frameworks were used largely in parallel rather than integrated with each other in the four papers, this chapeau ties the findings more closely together, thus strengthening the interdisciplinarity of the research.

3. Key findings organised by papers

The four papers studied barriers and drivers to PV deployment in different geographical contexts and using different approaches. In paper 1, a sociotechnical systems approach was used to identify and assess various barriers and drivers to PV deployment in Sweden. In paper 2, business models for PV deployment that have been successful in three important PV markets (the United States, Germany and Japan) were analysed regarding their ability to overcome country-specific barriers. In paper 3, drivers that could explain the relatively high adoption rates observed in certain Swedish municipalities were identified and assessed using a multiple-case study approach. In paper 4, social influence between peers (peer effects) was studied regarding how Swedish PV adopters have increased the willingness of their peers to adopt PV. In the following, the four papers are summarised one by one.

3.1. Paper 1 – Systems perspective on barriers and drivers to PV deployment (Sweden)

3.1.1. Background

The Swedish government has an outspoken ambition to increase the share of solar energy and other renewables in the country's energy system, and subsidies for PV deployment have been available for a number of years. As previously stated, the deployment of radical energy technologies is however a complex process that may encounter several unforeseen barriers. This calls for a systematic review of the overall conditions for PV deployment within the country. Such an analysis has previously been performed by Sandén et al. (2008), who included not only deployment but also development and production in their study. This thesis provides an updated study devoted solely to the deployment phase.

3.1.2. Objective and approach

The objective of this paper was to identify and assess barriers and drivers to the deployment of residential PV systems in Sweden. Such an analysis could result in information useful to policymakers. A technological innovation systems (TIS) approach was adopted, which is a sociotechnical systems perspective developed to analyse the dynamics of technology development, production and deployment, and to identify and assess barriers and drivers throughout a technology's value chain (see section 2.1.1). In the present thesis, however, the TIS framework was applied to the deployment phase exclusively, allowing for a more robust analysis of this phase.

Methods for data collection were comprehensive Internet searches, 22 interviews with experts, installation firms and electricity companies, as well as a number of brief communications with various actors. A large amount of secondary data, mainly identified through the Internet searches, was reviewed, including legislative texts, debate articles, organisations' websites, statistics from governmental organisations, governmental reports, etc.

The Swedish national borders were set as the geographical system boundary because they coincide with the reach of several important institutions and because a purpose of the study was to inform Swedish policymakers. Timewise, the study focused on the early 2010s.

3.1.3. Results

The analysis revealed that the Swedish TIS for PV deployment was small and underdeveloped, although the market was (in relative terms) in a state of rapid growth. Commercial actors involved in PV deployment were largely restricted to small installation companies, although electric utilities[1] and electricity retailers had also shown an increasing interest in PV systems sales and trade in solar electricity. Installation firms were typically small and with a local focus. They were often not exclusively devoted to PV technology, thus lacking the benefit of specialisation. Potentially important actors such as architects or construction companies were not

[1] In this thesis, an *electric utility* is defined as an organisation that operates an electrical distribution grid. Although the legal entity that is most directly responsible for operating the grid is not allowed by Swedish law to trade in electricity or appliances such as PV systems, a grid-operating entity and an electricity-trading entity can be (and are often) gathered within the same group of companies. The group of companies can then sell PV systems though the electricity-trading entity, while it runs the grid through its grid-operating entity. In this thesis, the term *utility* may refer to such groups of entities or to pure grid-operators. For companies engaged in electricity-trading but not in grid-operation, the term *electricity retailer* will be used.

engaged in PV deployment more than marginally. PV systems were almost exclusively purchased by the adopters, meaning that third-party ownership business models that have been common in some more developed markets were practically non-existent in Sweden. This lack of alternative business models could be a barrier to some potential adopters who would prefer to adopt PV without purchasing a system.

Overall, the most important barrier to PV deployment was found to be the poor economic profitability of investing in a PV system. This was not only because of expensive PV systems and relatively low amounts of solar influx, but also because electricity prices in Sweden have generally been relatively low by international standards. Thus, the Swedish PV market had been created and upheld by subsidies. However, the subsidy schemes in place were sub-optimally designed, impaired by uncertainties and complexities.

The most important subsidy for PV deployment has been an investment subsidy scheme available for residential PV since 2009. Through this subsidy, adopters have been reimbursed for a fixed share of their expenses for purchasing a PV system. The scheme has repeatedly reached its budget cap, after which no more applications have been approved until more funding has been added through political decisions. As the PV market was very dependent on this subsidy scheme, the reaching of the cap has led to discontinuations not only in the scheme but in the whole PV market. This has created severe problems for installation firms that have suddenly and repeatedly lost their source of revenue. It has most often been unknown to the actors if and when new funding was to be added to the scheme. The interviews revealed that, as a result of these uncertainties, installation firms have often postponed decisions regarding the recruitment of new employees, purchasing of equipment or acquiring of a more appropriate office.

Furthermore, whenever the cap had been reached, additional applications were placed in a queue to be considered if and when new funding was added through political decisions. This led to waiting times for getting applications approved gradually increasing to more than a year, creating complications not only for adopters but also for firms. The delays have resulted in extra transaction costs for installers who have often had the feeling that they have been forced to ‘sell the PV system twice’, once when the adopter contacts them before filing an application for the subsidy and again after the application has been approved.

In parallel to the investment subsidy scheme, a tradable green certificates (TGC) scheme has been in place since 2003. Through the TGC scheme, owners of PV systems and a number of other renewable electricity technologies have been granted tradable certificates for their electricity production (one certificate per megawatt-hour). Certificates have been sellable on a ‘free’ market, demand being created by legal obligations on other actors to acquire certificates in proportion to their production or use of electricity.

The TGC scheme was launched as the main Swedish policy instrument to support renewable electricity, and an important feature was its alleged 'technology neutrality'. It has been an important driver of the dissemination of renewable electricity technologies, mainly for wind power (Swedenergy, 2012). The scheme has, however, been poorly adapted for micro-generation of electricity (e.g. in residential PV systems). Trading small quantities of certificates has been complicated, and although PV owners have formally been entitled certificates corresponding to their whole production, hassle and extra costs have made it unattractive to acquire certificates for the self-consumed part of the production. Perhaps most importantly, expensive metering equipment has had to be installed by the PV owner for certificates to be granted for self-consumed electricity. The misalignment of the TGC scheme to micro-generation is illustrated by the fact that only a fraction of the Swedish PV adopters had found it worthwhile to apply for TGCs at the time of the study. For example, by the end of 2012 a mere 10% of all grid-connected PV systems in Sweden were benefiting from the scheme (Stridh et al., 2013).

As regards the institutional set-up beyond subsidies, existing institutions were found to be fairly well-aligned to residential PV deployment in the sense that no particular barriers of prohibitive magnitude could be identified. An important barrier was removed in 2010 when PV adopters were given the legal right to connect their system to the grid at no cost. Building permits for PV systems have usually been granted without prohibitive costs or hassle, and even though there has been some variation between municipalities' building permit policies, national regulation has kept these costs and restrictions within certain limits.

There have, however, been some barriers related to tax rules. Most of the existing tax rules of relevance were designed decades ago for a regime of centralised large-scale electricity generation, and have not always been straightforwardly applicable to micro-generation. For example, there have been uncertainties regarding whether micro-producers selling their surplus electricity to an electricity retailer are to be regarded as 'professional' and thereby subject to extra taxation and paper work. According to the tax agency, tax rules on the EU and Swedish levels have also prohibited net metering (the practice of subtracting any electricity fed into the grid from the consumption before applying taxes), although the tax agency's interpretation of the rules on this point has been opposed by some actors.

A large problem has been uncertainties regarding the future development of the institutional set-up. Most importantly, future taxes and subsidies have been unpredictable, both regarding their design and at what times they would be in operation. Apart from the aforementioned uncertainties regarding the investment subsidy, there were important uncertainties regarding the planned introduction of a tax reduction scheme for PV owners[2], for example regarding the compatibility of the tax reduction with existing tax rules.

The functional analysis revealed a linear chain reaction driving deployment. ‘Legitimation’ had been necessary for ‘resource mobilisation’ of the funding used for the investment subsidy scheme. This caused ‘market formation’ to take off, which in turn provided ‘guidance of the search’ for entrepreneurs to get involved in the PV installation business. The functions not mentioned in this chain reaction (‘knowledge development and diffusion’ and ‘entrepreneurial experimentation’) were excluded because little evidence was found that these functions operated on more than a basic level. Most installation had taken place in a rather traditional manner both technically and organisationally, and the experimentation of electric utilities and other commercial actors had remained a rather marginal phenomenon. The knowledge employed by actors involved in PV deployment was rather basic (add-on PV installation is in itself not a very complicated process), and the awareness of consumers necessary for their propensity to adopt PV was rather captured by the legitimation function. Because of the deployment focus, functional feedback mechanisms from deployment to production that are often analysed in TIS studies were not made visible in this case. However, the Swedish PV market was too small to significantly affect the global PV production system and such feedback mechanisms could thus be neglected.

3.2. Paper 2 – Business models for PV deployment (Germany, United States, Japan)

3.2.1. Background

In overcoming barriers to PV deployment, firms may play an important role through organisational innovation. The development and adaptation of new and existing business models have historically often been crucial in technological transitions. As PV is a radical technology in the electricity and housing sectors, business model innovation will most likely be key to coping with various barriers. Barriers, not least related to these sectors, can vary substantially between different geographical contexts, and there is thus a need to analyse how different business models can address barriers in different PV markets. Insights into how business models can

[2] After the publication of the paper, the tax reduction has been implemented in parallel to the other schemes, meaning that there are now (December 2016) three overlapping subsidy schemes.

counteract barriers to PV deployment could be useful to support deployment in Sweden and other emerging PV markets around the world. As revealed in paper 1, the TIS function 'entrepreneurial experimentation' was rather weak in Swedish PV deployment as practically all installation companies offered the same basic sales of turnkey PV systems. In other markets around the world, however, a variety of PV business models with rather different characteristics has emerged lately. Thus, paper 2 went beyond the Swedish setting to find empirical evidence on alternative business models.

3.2.2. Objective and approach

This study aimed at analysing how different business models for PV deployment can overcome barriers in different national contexts, and how different barriers and other contextual factors affect which kind of business models that will emerge and succeed in different settings. The study compared three distinctively different business models for PV deployment that have achieved success in three important PV markets, namely in Japan, Germany and the United States. In Germany, PV systems have been purchased and owned by the user as a financial investment. In the United States, third-party ownership (TPO) business models have proliferated. In Japan, the building industry has taken a leading role by integrating PV systems into prefabricated homes. An in-depth analysis was performed regarding the characteristics of each business model and the national contexts in which they thrive. How context has mattered for the success of the different business models, and implications for policymakers and firms, were then elaborated upon.

Based on theoretical sampling (Eisenhardt, 1989), the cases were selected for three key reasons. First, distinctively different business models have succeeded in the three countries, which allows for the identification of contextual factors that might explain why a certain business model thrives in a certain context. Second, the three countries together accounted for about 45% of the cumulative global installed PV capacity at the time of the study being performed (REN 21, 2014), making them important cases to learn from regarding successful PV deployment. Third, the extensive experience of PV deployment in the three countries was instrumental for data access.

Key data sources included firms' own material, such as websites, marketing material and annual reports. Also, legislative texts, standards, research reports, academic literature, trade journals etc. were used. In the case of Japan, the possibilities to use secondary data were more restricted due to the language barrier, and interviews were thus carried out with five companies in the prefabricated housing sector and with a number of experts, using an interpreter.

3.2.3. Results

Below, a case-by-case account of the different business models and their respective contexts is given. The conclusions are then accounted for.

3.2.3.1. United States

In the United States, business models based on third-party ownership (TPO) have been highly successful, accounting for 70-90% of residential installations in important sub-markets such as California, Arizona and Colorado. In these business models, the adopter is not the owner of the PV system. Instead, the system is owned by a firm providing a full-service solution including planning, installation and maintenance. Financing is obtained through an arrangement in which firms package several projects into funds that are sold to investors.

TPO models are commonly based on either a power purchase agreement (PPA) or a lease. In a PPA, adopters purchase the electricity that the PV system generates. Certain criteria are set for the price so that it is highly predictable over a period of 15-20 years. At the end of this term, the adopter can purchase the PV system, have it removed by the PPA provider or renew the agreement. In a lease, the adopter instead pays a time-based fee for using the system, and gets to use the produced electricity without additional payments. PV leasing has been common in states in which PPA has not been allowed.

The TPO models used in the United States have successfully addressed several common barriers to PV adoption. First, they have minimised consumer transaction costs. The adopter's only point of contact has typically been the firm providing the TPO model, rather than numerous actors such as installation and maintenance firms, banks, insurers and government agencies. The TPO firm has also taken care of any administrative tasks related to subsidies, permits and grid-connection. Second, risks related to the ownership have been shifted from the adopter towards the firm. Third, the adopter has not had to raise capital to finance the system.

TPO models have addressed barriers that have been particularly prevalent in the Unites States. Homeowners in the United States have had lower savings rates than homeowners in Japan or Germany, and potential adopters in the United States have thus been less likely to be able to finance a PV system upfront without a mortgage. Furthermore, access to home equity loans has been severely restricted in the wake of the financial crisis of 2008, which has left many homeowners 'underwater' (their home mortgage being larger than the value of their home), further restricting potential adopters' ability to finance a PV system purchase. People in the United States also tend to move relatively frequently, which for many potential adopters has likely increased the relative attractiveness of immediate electricity bill savings compared to a long-term investment in their home. Lastly, transaction costs in PV deployment have been higher in the United States than in Japan or Germany, which has made it more attractive for adopters to impose them on a third party.

3.2.3.2. Germany

In Germany, PV systems have mainly been financed and owned by the adopters themselves. In the business model dominating German PV deployment, the value proposition has been based on PV adoption as a low-risk financial investment fully competitive with other investment alternatives. Adopters have been guaranteed stable revenues for 20-21 years through a feed-in tariff scheme backed up by national legislation. Policymakers have regularly monitored the cost development of PV systems and adapted the feed-in tariffs to keep the IRR of PV adoption at around 7%.

Transaction costs in PV deployment have been relatively low in Germany. Institutional alignment and local learning among practitioners since the early 1990s have led to a relatively smooth deployment process, and legal-administrative processes related to PV deployment have become among the least complicated in Europe. The absence of high transaction costs has made the third-party owner somewhat redundant as a key function of a third-party owner is otherwise to absorb transaction costs. This is likely a partial explanation for German PV adopters' preference for purchasing and owning PV systems without the involvement of a third-party owner.

As German adopters have fully financed the upfront cost, the German business model has benefited from the availability of low-interest loans especially dedicated to PV. These loans have been provided through a government-owned bank since 1999. The loans have often been supplemented by equity from the customers, and the relatively high savings rates of German homeowners have thus facilitated the business model.

Just like firms in the United States, German firms have been offering a variety of services and features to reduce uncertainties and complexity. These include comprehensive insurance packages, long-term warranties for durability and performance, as well as certification of PV system components and installers through reputable organisations.

3.2.3.3. Japan

In Japan, the cross-selling of PV systems together with other products has been widespread, particularly in the construction sector. The *prefabricated homes industry* has been leading in this regard and, as early as 2011, about 60% of all new prefabricated homes came with a PV system. The prefabricated homes sector has held around 20% of the market for new homes and 10-15% of the residential PV market. The prefabrication of homes has been dominated by around ten large companies.

The value proposition has had several advantages compared to value propositions based on add-on PV systems. PV systems sold with new homes have been less expensive for the adopter than add-on systems, and roof integration has allowed for aesthetically appealing solutions. As the adopter has already established a contact with the supplier for the purpose of purchasing a home, transaction costs have been reduced for both parties. In Japan, PV adopters who have purchased their PV system together with a new home have typically been more satisfied with the adoption than have other PV adopters (Mukai et al., 2011).

The expenses for the PV system have generally been integrated into the home mortgage, reducing transaction costs and interest rates. As a mortgage needs to be issued for the home in any case, it has been easy to expand this loan to include the PV system. From the perspective of the financial institution issuing the loan, the income generated through the PV system has enhanced the adopter's creditworthiness. Building-integration has also been a benefit in this regard as a system physically integrated into the roof cannot as easily come adrift.

A key contextual factor explaining the success of this business model is the pre-existence of a highly industrialised prefabrication sector. Built upon large volumes, automation and advanced logistics systems, Japan's prefabrication industry has seemingly been the most industrialised house-building industry in the world. Industrialisation has brought about a high degree of standardisation, benefitting PV integration. The high level of industrialisation has, in turn, sprung out of a 'scrap and rebuild' culture in which almost 90% of all homes sold have been newly produced. Homes in Japan have typically depreciated very rapidly as they have increased in age.

Unlike in Western countries, prefabricated homes in Japan have been considered to be of higher quality than site-built homes, and they have typically been more expensive and equipped with more features. The cost savings achieved through industrialisation and mass-production have generally been used to add more features to the homes rather than to reduce consumer prices. Through this so called *mass customisation*, consumers have been offered a wide variety of choices between mass-produced components, including energy devices such as batteries, fuel cells, heat pumps and home energy management systems. PV systems have neatly fitted into this pattern.

Another relevant contextual factor has been the domestic PV industry, which has been dominated by large electronics companies keeping large parts of the PV value chain within their own organisation. The Japanese PV industry has played a key role in making prefabricated PV homes become common in Japan by marketing their products intensely towards the prefabrication industry rather than directly to consumers. They have also been seeking collaboration with prefabrication companies, something that, as revealed by the interviews, the prefabrication companies have often perceived as valuable and helpful. The interviews also revealed that house producers have tended to prioritise stable long-term partnerships with PV module suppliers over lower prices or higher efficiency of the modules. Although Japanese modules have been substantially more expensive than for example Chinese modules, all house producers interviewed used Japanese modules. They motivated this choice by explaining that communication with and reliability of the module producer and its products are crucial when modules are to be customised to fit the roofs.

Also, assurances of the national government that subsidies were to be present for an extended period have been important for the prefabrication industry to work with PV integration. Changing production lines is expensive, and the house-building industry has preferred certainty that PV systems were to remain attractive for their customers before making such investments.

3.2.3.4. Conclusions

In all three cases, the studied business models for PV deployment have enabled firms to overcome typical barriers faced by prospective PV adopters, such as complexity, transaction costs, risks and access to finance. Yet, the business models have been distinctively different. The analysis suggests that the differences between them have to a large extent been the result of differences in the national contexts in which they have occurred. The importance of context implies that business models for PV deployment cannot necessarily be viably transferred from one setting to another. (For example, recent attempts to implement TPO business models in Germany have not been very successful.)

The strong presence of TPO models in the United States and their absence in Germany and Japan is not likely to only be the result of differences in consumer preferences, but also of other contextual factors. TPO models have effectively addressed issues that have been particularly prevalent in the Unites States, such as low savings rates, restricted access to capital, high mobility on the housing market and high transaction costs. In Germany and Japan, on the other hand, higher savings rates, better access to low-interest loans, lower mobility on the housing market and lower transaction costs have made PV adopters more prone to purchase and finance the PV systems themselves.

TPO models for PV deployment may gradually lose their relevance for most adopters as PV markets mature. Market maturation usually entails a reduction in transaction costs and risks, which might make it more attractive for adopters to finance and own PV systems themselves. As TPO models require more middle-men capturing their share of the lifecycle economic gains of a PV system, business models based on self-ownership have the potential to become more financially beneficial for adopters. Once other barriers disappear, self-ownership could thus become the most viable option for most adopters also in markets such as the United States. A high proliferation of TPO models could perhaps even serve as an indicator for policymakers that there are barriers that should be dealt with. TPO models could, however, still prevail in mature markets to serve certain market segments, as some adopters might value the simplicity of TPO models more than the prospects of higher long-term financial gains.

3.3. Paper 3 – Local factors and information channels influencing PV deployment (Sweden)

3.3.1. Background

On the surface, the conditions for PV deployment seem to be rather homogenous throughout Sweden, as economic and institutional conditions do not differ much between different parts of the country. Yet, PV adoption rates vary between municipalities to an extent that is beyond what could be explained by local factors such as building stock characteristics, solar influx or average income. This raises the question of whether there are unknown local drivers present in these high-dissemination municipalities that have increased local adoption rates.

3.3.2. Objective and approach

This paper aimed at identifying and assessing factors that could explain high localised adoption rates of residential PV systems in Swedish municipalities. An explorative multiple-case study approach was used (Yin, 2009). Five municipalities that stood out in terms of high PV adoption rates were studied in depth. These main cases were then compared to 50 municipalities with low PV adoption rates, which were studied in less depth. Triangulation of quantitative and qualitative methods and different data sources was used to enhance the robustness of the findings.

The main cases were selected as follows. All Swedish municipalities were ranked by their per capita PV density and by their PV density in terms of number of PV systems per detached home. Those five municipalities that occurred in the top ten in *both* these rankings were selected. As comparison cases, the 50 municipalities with the lowest per capita PV adoption rates were selected (except for one municipality that was excluded because it had very few detached homes). The case selection was thus a combination of replication (cases with the same outcome on a key variable) and a 'two tail' design (cases on either extreme of a key variable) (Yin, 2009).

Data were collected by three main methods. First, a survey questionnaire (see appendix A) was sent by postal mail to all presumed PV adopters that could be identified in the five main case municipalities. The survey yielded 65 valid responses at a response rate of 80%. The aim of the survey was to assess various local information channels that might have affected the respondents' decision to adopt PV. Second, 16 interviews, as well as a number of shorter communications, were performed with local installers, electric utilities and other key actors. Third, comprehensive Internet searches were performed to identify actors and gather other relevant information about the cases.

The data necessary to estimate municipalities' adoption rates and to contact adopters were obtained from the Swedish Energy Agency. More specifically, a register of applications and approvals for the national investment subsidy scheme (this scheme has been described in section 3.1.3) was used, containing the names and addresses of adopters. Since few PV systems had been installed outside this scheme, these data were assumed to provide a good representation of the actual number of installations.

3.3.3. Results

The results pointed to local actors promoting PV as an important explanatory factor behind the relatively high adoption rates in the five main case municipalities. This finding was corroborated through triangulation, as the three main sources of data (survey, interviews and Internet searches) pointed largely to the same explanatory factors. Common to the five municipalities was the presence of local organisations promoting solar energy from an early stage, mainly electric utilities and installation firms selling PV systems and disseminating information. The survey respondents recognised that they had been influenced to a substantial extent by these activities. Overall, the respondents rated local information channels as slightly more influential than common non-local information channels such as nation-wide media, websites with a non-local focus and non-local acquaintances. The survey results indicated that the local factors had not only *raised the respondents' interest* in PV but also *influenced their final decision* to adopt, suggesting that these factors operated throughout a substantial portion of the innovation-decision process (cf. Rogers, 1983).

The relative importance of different factors varied between the studied municipalities. Regarding this variation, the survey results were largely in line with the results obtained through the interviews and Internet searches (factors that were found to be of high relative importance in a municipality using one method were also found to be of high relative importance using the other methods). For instance, in the two municipalities with the most active local utilities, the respondents regarded utilities as more important than respondents in the other three main case municipalities did. In one municipality where installations had been largely concentrated to one zip code area in which an installation company was based, peer effects and PV installers were recognised by the respondents as relatively important. In another municipality, where a local association has realised a number of larger ground-mounted PV installations, the presence of ground-mounted PV was recognised by the respondents as important in inspiring them to adopt PV.

Local electric utilities supporting PV appeared to have been a particularly important driver elevating local PV adoption rates. Local utilities promoting PV during the period studied were found in four of the five main case municipalities, while none of the local utilities in the 50 comparison municipalities were found to have engaged in PV promotion during or before the period studied. The local utilities supporting PV in the main case municipalities had started their promotion of PV *before* the PV market started taking off, indicating causation in the direction from utilities towards increased adoption rates. The importance of utilities was also recognised by the survey respondents. Seminars attended by the respondents had (as reported by the respondents) been arranged mainly by local utilities, and 54% and 24% of the respondents agreed that their final decision to adopt PV had to some or to a large extent, respectively, been due to their utility purchasing PV electricity.

The results also indicated some causality going in the other direction. During the interviews, some representatives of PV-promoting utilities acknowledged that their organisations had been influenced to some extent by customers adopting PV or contacting them for information on grid-connection of PV, thus pushing them towards developing strategies for PV. This reveals the presence of a positive feedback loop: customers influence their utilities, which in turn influence other customers to adopt. The interviews also revealed that the utilities' engagement in PV promotion had in most cases started largely as the result of one devoted staff member (usually the CEO). These persons had, for one reason or the other, adopted a positive attitude towards PV, and had had the personal drive to win their organisation over to promoting PV.

Lastly, respondents in all municipalities recognised having been influenced by PV adopters in their proximity (peer effects), both through direct communication with adopters and by observing PV systems in their neighbourhood. These findings were strengthened by the interviews with installation companies, which largely agreed that after installing a PV system at a particular place, they would often shortly thereafter get additional requests from homeowners in the same area. These homeowners had, according to the interviewees, often been inspired by the first installation. On average, the survey respondents considered local acquaintances to have been about as influential on their adoption decision as installation firms. However, local peers whom the respondents categorised as 'neighbours' were seen as having had a rather minor influence, indicating that the peer effects had been mediated through other kinds of social relations than those between people regarding each other primarily as neighbours.

3.4. Paper 4 – Peer effects in PV adoption (Sweden)

3.4.1. Background

The results of paper 3 suggested that peer effects (social influence between peers) have been a factor in reducing barriers to PV adoption in Sweden. A number of previous studies have also quantified peer effects in PV adoption in other settings, mainly Germany and the United States (Bollinger and Gillingham, 2012; Graziano and Atkinson, 2014; Graziano and Gillingham, 2014; Müller and Rode, 2013; Rai and Robinson, 2013; L.-L. Richter, 2013; Rode and Weber, 2013). This research has mainly been concerned with estimating the increased probability of PV adoptions occurring within a small geographical area as the result of previous adoptions in the vicinity. Little, however, has been known about the inner workings of peer effects in PV adoption. Thus, in paper 4, a closer look was taken at the role of peer effects among Swedish PV adopters.

3.4.2. Objective and approach

The study took a mixed-methods approach (combining quantitative and qualitative methods) to add knowledge of the inner workings of peer effects among Swedish PV adopters. More specifically, the research aimed at shedding light on what kinds of social relations mediate peer effects, what kind of information is transferred between the peers and what emotions are evoked leading to the adoption of a PV system.

Data were collected through a survey questionnaire (see appendix B) and interviews (see appendix C) with selected survey respondents. The survey was sent by postal mail to Swedish PV adopters. To maximise the occurrence of peer effects among the respondents, adopters living in zip code areas with high adoption rates were targeted. Just like for paper 3, data for estimating local adoption rates and addresses of adopters were obtained from the Swedish Energy Agency's register of applications and approvals for the national investment subsidy scheme. All Swedish zip code areas were ranked by their number of PV systems per capita, and the survey was sent to all 92 individuals that had had their applications for the subsidy approved in the 25 zip code areas with the highest adoption rates (except for five areas that were located in the municipalities studied in paper 3, which were excluded because the adopters on those areas had recently been sent a similar questionnaire). The survey yielded 65 valid responses at a response rate of 74% (four presumed adopters returned the questionnaire informing that they had in fact not adopted). The survey was mainly built upon five-point rating scales of both unipolar and Likert type, in which the respondents were asked to rate how they perceived that seeing PV systems or talking to PV adopters in or outside their neighbourhood had influenced their perceptions of PV technology.

Telephone interviews were performed with selected survey respondents. Those 22 respondents who reported having been in contact with at least one PV adopter in their neighbourhood prior to taking a final decision to adopt (and who had provided their telephone number) were selected, and full interviews were carried out with 16 of them. The interviews were recorded, and whenever the notes taken during the interviews were not considered detailed enough, the recordings were used to complement the notes. Key data were coded in a spreadsheet.

Considering that people tend to consistently underestimate the impact of social influence on their decision making (Nolan et al., 2008), the risk of overestimating peer effects using the chosen methodology, which relied on participants' self-estimation, was assumed to be small.

3.4.3. Results

As in paper 3, the presence of peer effects was widely recognised by the participating PV adopters. Among the survey respondents, 38% reported that contact with a peer (local or non-local) had been highly important ("4" or "5" in the rating scales) for raising their interest in PV. The corresponding figure for the final decision to adopt was 35%. Among respondents who had been in contact with an adopter in their neighbourhood before they decided to adopt (28 respondents), half agreed that the contact had been highly important for raising their interest in PV, and almost half did so regarding their final decision to adopt.

The interviews revealed that the contacts had almost exclusively occurred through pre-existing and rather close social networks, such as friends and family. Contacts with PV-using neighbours to whom the respondent had no deeper relationship had been rare and of minor importance (this was also suggested by the survey carried out for paper 3). This contrasts somewhat to what has been previously believed about peer effects in PV adoption, where the role of neighbour relations has (more or less implicitly) been assumed to be important. Furthermore, even though the sample was selected based on a presumed high occurrence of *local* peer effects, almost as many respondents reported having been highly influenced ("4" or "5" in the rating scales) by someone living *outside* as *inside* their neighbourhood.

The main function of the peer effects appears to have been a confirmation that PV works as intended and without hassle, rather than the procreation of unexpected insights or the provision of more advanced information. The confirmation was strengthened by the trustworthiness of the peers, who (apart from being known by the participants) as private homeowners were in a situation similar to that of the participants, and who (as opposed to PV installers) lacked economic incentives to recommend PV adoption. The information transferred had generally not been of a very advanced character, and had mainly related to ease of use and economic performance – that PV systems worked as intended and without hassle, and that they delivered as much electricity as expected. This information had, nevertheless, been perceived as useful by the interviewees; it had contributed to reducing a general uncertainty about PV as a new and 'unknown' technology, and had increased the participants' determination to adopt. Overall, few of the contact persons had recommended PV adoption outright – rather, they had provided more 'neutral' accounts of their experiences as adopters. Almost all interviewees had seriously contemplated PV adoption and acquired some knowledge of PV before any contact with previous adopters took place, and the contacts did thus not evoke much unexpected insight.

When it comes to the role of *passive* peer effects (influence of *seeing* PV), the results indicated that these had been of minor importance. As in the survey carried out for paper 3, seeing PV systems was regarded as a relatively important influential factor. However, a closer look at the data revealed that respondents who had seen a PV system in their neighbourhood tended to regard this as influential only if they had also been in contact with an adopter. The interviews confirmed that it was when a PV system had been seen in connection with adopter contact that it had been influential, for example when visiting a PV owner that demonstrated his or her PV system.

Contacts between the interviewees and previous adopters had come about in two principal ways: either the interviewee had approached the PV adopter with the purpose of acquiring information from him or her, or the topic had come up as they had met for another purpose. Only in one case had the interviewee experienced being approached by an adopter (other than a salesperson) who appeared to have had the purpose of talking about PV. In the previous literature, it has sometimes been assumed that seeing local PV systems tend to induce people to contact the systems' owners to get more information. However, the findings of the present study did not support that such an order of events had been common in the studied setting, as almost no contacts had come about as the result (partly or fully) of the interviewee first seeing the contact person's PV system.

4. Concluding discussion

In this section, a synthesis of the findings of the four papers will first be presented. The methodological contributions of the thesis will then be discussed. Based on the findings, some recommendations for policy will also be provided, both specific advice for reforms of Swedish policy and more general advice. Lastly, some pathways for further research will be suggested.

4.1. Synthesis of findings

The objective of this thesis was to identify and assess barriers and drivers to residential PV deployment in different geographical settings, taking the spatial dimension into account. The findings of each paper have been accounted for separately in section 3. The added value of this synthesis is that it builds a larger and more coherent picture of barriers and drivers on different spatial levels, thus contributing to an improved understanding of the geography of sustainability transitions (cf. Coenen et al., 2012; Hansen and Coenen, 2015).

While the price and performance of PV technology have been largely determined on the international level, the thesis goes into depth with barriers and drivers rooted in national and local settings. By studying altogether four national PV markets, papers 1 and 2 identify and assess barriers and drivers mainly rooted on the national level, providing various examples of how institutions, industry, culture and financial aspects have affected PV deployment. On the local level, papers 3 and 4 show how local organisations and private individuals have driven PV deployment through information provision and social influence. Together, barriers and drivers rooted on all these levels determine the conditions for PV deployment at any given location. Thus, an understanding of barriers and drivers on all levels is important.

Paper 1 took a systemic perspective to identify and assess barriers and drivers in Sweden. The analysis was facilitated by the technological innovation systems (TIS) framework, which guided the research to relevant actors, networks, institutions and processes. The analysis depicts a small, underdeveloped Swedish TIS for PV deployment, albeit in rapid growth in relative terms. Limited economic profitability in PV adoption was a crucial barrier during the period studied (also including subsidies). The results reveal that the Swedish policy environment has been uncertain and complex, creating problems for different actors. The institutional barriers in Swedish PV deployment (which have been described in more detail in section 3.1.3) could be coarsely summarised as follows: First, the fact that more than one subsidy scheme for PV deployment have been running in parallel is a complexity in itself. Second, there have been uncertainties regarding when different subsidies were to be available, and on what conditions. Third, important rules, mainly related to taxes, have been unpredictable.

Even though the institutions affecting PV deployment in Sweden have mainly been national, they have not always been fully controlled by the national government. For example, Swedish rules for taxes and building permits affecting PV deployment have partly been determined on the EU and the municipal levels, respectively. Paper 1 reveals that institutions on the EU level have restricted the ability of the Swedish government to adapt rules to PV and other micro-generation technologies, resulting in institutional rigidity that has contributed to a lock-in of the incumbent energy system (cf. Unruh, 2000).

The thesis also demonstrates that country-specific characteristics of a domestic industrial sector can be important for PV deployment. Paper 2 reveals that certain characteristics of the Japanese construction sector, such as a high degree of industrialisation and standardisation, have been important for the physical and organisational integration of PV into the construction of new buildings in Japan. Those factors are rather unique to the Japanese construction sector compared to other domestic construction sectors around the world. This is likely an important explanation of why the Japanese construction sector has been highly involved in PV deployment as compared to construction sectors in other important PV markets.

The thesis also identifies barriers and drivers that vary between countries but are less confined to administrative borders. Such factors include cultural and behavioural aspects such as savings rates, homeowner mobility (how often people move), accustomedness to TPO business models (not only for PV) and priorities regarding long-term versus immediate cost savings. As suggested by paper 2, these aspects will influence what kind of business models will be most viable within a certain context, as different business models are suited to overcome different barriers to deployment. Perhaps most importantly, this relates to the ability of potential adopters to raise capital and to their preferences regarding whether to own the PV system or consult a TPO firm. Another example is real estate prices, which have developed rather differently between countries and regions, influencing homeowners' ability to finance a PV system. If the value of a home substantially exceeds the mortgage for the same home, the homeowner can often quite easily get a home equity loan to finance a PV system. This will be the situation for most homeowners in regions where the prices of homes have increased substantially in recent years. On the other hand, there are many regions around the world in which the values of homes have decreased dramatically in the wake of the financial crisis of 2008. In these regions, homeowners will typically have less opportunity of getting a home equity loan, and many of them will be ‘underwater’, meaning that the value of their home is lower than their mortgage. These homeowners will often find it difficult to finance a PV system, and TPO business models might then be a viable option. As argued in paper 2, this is likely a contributing factor to the success of TPO business models in California, where housing prices declined substantially after the financial crisis.

Paper 2 illustrates that certain business models can successfully overcome complexities and uncertainties faced by prospective PV adopters on the national level. It is thus noteworthy that Sweden, with its complex and uncertain policy environment, has (as was found in paper 1) lacked alternative business models such as TPO even though these have been successful in addressing complexities and uncertainties in other countries. As argued in paper 2, a lack of alternative business models (such as TPO) could be a barrier for some categories of potential adopters, and trying to explain the absence of TPO models in Sweden is thus justified. Drawing on papers 1 and 2, this synthesis allows for some remarks in this regard. A first reason for the absence of TPO models in Sweden could be the low economic profitability of PV investments; TPO models require a middle-man taking a share of the life cycle economic gains of a PV system, and the total economic gains might simply have been too small in Sweden for TPO to be viable. Second, the small size of the Swedish PV market might have decreased the likelihood of TPO models occurring as they require a higher level of organisational sophistication. Third, the Swedish institutional uncertainties have created risks of events that would affect all installations simultaneously. This contrasts to risks of events that occur independently of one another for each installation. While TPO models do not address the former kind of risk (events affecting all installations simultaneously could ruin a TPO firm), they successfully address the latter kind by spreading the risks over a large number of installations. Fourth, the Swedish housing market has withstood the global financial crisis remarkably well from an international perspective, and the prices of homes have increased rather consistently during the last decade, which has made it easier for Swedish homeowners in general to finance PV systems themselves without the need for a TPO model.

When it comes to the local level, papers 3 and 4 point to local sources of information as being an important driver of PV deployment. Local information seminars organised by electric utilities seem to have had a substantial effect in increasing adoption rates in Swedish municipalities (paper 3), and basic information transferred between peers appears to have been important in convincing Swedish homeowners to adopt PV (paper 4). Even though information channels operating on a higher geographical level, such as websites directed towards a national or international audience and media with a national coverage, were important for the decision making of the participating adopters, the findings of paper 3 suggest that local sources of information were of equal or higher importance. A substantial function of the information appears to have related to raising the interest in PV among potential adopters, indicating a lack of basic awareness.

Even though the geographical entity studied in paper 3 was the municipality, the findings point to another geographical entity of relevance, namely the area covered by the electrical grid operated by a certain utility. Different utilities have developed different strategies and attitudes regarding PV, and the results of paper 3 strongly suggest that a local utility's supportive attitude can substantially increase local PV adoption rates. Even though these effects are surely not strictly confined to the area covered by the utility's grid, the reach of the grid is likely to be of significant importance as everyone connected to the grid is a customer of the utility and thus subject to its communication. While utilities might have different roles in different countries, previous research on local sources of market formation (Dewald and Truffer, 2012) has not acknowledged the role of utilities, which might be relevant in some (though likely not all) other countries as well.

A driver with an inherently large local component is *peer effects* (social influence between peers resulting in PV adoptions). Previous research has identified substantial localised peer effects in PV deployment using quantitative research methods (Bollinger and Gillingham, 2012; Graziano and Atkinson, 2014; Graziano and Gillingham, 2014; Müller and Rode, 2013; Rai and Robinson, 2013; L.-L. Richter, 2013; Rode and Weber, 2013). Little has been known, however, about the inner workings of peer effects in PV deployment. Together, papers 3 and 4 contribute to deepening the understanding of peer effects by surveying in total 130 PV adopters and interviewing 16 of them, thus introducing a qualitative perspective that has been lacking in the previous research. Paper 3 confirms that peer effects in PV adoption also exist in the Swedish setting, and the paper provides some tentative findings regarding their underlying mechanisms. In paper 4, the mechanisms behind the peer effects were investigated more deeply. The two papers used data from different sets of participants (one set for each paper) and, as some survey items were identical or very similar for the sets, they together provide a larger sample on some aspects.

Paper 4 suggests that the main function of the peer effects was a *confirmation* from a trustworthy source that PV adoption would be a sound choice. The information transferred was generally not of a very advanced character, and related mainly to ease of use and economic performance – that the technology worked as intended and without hassle, and that it delivered as much electricity as expected. This information was perceived as useful by the interviewees, and it contributed to reducing a general uncertainty regarding PV as a new and 'unknown' technology, thus reducing barriers to adoption. Paper 4 was unique not only to the Swedish context, but also globally, as peer effects in PV adoption had not previously been studied through interviews with adopters.

The results of papers 3 and 4 suggest that the main reason (at least in the studied setting) for peer effects having a large local component is that people who are family and friends tend to live close to one another, rather than people influencing one another through more superficial neighbour relations. Both papers reveal that relations with people who the adopters perceived as 'neighbours' were perceived to have been of minor importance – instead, the influence had taken place through closer and more established social networks. The high degree of localisation in peer effects has led to an assumption in the previous literature that neighbour relations and passive influence (through passively observing neighbours' PV systems) have been important mediators of peer effects. However, paper 4 suggests that passive peer effects played but a minor role in the studied context. One implication of these results relates to the fruitfulness of different computational models of peer effects in PV deployment. Two different approaches to such models are based on social networks and geography, respectively (Bale et al., 2013; Rode and Weber, 2013). The results of this thesis indicate that the former approach might more accurately reflect the underlying processes at work.

Lastly, the thesis demonstrates how the local nature of PV deployment can create inefficiencies, at least in a small and early market such as the Swedish one. Paper 1 reveals that the installation of PV systems in Sweden has been dominated by small, local firms that have often not been exclusively devoted to PV technology, thus lacking the benefit of specialisation. This can be seen as a consequence of the fact that PV systems need to be installed on-site by the firm's staff, in combination with a small market size. Several of the installers interviewed for paper 1 expressed the ambition to become more specialised, claiming that the small market size within their catchment area would not support specialisation. With limited demand for PV systems within a reasonable travelling distance, a full-time job cannot be sustained by the demand for PV installations only. This leads to poor economies of scale on the local level, and to a lack of competition as the number of installers offering their services in any given place will be limited.

4.2. Methodological contribution

The thesis makes some contributions regarding research methodology, which will be discussed below. A first contribution relates to the application of the TIS framework. In paper 1, this framework was used to study PV deployment separately from processes occurring earlier in the PV value chain. Paper 1 demonstrates that it is meaningful to apply the TIS framework to study deployment separately in order to identify and assess barriers and drivers, and that deployment taken on its own is a complex and systemic process that motivates the use of a holistic analysis tool such as the TIS framework. The thesis argues that in cases where a mature technology is to be deployed in a catching-up market that is small in relation to the international production system for the technology in question, a pure deployment focus is motivated in TIS analyses. The value of this contribution is made evident by the fact that a pure deployment focus allows the researcher to focus his or her resources on the deployment phase, thus avoiding spending valuable time studying technology development and production, and saving him or her the effort of doing an international and spatially differentiated TIS analysis. Furthermore, increasing global specialisation and division of labour, as well as an increasing availability of mature renewable energy technologies that can be deployed in new regions, can be expected to create an increasing need for deployment-focused TIS studies (see section 2.1.1.3).

The thesis also demonstrates how the TIS framework, the business models framework and Rogers' diffusion of innovations framework can be combined to study technology deployment (see section 2.1). The latter two frameworks fit within the scope of the TIS framework and are appropriate choices when zooming in on selected parts of a TIS that relate to technology deployment. The thesis argues that the latter frameworks connect well to certain phenomena described in the TIS literature, such as certain categories of actors and the functions 'entrepreneurial experimentation', 'knowledge development and diffusion', 'legitimation' and 'market formation'. Thus, the latter frameworks could well be positioned within the TIS framework – the very concept of a 'business model', as well as various core concepts within both the frameworks, could be incorporated into the TIS framework, in some cases perhaps by replacing existing terminology. This would, nevertheless, require a deeper analysis, which is beyond the scope of the present thesis.

Another methodological contribution relates more directly to the application of the business models framework. In paper 2, the viability of different business models for PV deployment in different countries was studied. Previous literature on business models had elaborated upon how business model innovation can bring new (sustainable) technologies to the market (Bocken et al., 2014; Boons and Lüdeke-

Freund, 2013; Mont et al., 2006; Reim et al., 2015; Tukker, 2004) and upon the role of the wider sociotechnical context for shaping business models (Birkin et al., 2009; Budde Christensen et al., 2012; Casper and Kettler, 2001; Linder and Cantrell, 2000; Provance et al., 2011). The methodological uniqueness of paper 2 was that it combined the business models framework with a comparative case study approach to pinpoint contextual factors in different geographical settings. This had not previously been done for PV technology and, to the best knowledge of the authors, it had not been done for the deployment of any other technology either. The approach proved useful in understanding how different business models can overcome contextual barriers (see section 3.2.3) to technology deployment and thereby create value for adopters and firms.

Also some contributions regarding methodology to study local variations in PV adoption rates were made. For paper 3, an approach based on comparative case studies was developed to identify and assess local drivers in Swedish municipalities. A combination of a replication and a 'two tail' design (Yin, 2009) was used. Five 'main cases' (municipalities with the highest adoption rates) and 50 'comparison cases' (municipalities with the lowest adoption rates) were studied. The number of comparison cases was larger because data were scarcer for this category. The comparative element of the approach was two-fold. First, the main cases were compared to one another. Second, the two categories of cases were compared to each other. The method proved useful to pinpoint local drivers that could explain why certain municipalities have stood out in terms of high PV adoption rates. To the best knowledge of the author, there has not previously been any research on local variations in technology adoption rates using an approach including the elements described above.

Furthermore, paper 3 introduced a novel approach for dealing with differences in building stock when selecting cases for comparative case studies of geographical differences in PV adoption rates. There is often a need to take building stock into consideration when studying causal factors behind PV adoption rates, as the characteristics of the built environment (e.g. the share of detached homes) may otherwise become an important confounding variable. For paper 3, all Swedish municipalities were ranked by their PV-density using two measures: the number of PV systems *per capita* and *per detached home*. Municipalities that occurred at the top or bottom of *both* these rankings were selected. The inclusion of the latter criteria served as a control mechanism, reducing the risk of local building stock characteristics confounding the selection process (see section 3.3.2).

Lastly, for paper 4, a mixed-methods approach was developed to study peer effects in PV adoption, combining qualitative and quantitative research methods through a survey and follow-up interviews with selected respondents. Thus, a qualitative perspective that had hitherto been lacking in studies of peer effects in PV adoption was introduced. As peer effects are by nature closely related to the adopters' own thoughts and emotions, survey data arguably need to be complemented with interviews – particularly in a stage where the understanding of the effects is limited – to make sure that the survey data have been interpreted correctly and to increase the chances of identifying any important matters not identified through the survey. The method proved useful to nuance the previous understanding of peer effects in PV adoption, and continued research using this or similar approaches may be fruitful in achieving a deeper understanding of peer effects in the adoption of PV or other technologies.

4.3. Implications for policymakers, firms and others

Based on the findings of this thesis, some recommendations can be derived for policymakers, firms and other actors aiming to support PV dissemination. Below, a set of general advice will first be provided. Then, a number of more specific recommendations for reforms of existing Swedish policy will follow.

A first set of advice relates to *business models* for PV deployment (paper 2). The findings regarding the relationship between business models and their surrounding context may be useful to both policymakers and firms. Even though the research on business models was not carried out in Sweden (as was the rest of the research), the findings might prove useful to overcome barriers in Sweden and other catching-up markets.

One piece of advice for policymakers is to remove any institutional barriers that might obstruct the use of certain business models, or to provide enabling legislation for business models that have proven viable in other contexts. Preferences vary between consumer groups, and a variety of business models for prospective adopters to choose from could thus increase the overall adoption rates by satisfying the preferences of a larger number of consumers. Furthermore, a substantial number of the potential adopters will, in many contexts, find it difficult to finance and own a PV system even if a purchase would be their first choice. Any institutions hindering TPO business models may thus impose a barrier to PV deployment. This does not necessarily mean that policy has failed if all business models that have proven successful in other markets are not present in the market of interest, as it might simply be the case that the market has selected against certain business models due to differences in consumer preferences or other contextual differences that are beyond the direct control of policymakers.

When it comes to firms, the findings on business models could be informative when planning to enter new markets or targeting certain consumer segments. The findings could also guide firms in how to respond to a changing context.

A second set of advice relates to *electric utilities* (organisations operating electrical grids). Paper 3 strongly suggests that local utilities can elevate PV uptake in their area by supporting PV. Policymakers could exploit this by influencing utilities to take a supportive attitude towards residential PV. Such influence could be exercised by informing utilities about PV technology and about how other organisations have worked with PV, for instance by offering utilities' staff training as to how to best support PV deployment. A web-based platform for the provision and exchange of information directed towards utilities could be implemented (perhaps as part of a larger platform for PV information directed to a broader audience). Educating utilities might both increase the chance of them choosing to support PV deployment, and make utilities perform better in providing their customers with relevant information. In cases where a government owns a utility (Swedish utilities are, for example, often owned by local governments), the government could steer the utility towards promoting PV. Utilities could also be regulated to take a more active role in PV deployment.

Another piece of advice is to arrange *information seminars* targeting private homeowners. Such seminars could be arranged by any actor (such as utilities, non-profit organisations, local governments and installation firms) interested in supporting PV deployment. Paper 3 suggests that local information seminars have been an effective strategy to convince homeowners to adopt PV in Sweden. The effectiveness of seminars might, nevertheless, depend on context-specific factors. Two key characteristics of the Swedish PV market are that it is in an early stage of development and that there is limited economic profitability in residential PV adoption. As convincingly argued by Noll et al. (2014), there are reasons to believe that information provision has the highest prospects of being effective in markets where PV is neither very profitable nor clearly unprofitable. Awareness of PV might also be lower in early markets, in which case there is a higher need for information dissemination. The generalisability this advice might thus be more or less limited to markets that are similar to Sweden in these respects.

A last piece of advice relates to *peer effects* (papers 3 and 4). Actors with a goal to increase PV uptake could seek to make use of peer effects by involving existing PV adopters in information campaigns or marketing. This might prove a cost-effective strategy for policy and businesses even if the existing adopters are economically compensated for their involvement.

Paper 4 reveals that information obtained from peers plays a partly different and complementary role compared to other information sources, such as the advice of professionals. Peers (at least in the context studied) seem to convince each other to adopt PV by giving reassurance that adoption is indeed a sound choice, rather than through the provision of more factual information (which can be found in written sources or obtained through professional advisers). Trust is not only gained through established social relations, but also through peers being in a similar situation (as private homeowners), having actual experience as adopters, and (as opposed to firms) lacking economic incentives to portray PV in an excessively positive manner. The participation of PV adopters in information campaigns or marketing could thus be effective as a complement to other means of information provision.

There are various conceivable strategies for making use of peer effects. One suggestion is to include sessions in information seminars where visitors get the opportunity to talk to adopters, for example in Q&A sessions or group discussions. Study visits could also be organised by firms or policymakers to the premises of adopters to let attendants see their PV system and talk to them. Another option would be to have local energy advisors provide citizens with contact information to local adopters. Policymakers might even want to target certain individuals to become PV adopters if these individuals could be expected to be particularly likely to create further adoptions through peer effects. If so, the findings of paper 4 suggest that socially well-connected individuals should be targeted rather than individuals who have the most visible rooftops.

4.3.1. Reforms of existing Swedish policy

A substantial portion of the research behind this thesis relates to existing Swedish institutions, and the results thus lend themselves to some Sweden-specific policy advice. This advice does not involve increased subsidisation, but rather changes in the design of existing subsidy schemes or other advice that does not require increased public spending. The advice relates to issues that were identified in the research *and* that are still present at the time of finishing the thesis (December 2016), which includes the majority of the issues identified in the research.

Paper 1 points to several uncertainties and complexities in the Swedish policy framework that could be addressed. First, the circumstance that more than one subsidy schemes for PV deployment have been running in parallel is an unnecessary complication that creates extra administration and transaction costs for adopters, installation firms and authorities, and that makes it more difficult for (potential) adopters to estimate the economic consequences of PV adoption. At the time of writing (December 2016), three subsidy schemes are running in parallel, as the proposed tax reduction was implemented after the completion of paper 1. Second, it was – and still is – unclear for how long the different subsidy schemes will run. The total budget for PV within these schemes should thus preferably be gathered within one coherent long-term strategy with high predictability and transparency.

The most important Swedish subsidy scheme for PV deployment – the investment subsidy launched in 2009 – has been flawed with uncertainties. This issue could be addressed through some relatively straightforward reforms. First, the scheme's duration and future remuneration levels should be planned and made transparent. This could be done through the setting of certain conditions to determine the future development of the scheme. For example, it could be decided that investing in a residential PV should yield a certain economic profitability, e.g. an IRR of around 5%. Factors that influence this figure (most importantly the cost development of PV systems) should then be monitored continuously so that remuneration levels can be adapted to keep the profitability at the desired level. Once the profitability reaches the desired level without the need for subsidies, the scheme has served its purpose and should be terminated. Second, measures should be taken to mitigate the long queue of applications awaiting approval. Even though the remuneration level has been reduced to 20% since paper 1 was finished while a substantial amount of long-term funding has been added, the long queue has persisted, resulting in waiting times of up to two years as of November 2016 (Svensk Solenergi, 2016). As regards the market fluctuations caused by discontinuations in the scheme, this problem appears to have been resolved. Even if new discontinuations in the scheme would occur, the current remuneration level of only 20% in combination with reduced prices of PV systems have induced an increased share of the new adopters to purchase the system *before* their application is approved, hoping to get the subsidy retroactively. This secures a more evenly distributed demand for PV systems regardless of any discontinuations in the scheme.

Paper 1 also shows that the tradable green certificates (TGC) scheme, which has been available for PV and other renewables since 2003, has been poorly adapted to residential PV and other modes of micro-production of electricity. To adapt this scheme, the selling of small quantities of certificates could be made easier. This could be achieved for example through the provision of a user-friendly web-based trading platform, or by authorities purchasing certificates at market rates from micro-producers using an automated system (the authorities could then re-sell the certificates in bulk to other actors). Another issue is the high cost for micro-producers of acquiring certificates for self-consumed electricity, as this requires the installation of additional metering equipment. This could – if the TGC scheme is to be intended for micro-producers in the future – be solved through for example relaxed requirements on metering, certificates for self-consumption being granted on the basis of a template, or by providing PV adopters with free metering equipment. However, a burning issue is whether the TGC scheme should be intended at all for micro-production. If so, the scheme should be adapted accordingly. If not, micro-production should be formally excluded from the TGC system (any subsidisation should then be carried out by other means).

The building permit system could also be reformed. To reduce complexity, rules could be standardised between municipalities. Building permits for residential PV could also be abolished if certain criteria are fulfilled (e.g. that the panels follow the inclination of the roof). Fees could be abolished, or only be due once a permit has been approved (thus reducing uncertainty and risk for prospective adopters). Information on building permits regarding fees, requirements, administration time etc. could be provided on municipalities' websites.

As regards uncertainties regarding tax rules, it was recently (after the completion of paper 1) established that residential PV adopters are under most circumstances indeed not subject to extra taxation and related administration. Any remaining uncertainties could be mitigated by adaptation of rules in a planned, transparent manner, by clear and official statements regarding the intended direction of future reform, or by clarifying official statements regarding how existing rules should be applied.

4.4. Suggestions for further research

In this section, some possible lines of research that could be addressed subsequent to this thesis will be identified. Four potential areas of research will be discussed, one following each paper.

4.4.1. Technological innovation systems (TIS)

As argued in this thesis, there will likely be an increasing need for TIS studies focusing exclusively on the deployment phase of PV (as was done in paper 1) and other technologies. Although this thesis makes some methodological contributions in how to perform such studies (see section 4.2), further methodological development is needed. For example, methods need to be developed regarding how to set system boundaries for geography and value chain based on what phenomena interact in a systemic manner and how different phenomena relate to space. A deployment focus is also likely to have implications regarding the functional dynamics of TISs. The relative importance of different functions might change in some generalisable ways and there might be differences in which functions are important on different geographical scales. New empirical research, or re-analysis of existing TIS literature with a 'new lens', might shed light on these issues.

Conceptual work could also be done regarding how the TIS framework connects to other streams of literature. As observed in this thesis (see section 2.1), the business models framework as well as Rogers' diffusion of innovations framework both fit within the scope of the TIS framework and are useful when zooming in on certain key parts of a TIS. These, and perhaps other, frameworks could be more elaborately positioned within the TIS framework in future conceptual work.

4.4.2. Business models and their context

Paper 2 served as a first step in analysing how business models for PV deployment depend on barriers and other contextual factors in different geographical settings. The findings pointed towards a number of factors that appeared to have influenced the success of different business models in the studied markets. However, more research is needed in order to gain a deeper understanding of how and to what extent these and other factors influence the viability of different business models. As an increasing number of PV markets become mature enough to host more elaborate business models, there will be more potential cases to study. Paper 2 could also be complemented through data collection from adopters (surveys, interviews) in the studied markets or in other markets. This could shed light on adopters' motives for preferring a certain business model, and on whether any particular contextual factors influenced their preferences. Furthermore, business models for the deployment of other technologies than PV could be studied in relation to their context. This could yield valuable technology-specific as well as generalisable knowledge regarding the relationship between business models and their context.

4.4.3. Local barriers and drivers

Paper 3 was and early attempt to identify causes of locally elevated adoption rates of residential PV. There are several ways to continue this line of research. First, the adopter perspective could be further explored, e.g. through interviews with adopters in municipalities with high adoption rates. This way, a deeper understanding of factors influencing the different stages of their adoption decision process could be gained. Approaches similar to that developed for paper 3 could also be used to study other settings than the Swedish one. This could reveal to what extent the findings of paper 3 are generalisable; for example, the findings might be specific for early PV markets or for some other characteristic that Sweden shares with certain other settings. Another possibility would be to use statistical regression analyses to compare municipalities or other geographical entities with each other, using PV adoption rates as the dependent variable. This could reveal correlations not visible through case study methodology.

One finding of paper 3 was that local electric utilities supporting PV appeared to have had a substantial positive effect on adoption rates. This could be further explored in different ways. For example, it could be investigated why some utilities choose to engage in PV promotion and sales. From a purely economic perspective, promoting PV might appear as a bad decision for utilities as increased PV penetration undermines their source of revenue. Furthermore, PV sales are arguably beyond their core business. Research on incumbent companies in the offshore oil and gas sector that have diversified into wind power suggests that a key reason for this diversification has been to attract the most talented staff for use in their core business (Hansen and Steen, 2015). However, there is as yet little research on the reasons for energy incumbents to engage in renewables, and on whether and under what circumstances such engagement might be economically rational for such organisations.

Furthermore, the role (current and potential) of utilities might differ between countries. For example, utilities are typically highly regulated on the national level, which might create rather different opportunities for utilities in different countries to act beyond their core tasks (and thus to support PV). This could be researched.

Lastly, more research could be done on the role of local information in increasing PV adoption rates. The findings of paper 3 indicated that information seminars have been important in the cases studied, but little is known about what defines successful information dissemination on the local level (e.g. how an information seminar should be designed in order to spur PV adoptions). As information dissemination can be a low-cost intervention, it can (if effective) be a cost-effective way to increase PV uptake. For example, it has been argued that information dissemination has the highest potential to be effective in early markets in which PV is neither very profitable nor clearly unprofitable (Noll et al., 2014), but there is currently little empirical evidence to support this.

4.4.4. Peer effects

This thesis offers an initial attempt to understand the inner workings of peer effects in PV adoption. To build a more solid understanding of the mechanisms behind these peer effects, more qualitative empirical research is needed. Using the approach developed for paper 4 or a similar methodology combining survey and interviews appears to be a fruitful way of moving this research forward. Data could be collected from adopters, non-adopters, or potential adopters in different settings.

Depending on the exact research question and on the expected occurrence of useful information among adopters, representative or purposeful sampling could be used. For example, peer effects could often be expected to be more common in areas with high adoption rates. Thus, any given sample size could yield more useful information through purposeful sampling in such areas. As large samples are costly to manage, purposeful sampling could be beneficial in situations where a representative sample is not necessary. Future research could in those cases imitate or be inspired by the sampling strategy developed for the present thesis.

Research could also be done to find out whether and how the characteristics of peer effects vary between different contexts, such as between early and more mature markets. For example, as early adopters are generally more cosmopolite than later adopters (Rogers, 1983), peer effects might be less localised in early markets (as was the case in the studied Swedish early market).

The findings of this thesis raise some doubt as to the role of passive peer effects in PV adoption. In previous literature, these have often been assumed to be an important part of the 'total' peer effects. The importance of the passive component could be assessed by investigating the impact of PV systems' visibility. If, for example, rooftop PV systems facing roads generate substantially larger increases in local adoption rates than PV systems facing backyards, this could indicate a large passive component.

Lastly, the possibilities of utilising peer effects in campaigns could be explored. Is, for example, information provision (e.g. seminars) more effective when adopters are involved? How should they be engaged to make the highest impact: should they give lectures, be available for Q&A sessions, or take part in conversation groups? (As anecdotal evidence, small conversation groups among seminar participants were described as a very important influential factor by one of the interviewees.) Would it be cost-effective to pay them to participate? Are organised study visits to PV adopters' premises a viable strategy? Such alternatives could be investigated, for example through experiments.

5. Conclusions

This thesis identifies and assesses various barriers and drivers to the deployment of residential PV systems in different geographical contexts. Using a sociotechnical systems approach, the thesis demonstrates how the *technological innovation systems* TIS framework can be amended by the *business models* and the *diffusion of innovations* frameworks to study the deployment of a mature technology (in this case PV) in a catching-up market, treating the development and production of the technology as a 'black box'. On the national level, the analysis shows that the Swedish sociotechnical system for residential PV deployment has been immature and infested by various institutional barriers. Most notably, the Swedish subsidy schemes for PV deployment have been flawed with uncertainties and complexities, and there have been important uncertainties regarding the future development of the Swedish institutional set-up. The results also demonstrate how barriers in different national contexts have affected what kinds of business models for PV deployment that have been viable. On the local level, the results demonstrate how actors such as local electric utilities and private individuals have influenced homeowners to adopt PV through information dissemination and social influence (peer effects). The findings can inform policymakers, firms and other actors as to how to better support PV deployment.

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