AHRI Standard 140-2023 (I-P) with Erratum 1

Evaluation of Air-conditioning and Heating Equipment Test Stands

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ERRATUM SHEET FOR
AHRI STANDARD 140-2023 (I-P)

EVALUATION OF AIR-CONDITIONING AND HEATING EQUIPMENT TEST STANDS

November 2024

Erratum 1 of AHRI Standard 140-2023 (I-P) is provided as follows. Erratum deletions are shown with ~~strikethroughs~~ and erratum additions are shown by shading in gray in the already published 2023 version of AHRI Standard 140 to prevent confusion.

1. Revision to Section C3.2.5., Data Analysis, on page 18.

C3.2.5. *Data Analysis*. Calculate the following for Tests 1 and 2.

C3.2.5.1. Difference Between Average Entering Air Temperatures and Average Leaving Air Temperatures shall be compared as shown in Equation 2.

$$\Delta T_{average} = T_{1_{average}} - T_{2_{average}} \quad \textbf{2}$$

Where:

T_1 = Entering dry bulb or wet bulb temperature

T_2 = Leaving dry bulb or wet bulb temperature ~~**2**~~

2. Revision to Section C3.3.5., Data Analysis, on page 19.

C3.2.5. *Data Analysis*. Each test (1, 2, or 3) will produce a flow rate measurement for each nozzle combination (A and B) that shall be compared as shown in Equation 3.

C3.2.5.1. Difference Between Average Entering Air Temperatures and Average Leaving Air Temperatures shall be compared as shown in Equation 2.

$$\Delta Q_n = \left[\frac{Q_A - Q_B}{\frac{Q_A + Q_B}{2}}\right]_n \cdot 100 \quad \textbf{3}$$

Where:

ΔQ_n = Deviation in average air flow rate between nozzle combination A and nozzle combination B in percent.

~~combination B in percent.~~

Q_A = Measured air flow rate from nozzle combination A.

Q_B = Measured air flow rate from nozzle combination B.

n = Test points 1, 2, or 3 as defined in Table 7.

A, B = Nozzle combinations as defined in Table 7.

3. Revisions to Section C3.7.3.1., Test Points, on page 24.

C3.7.3.1. *Test Points*. The UUT shall be tested, at the ~~two conditions~~ condition, shown in Table 10.

4. Revisions to Table 10 on page 25.

Table 10 Latent Heat Measurement Test[1]

~~Test Condition~~	~~Test Stand Operational Condition~~	~~UUT Blower Speed~~	~~Test Condition~~
~~1~~	~~Mean of Minimum and Maximum total capacity ± 25%~~	~~Lowest setting at test condition.~~	~~Full-load cooling standard rating condition *reference rating standard*~~
~~Notes:~~ ~~1. The test shall be run over three (3) consecutive minimum 10-minute periods.~~			

Table 10 Latent Heat Measurement Test

Test Condition	Test Stand Operational Condition	UUT Blower Speed	Test Condition
1	Mean of minimum and maximum total capacity ± 25%	Lowest setting at test condition.	Full-load cooling standard rating condition Reference Rating Standard
Note: • The test shall be run over three consecutive minimum ten-minute periods.			

IMPORTANT

SAFETY DISCLAIMER

AHRI does not set safety standards and does not certify or guarantee the safety of any products, components or systems designed, tested, rated, installed or operated in accordance with this standard/guideline. It is strongly recommended that products be designed, constructed, assembled, installed, and operated in accordance with nationally recognized safety standards and code requirements appropriate for products covered by this standard/guideline.

AHRI uses its best efforts to develop standards/guidelines employing state-of-the-art and accepted industry practices. AHRI does not certify or guarantee that any tests conducted under its standards/guidelines will be non-hazardous or free from risk.

ICS Codes: 17.060, 17.080, 17.100, and 17.120

Note:

This is a new standard; a prior version does not exist.

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Intent

This standard is intended for the guidance of the industry, including manufacturers, engineers, installers, efficiency regulators, contractors, and users.

Review and Amendment

This standard is subject to review and amendment as technology advances.

2023 Edition

This edition of AHRI Standard 140-2023 (I-P), *Evaluation of Air-conditioning and Heating Equipment Test Stands*, was prepared by the Unitary Small Equipment Standards Technical Committee. The standard was published by the Unitary Standards Subcommittee on 12 June 2023.

Origin and Development of AHRI 140-2023 (I-P)

This is the initial publication of AHRI Standard 140-2023 (I-P), *Evaluation of Air-conditioning and Heating Equipment Test Stands*. AHRI Standard 140-2023 (I-P) was developed to:

Build on work done with Laboratory Evaluation and Adjustment Plan

Help improve certification programs that utilize witness testing

Support AHRI's certification services

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Unitary Small Equipment Standards Technical Committee Scope:

The Unitary Small Equipment (USE) Standards Technical Committee is responsible for the development and maintenance of AHRI standards and guidelines pertaining to Unitary Air-conditioning and Air-source Heat Pump

Equipment, Mini-Split (1:1) Air-conditioning and Heat Pump Equipment, and Demand Response through Variable Capacity HVAC Systems in Residential and Small Commercial Applications.

The following product types are out of scope for this STC: Packaged Terminal AC/HP, Commercial or Industrial AC/HP, Furnaces, Variable Refrigerant Systems (VRF), Geothermal and Water Source HP, Single Package Vertical Unit (SPVU), and Performance Rating of Zoning products.

For product definitions, refer to AHRI's website.

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The scope of the Unitary Standards Subcommittee is standards and guidelines related to the end products that are part of the AHRI Unitary Industry Sector. (The definition of and list of products associated with each sector are found on AHRI's website.)

These lists represent the membership at the time the Standards Technical Committee and Standards Subcommittee were balloted on the final text of this edition. Since that time, changes in the membership may have occurred. Membership on these committees shall not in and of itself constitute an endorsement by the committee members or their employers of any document developed by the committee on which the member serves.

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EVALUATION OF AIR-CONDITIONING AND HEATING EQUIPMENT TEST STANDS

Section 1. Purpose

1.1 *Purpose*. The purpose of this standard is to establish for Test Stands: definitions; test requirements; rating requirements; minimum data requirements for Published Ratings; nomenclature; and conformance conditions.

Section 2. Scope

2.1 *Scope*. This standard applies to Test Stands used for performance testing for the following equipment types:

1) Unitary Air-conditioning and Air-source Heat Pump Equipment within the scope of AHRI Standard 210/240.
2) Commercial and Industrial Unitary Air-conditioning and Heat Pump Equipment within the scope of AHRI Standard 340/360.
3) Computer and Data Processing Room Air Conditioners within the scope of AHRI Standard 1360.
4) Variable Refrigerant Flow (VRF) Multi-split Air-conditioning and Heat Pump Equipment within the scope of AHRI Standard 1230.
5) Single Package Vertical Air-conditioners and Heat Pumps within the scope of AHRI Standard 390.
6) Packaged Terminal Air-conditioners and Heat Pumps within the scope of AHRI Standard 310/380.

2.2 *Exclusions.* Qualification procedures for water-cooled and evaporatively cooled equipment are not covered by this standard.

Section 3. Definitions

All terms in this document follow the standard industry definitions in the ASHRAE Terminology website unless otherwise defined in this section.

3.1 *Airflow Measurement Apparatus*. A device for determining the volume rate of air passing through the UUT. Commonly referred to as "code tester" within the industry.

3.2 *Air Side Capacity Measurement System*. The equipment used to determine UUT capacity including inlet psychrometric air properties, outlet psychrometric air properties, and the Air Flow Measurement Apparatus.

3.3 *Baseline Test*. A test conducted in accordance with a Reference Rating Standard on a Correlation Sample at a Reference Test Stand.

3.4 *Correlation Sample*. A sample with documented performance data from a Reference Test Stand

3.5 *Cyclic Test*. A test where all or part of the system is turned on and off in a cycle.

3.6 *Drain Trap*. A plumbing drain fixture designed to retain a small amount of the draining water to seal the pipe and prevent any gases from flowing through the pipe.

3.7 *Electric Heat Box*. Test apparatus used to supply a known quantity of heat to the air stream.

3.8 *Error*. The difference between the true value of the quantity measured or calculated and the observed value. All errors in experimental data can be classified as one of two types: systematic (fixed) errors or random (precision) errors. The terms accuracy and precision are often used to distinguish between systematic and random errors.

3.8.1 *Fixed Error*. See Systemic Error

3.8.2 *Random Error*. An error that causes readings to take random values on either side of a mean value. The random error is quantified based on how well an instrument can reproduce subsequent readings for an unchanging input. Random errors cannot be corrected through calibration.

3.8.3 *Systematic Error*. An error that persists and cannot be deemed as due entirely to chance. Systematic error can be corrected through calibration

3.9 *External Static Pressure Drop Verification*. The percent difference between the exact coil only ASHRAE duct configuration baseline pressure and the corresponding test measured value from either conventional or alternative psychometric testing configuration divided by the corresponding test measured value from either conventional or alternative psychometric testing configuration.

3.10 *Heat Balance*

3.10.1 *Latent Heat Balance*. The percent difference between the latent heat calculated from the measured condensate flow rate and the measured psychrometric latent capacity, q_{lci}.

3.10.2 *Sensible Heat Balance*. The percent difference between the measured psychrometric sensible heat and measured electric heat added to the system.

3.11 *Indoor Blower*. The fan used to move air through the indoor side of the UUT.

3.12 *Laboratory*. The facility that houses the Test Stand(s).

3.13 *Leakage Rate*. The volume of air entering or leaving the Test Stand between the UUT outlet connection and the Nozzle Plate location.

3.14 *Measured Airflow Difference*. The deviation between two different Air Flow Measurement Apparatus nozzle size combination readings at the same airflow in CFM.

3.15 *Nozzle Chamber*. Apparatus containing the air flow measurement nozzles. Part of the Airflow Measurement Apparatus.

3.16 *Nozzle Plate*. A plate designed to seal the cross-sectional area of a duct with nozzles attached to allow air to pass through. Part of the Nozzle Chamber.

3.17 *Passive Pressure Drop Device*. A custom-built assembly, constructed without internal insulation, sealed to prevent any external or internal air leakage, and sized to provide a designated external static pressure over a range of airflow as shown in Appendix C.

3.18 *Qualified Facility*. A test laboratory that meets all of the requirements of the AHRI Standard 140.

3.19 *Reference Rating Standard*. The standard used to rate the UUT.

3.20 *Reference Test Stand*. A Test Stand that has been proven through data collection to provide baseline measurements.

3.21 *"Shall" or “shall not” and” should” or "should not”*

3.21.1 *“Shall” or “shall not”*. Indicate mandatory requirements to strictly conform to the standard and where deviation is not permitted.

3.21.2 *"Should" or "should not"*. Express recommendations rather than requirements. In the negative form, a recommendation is the expression that a suggested possible choice or course of action is not preferred but not prohibited.

3.22 *Test Stand*. Facility constructed for the purpose of testing or developing ratings in accordance with a Reference Rating Standard.

3.22.1 *Indoor Room*. A portion of the facility used to maintain a controlled environment for the indoor test rating conditions in accordance with the Reference Rating Standard.

3.22.2 *Outdoor Room*. A portion of the facility used to maintain a controlled environment for the outdoor test rating conditions in accordance with the Reference Rating Standard.

3.23 *Test Type*. A specific test within this standard to verify a particular function of the Test Stand. Test Types are listed in Section 4.

3.24 *Uncertainty*. An estimated value for the error in a measurement or calculation, that can be the result of both Systematic and Random Error.

3.25 *Unit Under Test (UUT)*. The Correlation Sample used to validate the Test Stand. Each UUT is rated in accordance with a Reference Rating Standard.

3.26 *Validation*. The process of evaluating if a system accomplishes its purpose or intent.

3.27 *Verification*. The process of determining if a Test Stand is built according to specifications provided in a design, drawing, statement of work, or other document.

Section 4. Test Requirements

4.1 *Test Requirements*. All testing shall be conducted in accordance with the test methods and procedures as described in this standard and its appendices. Each Test Stand is tested in accordance with the Reference Rating Standard. Refer to Table 1 below for Test Types required per Reference Rating Standard. If the Test Stand is not able to meet these criteria, adjustments shall be made to resolve the issue.

Table 1. Test Requirements per Rating Standard

AHRI 140 Test Procedure	AHRI Reference Rating Standard					
	210/240	**340/360**	**1360**	**1230**	**390**	**310/380**
Air Flow Measurement Apparatus Leakage	■	■	■	■	■	■
Zero Load	■	■		■	■	■
Air Flow Measurement Apparatus	■	■	■	■	■	■
Sensible Heat Measurement	■	■	■	■	■	■
Mixing Efficiency	■	■	■	■	■	■
Latent Heat Measurement	■	■	■	■	■	■
External Static Pressure Measurement	■	■	■	■	■	■
Thermal Energy Storage Effect for CD Testing	■	-	-	-	-	-
Full System Psychrometric Round Robin Testing[1]	■	■	■	■	■	■

Note:

1. If only one test facility exists, correlate between multiple indoor rooms. Run a complete set of tests with Room A and Room B. Then repeat the tests by swapping units between Room A and Room B. As an alternative, if only one room exists completely disassemble and reassemble the setup at a different date. This will show repeatability.

4.1.1 *Data Acquisition*. All test data shall be recorded in accordance with Appendix D.

4.1.2 *Instrumentation Calibration*. All measurement equipment should be calibrated in accordance with Appendix E.

4.1.3 *Uncertainty Analysis*. An Uncertainty analysis shall be completed. An example is shown in Appendix F.

Section 5. Evaluation Requirements

5.1 *Qualification Requirements*. Each Test Stand shall be qualified as defined in Section 5 within the tolerances shown in Table 2

5.2 *Table 2.*

5.2.1 *Reference Rating Standard*. Each Test Stand shall be qualified in accordance with at least one Reference Rating Standard. Where more than one Reference Rating Standard applies, each Test Stand shall be qualified separately for each Reference Rating Standard.

5.2.2 *Validation Checks*. Each Test Stand shall be qualified using the validation checks defined in this Section.

Ratings related to airflow measurement are provided for a specific Airflow Measurement Apparatus.

5.2.2.1 *Air Flow Measurement Apparatus Leakage*. Test Stand air flow leakage shall be verified for a given Nozzle Chamber and ductwork configuration by measuring Leakage Rates at the following locations within the measurement apparatus system:

1) Nozzle Plate
2) Airflow Measurement Apparatus, including all permanent ductwork components from Nozzle Plate to UUT connection point.

Leakage Rates at each location are established at the target static pressure setpoints

5.2.2.2 *Zero Load*. Test Stand instrument induced error shall be verified for a given Nozzle Chamber across a range of airflow by the following:

1) Sensible Error
2) Latent Error
3) Pressure Transducer Zero Error

These deviations are established by comparing the total sensible and latent heat input of the UUT to the sensible and latent heat measured at a zero-load condition.

5.2.2.3 *Air Flow Measurement Apparatus Verification*. Test Stand air flow measurement shall be verified for a given Nozzle Chamber across a range of its nozzle configurations. Airflow measurements are verified by comparing two different Air Flow Measurement Apparatus nozzle size combinations at the same pressure drop using the Passive Pressure Drop Device.

5.2.2.4 *Sensible Heat Measurement*. Test Stand sensible heat measurements shall be verified for a given Capacity Measurement System by confirming Sensible Heat Balance.

Sensible Heat Balance is verified by comparing the total sensible heat input of the UUT to the sensible heat measured at Minimum Airflow, Mean of Minimum and Maximum Airflow, and Maximum Airflow.

5.2.2.5 *Mixing Efficiency*. Test Stand Mixing Efficiency shall be verified by comparing the difference between the maximum and minimum recorded temperatures on the outlet temperature grid with the difference between the average outlet and average inlet temperatures.

5.2.2.6 *Instrument Induced Humidity Ratio Verification*. Instrument induced humidity ratio verification is the measure of accuracy of the latent measurement equipment during sensible heat measurement tests where no latent change is expected.

5.2.2.7 *Latent Heat Measurement*. Test Stand latent heat measurement shall be verified for a given Capacity Measurement System by confirming the Latent Heat Balance.

Latent Heat Balance is verified by comparing the latent heat calculated from measured air properties against the latent heat calculated from measured condensate draining from the indoor coil of the system.

5.2.2.8 *External Static Pressure Measurement*. Test Stand external static pressure measurement shall be verified by comparing ANSI/ASHRAE Standard 37 duct configurations to ANSI/ASHRAE Standard 116 duct configurations.

5.2.2.9 *Thermal Energy Storage Effect for CD Rating*. Test Stand thermal energy storage effect shall be determined for CD testing by cycling the heater in the Electric Heater Box. The result shall be used in accordance with Section 9.2 of ANSI/ASHRAE Standard 116.

5.2.2.10 *Full System Psychrometric Round Robin Testing*. Test Stand overall measurement accuracy shall be verified by correlation testing with one or more Reference Test Stands

5.2.2.11 *Large Unitary Sensible Heat Measurement*. Sensible heat measurement specific to Large Unitary devices.

5.2.3 *Test Stand Limits of Operation*. Test Stand minimum and maximum operational limits, as defined in Table 3, shall be established at the standard rating conditions specified by the Reference Rating Standard.

5.2.4 *Uncertainty of Measurement*. Uncertainty for all measurements (such as capacity, power, efficiency, pressure drop) shall be calculated.

Table 2. Qualification Tolerance Limits per Reference Rating Standard

Symbol	Description	Tolerance	Reference Paragraph
Airflow Measurement Apparatus Leakage			
B4	Test 1: Nozzle Plate Leakage	Final before nozzle pressure ≥ -0.1 in H_2O	C3.1.5
Q_2	Test 2: Overall System Leakage Rate	< 1.0% of the minimum airflow rate or 5 CFM whichever is greater	C3.1.5
Q_3	Test 3: Overall System Leakage Rate	>Q_2	C3.1.5
Q_4	Test 4: Overall System Leakage Rate	< Q_2	C3.1.5
Airflow Measurement			
ΔQ_n	Measured Airflow Difference	1.0%	C3.3.5
Zero Load			
ΔT_{ave}	Inlet/Outlet Air Temperature Difference	Greater of ± 0.03ºF or Calibrated Accuracy of Measurement Device	C3.2
ΔP_{Nozzle}	Nozzle Delta Pressure	0 ± 0.01 in. wg	C3.2
P_0	Test 3: External Static Pressure	0.01 in. wg	C3.2
Sensible Heat Measurement Rating			
B_{SH_n}	Sensible Heat Balance	± 2.0%	C3.4.5.1
Mixing Efficiency			
η_{mixing}	Mixing Efficiency	0 – 0.1	C3.5.2
Instrument Induced Humidity Ratio			
ΔW	Instrument Induced Humidity Ratio	± 0.0002	C3.6.2.3
Latent Heat Measurement Rating			
B_{LH}	Latent Heat Balance	5.0%	C3.7.5
External Static Pressure Measurement Rating			
B_{ST}	External Static Pressure Drop Verification	5.0% or 0.01 in wg whichever is greater	C3.8.5.1
Thermal Energy Storage Effect for CD Rating			
$mc_{pm}(\mu)$	Cyclic Capacity of the Dry Coil	4.0 Btu/°F	C3.9.5.3
Full System Psychrometric Round Robin Rating			
Δq_{sci}	Sensible Capacity Difference	2.0%	C3.10.4.1
Δq_{lci}	Latent Capacity Difference	2.0%	C3.10.4.2
ΔE_i	Indoor Power Difference	1.0%	C3.10.4.3
ΔE_t	Total Power Difference	1.0%	C3.10.4.3
Uncertainty of Measurement			
-	Minimum Cooling Capacity	5%	-
-	Minimum Heating Capacity	5%	-

Symbol	Description	Tolerance	Reference Paragraph
-	Minimum Power	3%	-
-	Maximum Cooling Capacity	3%	-
-	Maximum Heating Capacity	3%	-
-	Maximum Power	3%	-

Section 6. Minimum Data Requirements for Qualified Facilities

6.1 *Minimum Data Requirements for Qualified Facilities*. Table 3 provides minimum data requirements to publish Test Stand qualification.

All claims to qualification within the scope of this standard shall include the statement “Qualified in accordance with AHRI Standard 140 for performance testing in accordance with [Reference Rating Standard].”, where “[Reference Rating Standard]” shall be replaced by the Reference Rating Standard used to rate the Test Stand in the following format of [Publisher] [Number]-[Publication Year] [(units)] (for example: AHRI 210/240-2017 (I-P).

All claims to qualifications outside the scope of the standard shall include the statement “Outside the scope of AHRI Standard ####.”

Table 3. Facility Specifications

Specification	Unit of Measure	AHRI Reference Rating Standard	
		210/240	340/360, 1360, 1230, 390, 310/380
General			
Size – Maximum Available for UUT	-	-	-
Indoor Room (height, width, length)	ft	■	■
Outdoor Room (height, width, length)	ft	■	■
Outdoor Ambient Design Conditions	-	-	-
Dry Bulb Temperature	°F	■	■
Wet Bulb Temperature	°F	■	■
Fluids Available for Testing	-	■	■
Refrigerants Available for Testing	-	■	■
Electrical Connection(s) Available	-	-	-
Maximum Single-Phase Power	kW	■	■
Maximum Three Phase Power	kW	■	■
Volts	**V**	■	■
Phase	-	■	■
Frequency	Hz	■	■
Off Mode Power Capable	Y/N	■	■

Specification	Unit of Measure	AHRI Reference Rating Standard	
		210/240	340/360, 1360, 1230, 390, 310/380
Indoor Room	-	-	-
Air Flow Range	cfm	■	■
UUT Static Pressure at Air Flow	in H2O	■	■
Dry Bulb Temperature Range	°F	■	■
Nominal Cooling Capacity Range	btu/h	■	■
Nominal Heating Capacity Range	btu/h	■	■
Max Humidification Rate	lbs/hr	■	■
Max Dehumidification Rate	lbs/hr	■	■
Outdoor Room	-	-	-
Air Flow Range[1]	cfm	■	■
UUT Static Pressure at Air Flow	in H2O	■	■
Dry Bulb Temperature Range	°F	■	■
Nominal Cooling Capacity Range	btu/h	■	■
Nominal Heating Capacity Range	btu/h	■	■
Max Humidification Rate	Lbs/hr	■	■
Max Dehumidification Rate	Lbs/hr	■	■
Heat Pump Capable	Y/N	■	■
Cyclic Testing			
Indoor Room	-	-	-
Air Flow	cfm	■	-
Fluid Flow	gpm	■	-
Nominal Cooling Capacity	btu/hr	■	-
Nominal Heating Capacity	btu/hr	■	-
UUT Pressure at Fluid Flow	Ft H2O	■	-
Outdoor Room	-	-	-
Air Flow	cfm	■	-
Fluid Flow	gpm	■	-
Nominal Cooling Capacity	btu/hr	■	-
Nominal Heating Capacity	btu/hr	■	-
UUT Pressure at Fluid Flow	Ft H2O	■	-
Uncertainty of Measurement (Confidence Interval of 95%)			
Net Cooling Capacity	btu/h	■	■
Net Heating Capacity	btu/h	■	■
Power	kW	■	■

Notes:

1. If available.

Section 7. Conformance Conditions

7.1 *Conformance*. While conformance with this standard is voluntary, conformance shall not be claimed or implied for Test Stands within the standard's Purpose (Section 1) and Scope (Section 2) unless such claims meet all of the requirements of the standard and all of the testing and qualification requirements are measured and reported in complete compliance with the standard. Any Test Stand that has not met all the requirements of the standard cannot reference, state, or acknowledge the standard in any written, oral, or electronic communication.

APPENDIX A. REFERENCES – NORMATIVE

A1. Listed here are all standards, handbooks, and other publications essential to the formation and implementation of the standards. All references in this appendix are considered as part of the standard.

A1.1. AHRI Standard 210/240-2017 (with Addendum 1), *Unitary Air-Conditioning and Air-Source Heat Pump Equipment*, 2019, Air Conditioning, Heating and Refrigeration Institute, 2311 Wilson Boulevard, Suite 400, Arlington, VA 22201, U.S.A.

A1.2. AHRI 310/380-2017, *Packaged Terminal Air-Conditioners and Heat Pumps*, 2017, Air Conditioning, Heating and Refrigeration Institute, 2311 Wilson Boulevard, Suite 400, Arlington, VA 22201, U.S.A.

A1.3. AHRI 340/360-2019, *Performance Rating of Commercial and Industrial Unitary Air-conditioning and Heat Pump Equipment*, 2019, Air Conditioning, Heating and Refrigeration Institute, 2311 Wilson Boulevard, Suite 400, Arlington, VA 22201, U.S.A.

A1.4. AHRI 390-2021 (I-P), *Single Package Vertical Air-Conditioners and Heat Pumps*, 2021, Air Conditioning, Heating and Refrigeration Institute, 2311 Wilson Boulevard, Suite 400, Arlington, VA 22201, U.S.A.

A1.5. AHRI 1230-2021 (I-P), *Variable Refrigerant Flow (VRF) Multi-split Air-conditioning and Heat Pump Equipment*, 2021, Air Conditioning, Heating and Refrigeration Institute, 2311 Wilson Boulevard, Suite 400, Arlington, VA 22201, U.S.A.

A1.6. AHRI 1360-2017, *Computer and Data Processing Room Air Conditioners*, 2017, Air Conditioning, Heating and Refrigeration Institute, 2311 Wilson Boulevard, Suite 400, Arlington, VA 22201, U.S.A.

A1.7. ANSI/ASHRAE Standard 37, 2009 *Methods of Testing for Rating Electrically Driven Unitary Air-Conditioning and Heat Pump Equipment*, 2009, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. 1791 Tullie Circle NE, Atlanta, GA 30329, U.S.A.

A1.8. ANSI/ASHRAE Standard 116, 2010 *Methods of Testing for Rating Seasonal Efficiency of Unitary Air Conditioners and Heat Pumps*, 2010, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. 1791 Tullie Circle NE, Atlanta, GA 30329, U.S.A.

A1.9. ASHRAE Terminology. ASHRAE. Accessed November 18, 2021. https://www.ashrae.org/technical-resources/free-resources/ashrae-terminology.

APPENDIX B. REFERENCES – INFORMATIVE

B1. Listed here are standards, handbooks and other publications which may provide useful information and background but are not considered essential. References in this appendix are not considered part of the standard.

B1.1. ASHRAE Handbook – Fundamentals: 2017, ASHRAE,. 180 Technology Parkway NW, Peachtree Corners, GA 30092, U.S.A.

B1.2. ASME PTC 19.1-2013, *Test Uncertainty*, The American Society of Mechanical Engineers, Two Park Avenue, New York, NY 10016, USA

APPENDIX C. METHOD OF TESTING AIR-CONDITIONING, HEATING, OR REFRIGERATION UNIT TEST STANDS – NORMATIVE

C1. *Purpose*. This appendix prescribes a method of testing for Test Stands.

C2. *Devices for Verification*.

C2.1. *Passive Pressure Drop Device*. Construct the assembly as detailed in Table 4 based on the Test Stand minimum and maximum airflow. A graphical representation of a Passive Pressure Drop Device is shown in Figure 1.

C2.2. *Design of Restriction Plate*. The restriction plate can be made with several different hole combinations. Holes can be covered during testing to achieve required pressure drop.

Table 4. Passive Pressure Drop Device – Informative

Item	**Specification per Airflow (CFM) Range**			
	≥ 200 and ≤ 2,500	**≥ 1,000 and ≤ 5,000**	**≥ 2,500 and ≤ 10,000**	**>8000 and <30,000**
Cross Sectional Area[1]	2.5 ft^2	5 ft^2	10 ft^2	30 ft^2
Length	≥ 4.74 ft	≥ 6.71 ft	≥ 9.49 ft	≥16.43 ft
Position of restriction plate[2,3]	Centered on length	Centered on length	Centered on length	Centered on length
Position of pressure measurement locations	8 total, evenly spaced along length and centered in cross sectional dimension	8 total, evenly spaced along length and centered in cross sectional dimension	8 total, evenly spaced along length and centered in cross sectional dimension	8 total, evenly spaced along length and centered in cross sectional dimension

Notes:

1. Sized to allow only air velocity ≤ 1000 feet per minute through the open assembly.
2. More than one passive restriction plate may be required to meet pressure drop requirements.
3. Restriction shall be kept consistent throughout the testing.

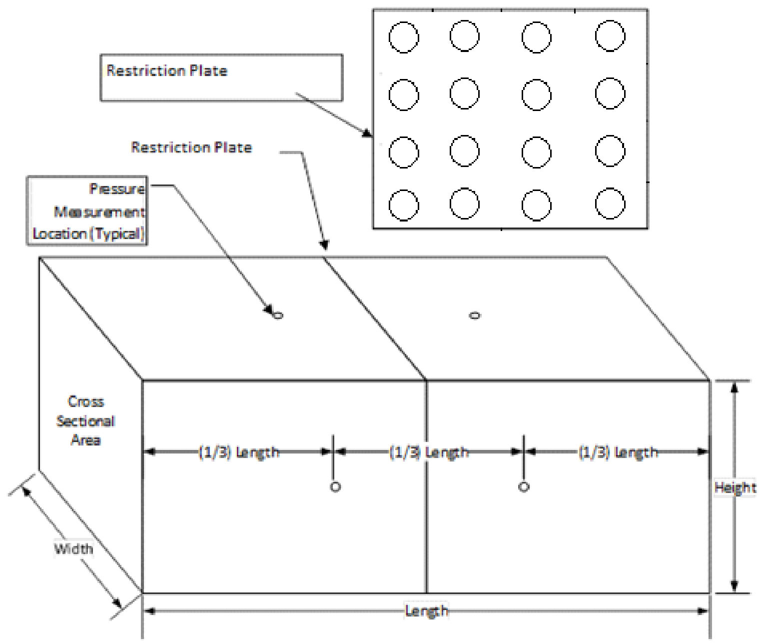

Figure 1. Passive Pressure Drop Device

C2.3. *Electric Heat Box*. Shall be constructed with low thermal mass wire wound heater elements split into two sections side by side. Each heater element shall have the capacity to provide a minimum 10°F increase in air temperature at maximum Test Stand airflow. Heater shall be positioned in duct in such a way as be out of the line of sight of any sensors. See Figure 2. The Electric Heat Box shall have all joints and seams taped or sealed (internally and externally as required) for all tests to eliminate air from leaking past the heater.

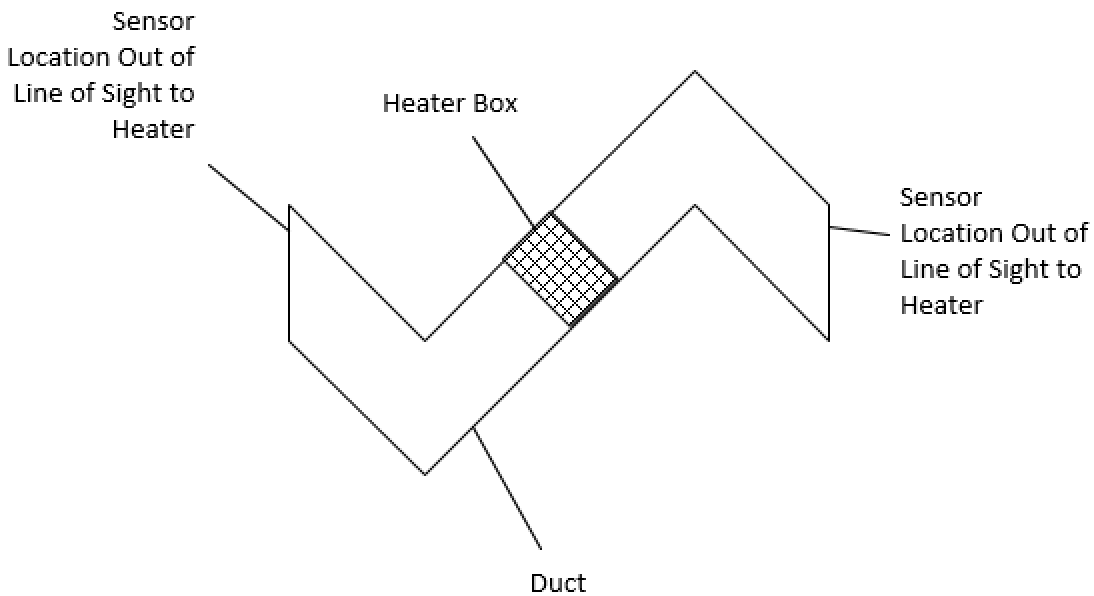

Figure 2. Example of Heater Box in Duct

C3. *Test Requirements*. All Test Stand tests shall be conducted in accordance with the Reference Rating Standard.

C3.1. *Air Flow Measurement Apparatus Leakage*.

C3.1.1. *Selection of Equipment*. The permanently installed Nozzle Chamber and associated UUT connection ductwork and outlet sampling section shall be used to conduct the test.

C3.1.2. *Setup*. Specified leakage nozzle shall be sized to measure 1%- 2% of the minimum air flow.

C3.1.3. *Procedure*.

C3.1.3.1. *Nozzle Plate Leakage*.

- Cap all nozzles
- Cap end of duct at UUT connection
- Slowly run blower up to the target static pressure setpoint as described in Table 5 – minimum 90 seconds duration
- Measure and record the target static pressure setpoint pressure and before nozzle pressure at intervals no greater than 10 seconds as the blower is ramped up.
- Hold blower speed at the target static pressure setpoint pressure and record setpoint pressure and before nozzle pressure at intervals no greater than 10 seconds for an additional 90 seconds minimum.
- Final before nozzle pressure shall be less than the value specified in Table 2.

C3.1.3.2. *Overall System Leakage.*

- Cap nozzles except for specified leakage nozzle
- Cap end of duct at UUT connection

- Use nozzle, or insert a nozzle plug with a leakage nozzle to allow the CFM to be measured. See Figure 3.
- If inlet side of the nozzles is not accessible, a cap with a leakage nozzle can be used. See Figure 4
- Slowly run blower up to the target static pressure setpoint per Table 5 – minimum 90 seconds duration
- Measure and record the target static pressure setpoint pressure and the leakage airflow at intervals of no greater than 10 seconds.
- For an additional 90 seconds, measure flow rate through small nozzle.
- Overall system leakage as measured using the small nozzle shall be less than value specified in Table 2.

Table 5. Air Flow Measurement Apparatus Leakage Evaluation[2]

Test	Target Static Pressure Setpoint	Measurement	Measurement Location
1	- 4.0 in H_20 in the Nozzle Chamber after the Nozzle Plate	Nozzle Plate leakage	Before Nozzle Plate
2	- 1.0 in H_20 in the Nozzle Chamber before the Nozzle Plate	Overall system leakage[1]	Leakage Nozzle Delta P
3	- 2.0 in H_20 in the Nozzle Chamber before the Nozzle Plate	Overall system leakage[1]	Leakage Nozzle Delta P
4	- 0.5 in H_20 in the Nozzle Chamber before the Nozzle Plate	Overall system leakage[1]	Leakage Nozzle Delta P

Notes:

1. Tests performed at the different prescribed pressure drops should show different Leakage Rates if the system is setup correctly.
2. Leakage in any one of the tests will influence the others. Any leakage remediation requires a retest of all.

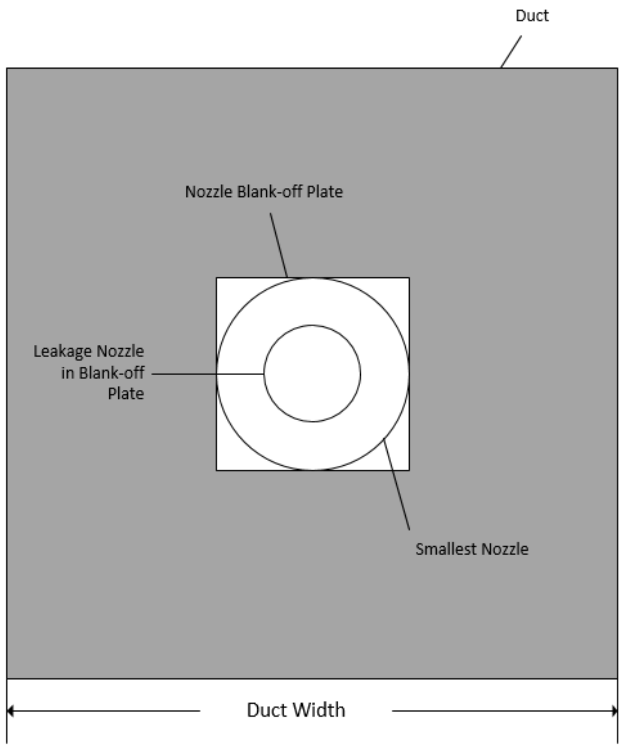

Figure 3. Blank-off Plate with Nozzle Plug

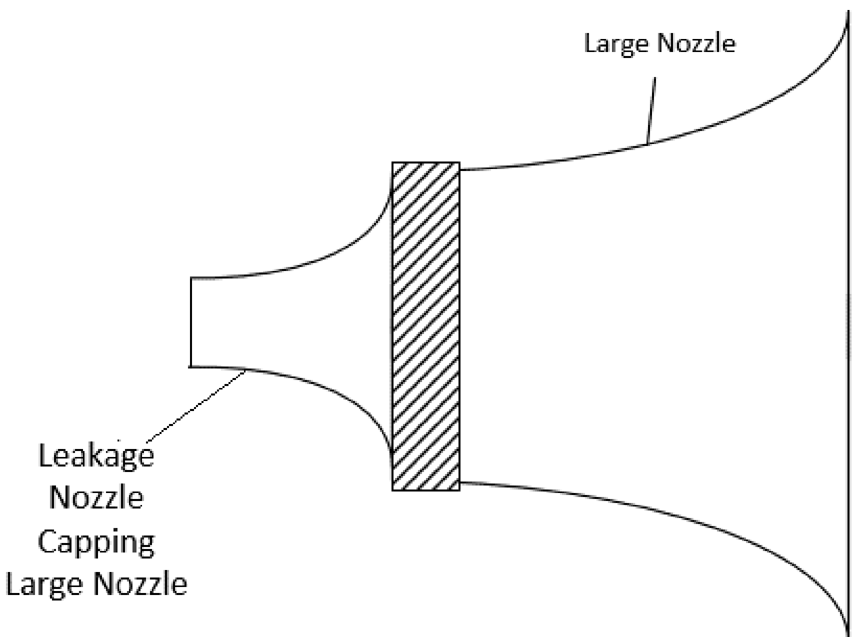

Figure 4. Nozzle with Leakage Nozzle Cap

C3.1.4. *Recorded Data*. Before nozzle, nozzle delta P, and airflow data shall be recorded for this Test Type.

C3.1.5. *Data Analysis*. Overall system leakage shall be compared to the Test Stand Minimum Air Flow as shown in Equation 1.

$$Q_{lmax} = Q_{min} \cdot 0.01 \quad (1)$$

Where:

Q_{min} = Test stand minimum airflow rate.
Q_{lmax} = Maximum allowed leakage
Q_n = Measured leakage airflow
n = Test points 2, 3, or 4 as defined in Table 5.

C3.2. *Zero Load*.

C3.2.1. *Selection of Equipment*.

C3.2.1.1. The UUT and Electric Heater Box, or both are not required for this test. However, if UUT and Electric Heater Box, or both are installed, these shall be turned off and the UUT drain pan shall be dry.

C3.2.2. *Setup*.

C3.2.2.1. *Temperatures*. Average inlet and outlet dry bulb and wet bulb temperatures shall be measured.

C3.2.3. *Procedure*. Only nozzle combinations approved through the Air Flow Measurement Apparatus Verification shall be used in this test.

C3.2.3.1. *Indoor Room Air*. Inlet conditions shall be those specified by the Reference Rating Standard for the full-load cooling standard rating condition.

C3.2.3.2. *Test Type*. The Electric Heat Box power supply shall not be energized.

C3.2.3.3. *Test Conditions*. The Test System shall be operated at the following conditions shown in Table 6.

Table 6. Zero Load Test Points[1]

Test Condition	Test Type	Target Airflow Setpoint[2]	Electric Heat Box Setpoint[3]
1	Zero Load	Zero Airflow[4]	OFF
2	Zero Load	Test Stand Maximum	OFF
3	Zero Load	Test Stand Minimum	OFF

Notes:
1. Each test shall be run over a minimum 5-minute period.
2. For each test, the Target Airflow shall be selected based on the Minimum and Maximum airflow range.
   a. Minimum target is (Test Stand Minimum up to 1.1 * Test Stand Minimum)
   b. Maximum target is (Test Stand Maximum down to 0.9 * Test Stand Maximum)
3. If the Electric Heat Box is installed, it shall be turned off. For the duration of the test, the entering and leaving Electric Heat Box temperatures shall be equal within 0.03 °F or the calibrated sensor accuracy whichever is greater.
4. For zero load, zero airflow condition, verify the nozzle delta pressure, before nozzle pressure, external static pressure, are all zero ± 0.01 H_2O.

C3.2.4. *Recorded Data*. Inlet and outlet dry bulb and wet bulb temperatures, airflow, nozzle delta pressure, before nozzle pressure, and external static pressure.

C3.2.5. *Data Analysis*. Calculate the following for Tests 1 and 2.

C3.2.5.1. Difference Between Average Entering Air Temperatures and Average Leaving Air Temperatures shall be compared as shown in Equation 2.

$$\Delta T_{average} = T_{1_{average}} - T_{2_{average}} \qquad 2$$

Where:

T_1 = Entering dry bulb or wet bulb temperature

T_2 = Leaving dry bulb or wet bulb temperature ~~2~~

C3.3. *Air Flow Measurement Apparatus Verification*.

C3.3.1. *Selection of Equipment*. A Passive Pressure Drop Device shall be used to conduct the test.

C3.3.2. *Set up.* Passive Pressure Drop Device shall be setup in the Test Stand as if it were a UUT.

C3.3.3. *Procedure*.

C3.3.3.1. *Indoor Room Air*. Inlet conditions shall be those specified by the Reference Rating Standard for the full-load cooling standard rating condition.

C3.3.3.2. *Test Points*. The Passive Pressure Drop Device shall be tested, at the six (6) conditions, show in in Table 7, using the smallest and largest nozzle combination at each target airflow and static pressure setpoint. Each test shall be run over a minimum 5-minute period.

Table 7. Air Flow Measurement Apparatus Test Points

Test	Target Airflow Setpoint	Target Static Pressure Setpoint[4]	Nozzle Combination[3]
1	Test Stand Minimum ± 10%	UUT Static Pressure Drop at Minimum Air Flow	A[1]
			B[2]
2	Test Stand Maximum ± 10%	UUT Static Pressure Drop at Maximum Air Flow	A
			B[2]
3	Mean of Test Stand Minimum and Maximum ± 10%	The UUT Static Pressure Drop at Mean Airflow	A[1]
			B

Notes:

1. A = Smallest available nozzle combination at the rated airflow.
2. B = Largest available nozzle combination at the rated airflow.
3. Additional combinations may be required to confirm all nozzles have been verified.
4. UUT static pressure drop through the Passive Pressure Drop Devices shall be within 0.2 to 3.6 in H_2O.

C3.3.4. *Recorded Data.* Pressure drop across the Passive Pressure Drop Device, inlet dry bulb temperature, inlet humidity, inlet barometric pressure, air flow, nozzle delta pressure, and the nozzle combination.

C3.3.5. *Data Analysis*. Each test (1, 2, or 3) will produce a flow rate measurement for each nozzle combination (A and B) that shall be compared as shown in Equation 3.

$$\Delta Q_n = \left[\frac{Q_A - Q_B}{\frac{Q_A + Q_B}{2}}\right]_n \cdot 100 \qquad \textbf{3}$$

Where:

ΔQ_n = Deviation in average air flow rate between nozzle combination A and nozzle combination B in percent.
~~combination B in percent.~~
Q_A = Measured air flow rate from nozzle combination A.
Q_B = Measured air flow rate from nozzle combination B.
n = Test points 1, 2, or 3 as defined in Table 7.
A, B = Nozzle combinations as defined in Table 7.

C3.4. *Sensible Heat Measurement*.

C3.4.1. *Selection of Equipment*. The UUT and Electric Heat Box can be installed for this test.

C3.4.2. *Setup*. Setup shall match Zero Load testing.

C3.4.3. *Procedure*. Only combinations approved through the Air Flow Measurement Apparatus Verification shall be used in this test.

C3.4.3.1. *Indoor Room Air*. Inlet conditions shall be maintained at 70ºF dry bulb ± 0.5ºF and 60ºF wet bulb ± 0.3ºF.

C3.4.3.2. *Electric Heat Box Air Temperature*. Over the tested airflow rates, the voltage to the Electric Heat Box shall be maintained in order to maintain a stable differential temperature across the Electric Heat Box between 10ºF and 20ºF.

C3.4.3.3. *Sensible Heat Test*.

C3.4.3.3.1. During this test, the UUT blower shall not be energized, and the Electric Heat Box shall be energized. The heater shall be powered to a level that maintains the capacity to meet the requirements of C3.4.3.2.

There shall be a minimum of nine grid thermocouples.

The temperature measured by each of the grid thermocouples shall meet the requirements of Equation 4.

$$T = T_{Average} \pm 0.75°F \quad \textbf{4}$$

C3.4.3.4. *Test Conditions*. The UUT and Electric Heat Box shall be operated, at the three (3) conditions shown in Table 8.

Table 8. Sensible Heat Measurement Test Points[1,2]

Test Condition	Test Type	Target Airflow Setpoint[3,5]	Electric Heat Box Setpoint[3]
1	Sensible Heat Test	Test Stand Minimum	BOTH SIDES ON
2		Mean of Test Stand Minimum and Maximum	BOTH SIDES ON
3		Test Stand Maximum[4]	BOTH SIDES ON

Notes:

1. Each test shall be run over a minimum 10-minute period.
2. Data scan rate shall no greater than 30 seconds.
3. For each test, the Target Airflow shall be selected based on the Test Stand Minimum and Maximum airflow range.
    a. Minimum target is (Test Stand Minimum up to 1.1 * Test Stand Minimum)
    b. Maximum target is (Test Stand Maximum down to 0.9 * Test Stand Maximum)
    c. Mean target is ((Test Stand Maximum – Test Minimum) / 2) +/- 10%
4. Electric Heat Box power supply shall have a maximum deviation of 100 W per 1000 SCFM measured.
5. The average airflow deviation shall be less than 1.0% or 5 SCFM of target value whichever is greater.

C3.4.4. *Recorded Data*. Electric Heater Power, entering dry bulb temperature, leaving dry bulb temperature, entering wet bulb temperature, leaving wet bulb temperature, total capacity, sensible capacity, latent capacity, and airflow.

C3.4.5. *Data Analysis*. Calculate the following for all tests.

C3.4.5.1. *Sensible Heat Balance*, B_{SH}. Calculate using Equation 5 and Equation 6.

$$B_{SH_n} = \left[\frac{q_{sri} - q_{thi}}{q_{sri}}\right]_n \cdot 100 \qquad (5)$$

Where:
n = Test condition.

q_{thi} = Sensible heat as calculated in ASHRAE Standard 37 (7.3.4.1)

$$q_{sri} = E_h \cdot 3.412 \qquad (6)$$

Where:
E_h = Electric heat

C3.5. *Mixing Efficiency*

C3.5.1. *Selection of Equipment*. The Electric Heat Box shall be constructed in such a way as to allow one half of the flow to be heated, forcing a temperature differential to be created side to side. See Figure 5.

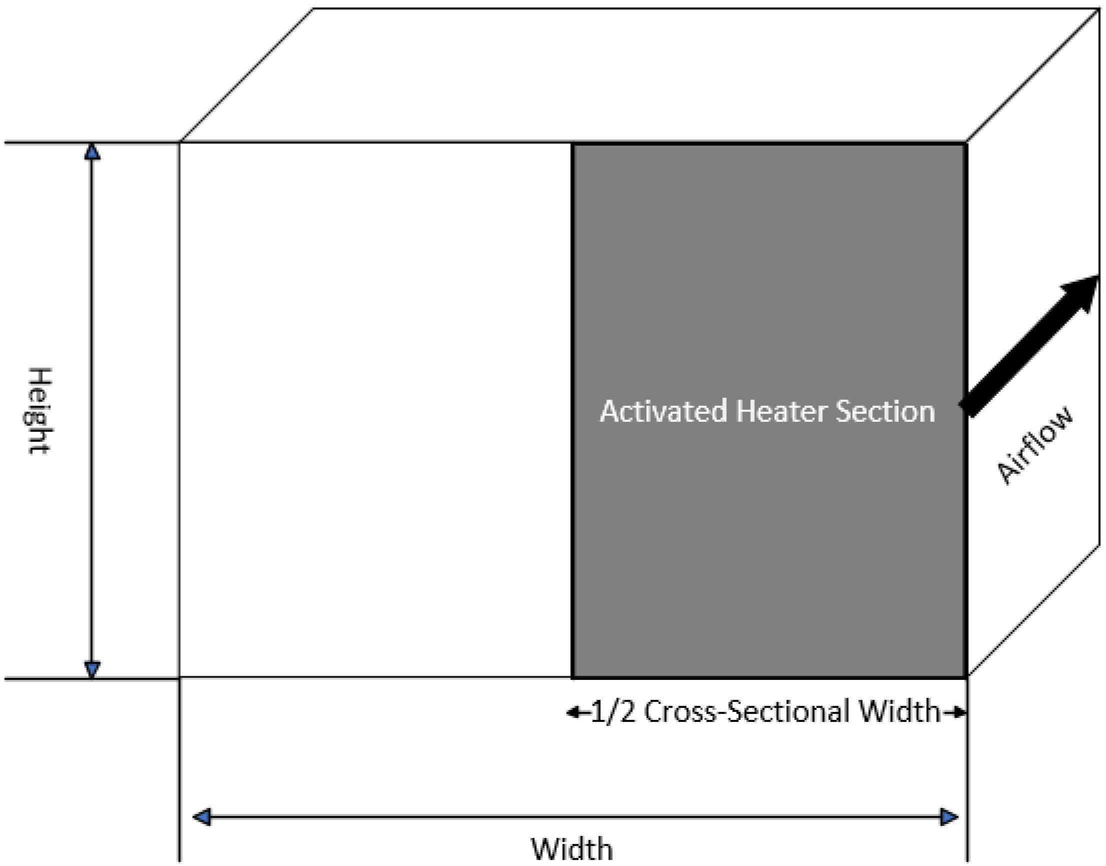

Figure 5. Heater Section

C3.5.2. *Setup*.

C3.5.2.1. *Methodology*. A temperature measurement grid consisting of nine thermocouples evenly spaced across the cross-sectional area of the flow and each producing individual temperature measurements shall be placed at the inlet and outlet of the Electric Heat Box.

C3.5.2.2. *Creation of Inlet Temperature Gradient*. At the rated min, max and mid airflow of the Airflow Measurement Apparatus , the electric heater shall be turned on to create an inlet temperature gradient. The mean temperature rise from the inlet to the outlet shall be between 10ºF and 20ºF. Each test shall be done three times. Once with the entire heater turned on, once with the left side of the heater turned on, and once with the right side of the heater turned on. See Table 9.

Table 9. Mixing Efficiency Test Points[1]

Test Condition	**Test Type**	**Target Airflow Setpoint[2]**	**Electric Heat Box Setpoint[3]**
1	Mixing Efficiency Heat Test	Rated Minimum	Both Sides ON
2			Left Side ON
3			Right Side ON
4		Mean of Rated Minimum and Maximum	Both Sides ON
5			Left Side ON
6			Right Side ON
7		Rated Maximum[4]	Both Sides ON
8			Left Side ON
9			Right Side ON

Notes:

1. Each test shall be run over a minimum 10-minute period.
2. For each test, the Target Airflow shall be selected based on the rated Minimum and Maximum airflow range.
   a. Minimum target is (Rated Minimum up to 1.1 * Rated Minimum)
   b. Maximum target is (Rated Maximum down to 0.9 * Rated Maximum)
   c. Mean target is ((Rated Maximum – Rated Minimum) / 2) +/- 10%
3. Electric Heat Box power supply shall have a maximum deviation of 100 W per 1000 SCFM measured.
4. Maximum airflow may be limited by the heating limit or airflow capacity of the electric heater rather than the rated maximum airflow of the test unit.

C3.5.1. *Recorded Data*. Electric Heater Power, inlet thermocouple grid, outlet thermocouple grid, entering dry bulb temperature, leaving dry bulb temperature, entering wet bulb temperature, leaving wet bulb temperature, total capacity, sensible capacity, latent capacity, and airflow.

C3.5.2. *Calculation of Mixing Efficiency*. For each mixing test, calculate the efficiency as shown in Equation 7. Verify the mixing efficiency is between 0 and 0.1.

$$\eta_{mixing} = \frac{\Delta T_{outlet}}{T_{outlet} - T_{inlet}} \quad (7)$$

Where:

$\Delta T_{outlet} = Max\ T - Min\ T$
$Max\ T = Average\ Temperature\ of\ the\ Highest\ Temperature\ TC\ on\ the\ Outlet\ Grid$
$Min\ T = Average\ Temperature\ of\ the\ Lowest\ Temperature\ TC\ on\ the\ Outlet\ Grid$
$T_{outlet} = Average\ Outlet\ Grid\ Temperature$
$T_{inlet} = Average\ Inlet\ Grid\ Temperature$

C3.6. *Instrument Induced Humidity Ratio Verification*.

C3.6.1. *Selection of Equipment*. The UUT and Electric Heat Box can be installed for this test.

C3.6.2. *Setup*.

C3.6.2.1. *Methodology*. Using the sensible heat test set up to verify the accuracy of the latent measurement equipment at a zero latent load condition.

C3.6.2.2. *Calculation of Humidity Ratio*. For each sensible heat capacity test, the inlet and outlet humidity ratio shall be calculated.

C3.6.2.3. *Calculation of Humidity Ratio Deviation*. For each sensible heat capacity test, calculate the deviation as shown in Equation 8. Verify the result is between ± 0.0002.

$$[\Delta \boldsymbol{W}]_{\boldsymbol{n}} = \boldsymbol{W}_{\boldsymbol{out}} - \boldsymbol{W}_{\boldsymbol{in}} \quad \textbf{8}$$

Where:

W_{out} = Outlet humidity ratio
W_{in} = Inlet humidity ratio
n = Test condition.

Informative Note: At an inlet condition of 70ºF and outlet condition of 82ºF and 1000 SCFM airflow at 1 atmosphere, a difference at either limit of the tolerance indicates a wet bulb error of 0.19ºF.

C3.7. *Latent Heat Measurement*.

C3.7.1. *Selection of Equipment*. The cooling system of UUT(s) used to conduct the Sensible Heat Measurement Test at the Test Stand shall be selected to operate at 80ºF dry bulb/67ºF wet bulb.

C3.7.2. *Setup*.

C3.7.2.1. *Methodology*. During cooling mode tests, the latent capacity shall be determined from measurements of the condensate flow rate.

C3.7.2.2. *Condensate Measurement*. The required setup is to connect tubing between the condensate drain on the indoor coil and a secondary reservoir. A Drain Trap shall be used in the tubing between the outlet of the condensate pan and the secondary reservoir. The secondary reservoir shall be placed upon a scale capable of measuring weight to the nearest 0.01 lb or shall be a container capable of measuring volume to the nearest 0.2 oz.

C3.7.3. *Procedure*. Only setups approved through the Air Flow Measurement Apparatus Verification shall be used in this test.

C3.7.3.1. *Test Points*. The UUT shall be tested, at the ~~two conditions~~ condition, shown in Table 10.

C3.7.3.2. *Condensate Mass Flow Rate*. The condensate mass flow rate draining off of the indoor coil shall be measured for three consecutive periods for each test.

C3.7.3.2.1. *Measurement*. At a minimum, measure the weight or volume at the beginning and at the end of each individual test (± 10 seconds). Calculate the difference and divide it by the total time to obtain the condensate mass flow rate in lbs/hr.

C3.7.3.2.2. *Stability Criteria*. Single test condensate mass flow rate shall be with ± 6% of the mean of all three consecutive periods for each test.

Table 10. Latent Heat Measurement Test

Test Condition	Test Stand Operational Condition	UUT Blower Speed	Test Condition
1	Mean of Minimum and Maximum total capacity ± 25%	Lowest setting at test condition.	Full-load cooling standard rating condition Reference Rating Standard
Note: • The test shall be run over three consecutive minimum ten-minute periods.			

C3.7.4. *Recorded Data*. Entering and leaving dry bulb and wet bulb temperatures, air flow rate, and condensate flow rate shall be recorded.

C3.7.5. *Data Analysis*.

C3.7.5.1. *Latent Heat Balance*. Calculate the Latent Heat Balance based on the measured condensate flow rate, w_c and measured latent capacity, q_{lci} using Equation 9:

$$B_{LH_n} = \left[\frac{q_{lcc} - q_{lci}}{q_{lcc}}\right]_n \cdot 100 \qquad \textbf{9}$$

Where:

n = Test condition.

$q_{lcc} = 1061 \cdot w_c$

C3.8. *External Static Pressure Measurement*.

C3.8.1. *Selection of Equipment*. A Passive Pressure Drop Device shall be used to conduct the test in accordance with Section C2.1.

C3.8.2. *Setup*. Passive Pressure Drop Device shall be setup in the Test Stand as if it were a UUT in the following duct configurations:

C3.8.2.1. *Exact ASHRAE Duct Configuration Baseline Test*. The Passive Pressure Drop Device shall be set up with an entering (coil only) and leaving duct with the dimensions outlined in Figure 6 as described in ANSI/ASHRAE 37 - 2005. The entering duct shall have free flow of air and shall not be on top of an Inlet Duct System employed for Cyclic Testing.

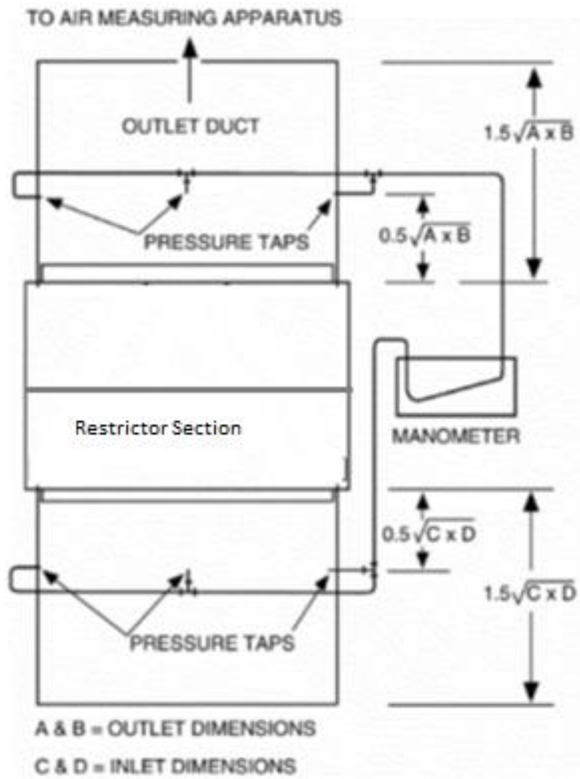

Figure 6. Exact ASHRAE Duct Configuration

C3.8.2.2. *Actual Psychrometric Testing Configuration*. This testing shall utilize the Inlet Duct System and methods such as pressure skirt with four manifolded pressure taps on top of the damper and entering ASHRAE duct. that the Laboratory Facility utilizes for measuring inlet air pressure, temperature, and humidity to the Passive Pressure Drop Device. The outlet duct between the upper damper and the outlet of the Passive Pressure Drop Device shall be whatever conventional configuration that will be utilized by the test facility for certification testing. Any alternate configuration the Test Stand employs to measure these systems shall be tested to validate against the setup in Section C3.8.2.1.

C3.8.3. *Procedure*. Only combinations approved through the Air Flow Measurement Apparatus Verification shall be used in this test.

C3.8.3.1. *Indoor Room Air*. Inlet conditions shall be those specified by the Reference Rating Standard for the full-load cooling standard rating condition.

C3.8.3.2. *Test Points*. The Passive Pressure Drop Device shall be tested at the six conditions shown in Table 11. The three additional points specified in Test 3 shall be run if needed to qualify the Alternative Psychrometric Testing Configuration.

Table 11. External Static Pressure Measurement Test Points[1]

Test	Duct Configuration	Target Airflow Setpoint[2,3]
1	Exact Coil Only ASHRAE Duct Configuration Baseline Test	Rated Minimum
		Mean of Rated Minimum and Maximum
		Rated Maximum
2	Actual Psychrometric Testing Configuration	Rated Minimum
		Mean of Rated Minimum and Maximum
		Rated Maximum
3	Alternative Psychrometric Testing Configuration (Optional)	Rated Minimum
		Mean of Rated Minimum and Maximum
		Rated Maximum

Notes:

1. Each test shall be run over a minimum 10-minute period.
2. For each test, the Target Airflow shall be selected based on the rated Minimum and Maximum airflow range.
    a. Minimum target is (Rated Minimum up to 1.1 * Rated Minimum)
    b. Maximum target is (Rated Maximum down to 0.9 * Rated Maximum)
    c. Mean target is ((Rated Maximum – Rated Minimum) / 2) ± 10%
3. Record pressure drop across the pressure box for all tests.

C3.8.4. *Recorded Data*. Air flow rate and static pressure drop shall be recorded.

C3.8.5. *Data Analysis*.

C3.8.5.1. *External Static Pressure Drop Verification*. For each test in Table 11, B_{ST_n} shall be calculated using Equation 10:

$$B_{ST} = \left[\frac{\Delta Pst_E - \Delta Pst_M}{\Delta Pst_M}\right]_n \cdot 100 \qquad \textbf{10}$$

Where:

$\Delta P_{st_E} =$ Exact Coil Only ASHRAE Duct Configuration Baseline Test

$\Delta P_{st_M} =$ Equivalent Test measured value from either Conventional or Alternative Psychometric Testing Configuration

C3.9. *Thermal Energy Storage Effect for C_D*.

C3.9.1. *Selection of Equipment*. The UUT and Electric Heat Box shall match those used in the Sensible Heat Measurement testing (Section C3.4).

C3.9.2. *Setup*. Test setup shall match the requirements of Section C3.4 testing with the following additional requirements.

C3.9.2.1. *Large Thermal Mass Temperature*. At least three thermocouples shall be attached through solder method (per ANSI/ASHRAE Standard 41.1 Section 7.2.10) or mechanically to each potential large thermal mass between the outlet of the Electric Heat Box and the grid of thermocouples specified in Section C2.2.2.1. Individual thermocouples shall be averaged, or thermocouples shall be connected in parallel. Thermocouples shall be mounted on the downstream side of the thermal mass and insulated. The thermocouples must be out of line of sight of Electric Heat Box.

C3.9.3. *Procedure*.

C3.9.3.1. *Indoor Blower Off*. The Indoor Blower motor shall be left unpowered.

C3.9.3.2. *Indoor Room Air*. Inlet conditions shall be 70ºF dry bulb.

C3.9.3.3. *Large Thermal Mass Temperature*. The mean thermocouple temperature of the largest thermal mass in the test facility shall be recorded for the duration of the ten-minute ON time of each Cycle Test.

C3.9.3.4. *Test Types.*

C3.9.3.4.1. *Radiant Heat Affect*. To confirm that the leaving thermocouple grid is not affected by the radiant heat coming from the heater element, conduct a ten-minute test comparing the leaving thermocouple grid and the outlet RTD. If the thermocouple grid is greater than the RTD by more than 0.75ºF, then shield the thermocouple grid to prevent radiant heat affect.

C3.9.3.4.2. *Cyclic*. During the test the Electric Heat Box is cycled a minimum of four on and off cycles as defined in Table 12.

Table 12. Thermal Energy Storage Effect for C_D

Test Condition	Test Type	Target Airflow Setpoint[2]	Electric Heat Box Setpoint[3]
1	Radiant Heat Affect[1]	Rated Minimum	ON[4]
2	Cyclic	Rated Minimum	ON/OFF[5]
3		Mean of Rated Minimum and Maximum	
4		Rated Maximum	

Notes:

1. Test shall be run over a minimum 10-minute period.
2. For each test, the Target Airflow shall be selected based on the rated Minimum and Maximum airflow range.
    a. Minimum target is (Rated Minimum up to 1.1 * Rated Minimum)
    b. Maximum target is (Rated Maximum down to 0.9 * Rated Maximum)
    c. Mean target is ((Rated Maximum – Rated Minimum) / 2) ± 10%
3. Electric Heat Box power supply shall be maintained to ± 0.1kW per 1000 SCFM measured.
4. Maintain a differential temperature between 10ºF and 20ºF across the Electric Heat Box.
5. Electric Heat Box shall be cycled ON for 10 minutes (± 2 seconds) then OFF for 10 minutes (± 2 seconds). Four (4) ON/OFF cycles shall constitute a complete test. Total watts for all cycles shall not vary by more than 10 watts from the average of tests 2, 3, and 4.

C3.9.4. *Recorded Data*. The entering and leaving air dry bulb temperatures, air flow rate, the electric heater power, and the thermal mass thermocouple temperatures.

C3.9.5. *Data Analysis*. This test is measuring $q_{cyc,h}$, $q_{cyc,hoff}$, and q_{ts} to determine the mc_{pm} term.

C3.9.5.1. *Cyclic Thermal Storage Capacity Correction (q_{ts})*. The test is performed with the Electric Heat Box as the source of capacity that is assumed to be instantly ON, therefore, the OFF cycle integrated capacity ($q_{cyc,hoff}$) is the measure of heat storage in the thermal mass as shown in Equation 11.

$$q_{ts} = q_{cyc,hoff} \quad \mathbf{11}$$

C3.9.5.2. *Thermal Storage Potential (Γ_m)*. The integrated change in temperature of the thermal mass (thermal storage potential), for the duration of each ON cycle shall be calculated as shown in Equation 12.

$$\Gamma_m = \int_{\theta_1}^{\theta_2} [t_m(\theta)] d\theta \quad \mathbf{12}$$

Where:

$\theta_{1,2}$ = Test time from the start (θ_1) to the stop (θ_2) of each ON cycle

Integrated change in temperature (thermal storage potential) for the ON portion of each of the last three cycles shall not vary by more than 0.3°F using the average of the last three cycles.

C3.9.5.3. Record the integrated cyclic single or multiple thermocouple average temperature, representative of the bulk temperature of the largest thermal mass of the test equipment.

C3.9.5.4. Determine mc_{pm} for each cycle as shown in Equation 13.

$$mc_{pm} = q_{cyc,hoff} / [t_m(0) - t_m(\Theta_I)] \quad \mathbf{13}$$

Report the mean of mcpm for all cycles, use last three cycles for calculation of Equation 14.

$$mcpm(\mu) = \sum mcpm / 3 \quad \mathbf{14}$$

If $mc_{pm}(\mu) \leq 4.0$ Btu/°F, no adjustments to cyclic data is required.

If $mc_{pm}(\mu) > 4.0$ Btu/°F, thermocouples shall remain on the device with the greatest thermal energy storage effect and adjustment made to all Cyclic Test Stand tests as per the following.

C3.9.5.4.1. *Cooling—Cyclic*. Equation 15, Equation 16, Equation 17, Equation 18, Equation 19, Equation 20, Equation 21, and Equation 22 shall be used to determine the cyclic cooling capacity for a dry coil:

$$q'_{cyc} = 60 Q_{mi} c_{pa} \Gamma / [v'_n (1 + W_n)] \quad \mathbf{15}$$

Where Q_{mi}, c_{pa}, v_n', *and* W_a shall be determined from a steady-state test at the same ambient conditions as for the Cyclic Test.

$$\Gamma = \int_0^{\Theta_t} [t_{a1}(\theta) - t_{a2}(\theta)]\, d\theta \qquad \textbf{16}$$

Where Θ_t is the length of the integration time within a cycle as defined in specific test procedures such as AHRI Standard 210/240.

To correct q'_{cyc} for thermal storage effects the following equations shall be used:

$$q_{cyc} = q'_{cyc} + q_{ts} \qquad \textbf{17}$$

$$q_{ts} = mc_{pm}[t_m(0) - t_m(\Theta_t)] \qquad \textbf{18}$$

where $t_m(0)$ is the temperature of the thermal storage device at the beginning of the cycle ON period and $t_m(\Theta_t)$ is the temperature at the end of time Θ_I.

For units without an indoor fan, q_{cyc} shall have a fan correction. The fan correction shall be for a period for Θ_I, whose definition source is indicated above. The fan-corrected q_{cyc} shall be the correct capacity value to be used with the Cyclic Test.

The cyclic energy-efficiency ratio shall be determined by $EER_{cyc} = q_{cyc}/E_{cyc}$, where E_{cyc} is the total electric energy used during a test cycle consisting of one compressor ON period and one compressor OFF period. The electrical energy used by the indoor fan shall be measured for the integration time Θ_t as defined in specific test procedures. For units without indoor fans, a fan correction must be made to the electrical energy used as defined in specific test procedures.

The cooling load factor shall be determined by Equation 21.

$$CLF = q_{cyc}/(\dot{q}_{tci} \cdot \Theta_{cyc}) \qquad \textbf{19}$$

Where:

$\dot{q}_{tci}$ = the total dry-coil cooling capacity from a steady-state dry-coil test.

The degradation coefficient for cooling cyclic operation shall be determined by

EER_{ss} = energy-efficiency ratio from a steady-state dry-coil test. **20**

C3.9.5.4.2. *Heating, Steady-State*. The total heating capacity based on indoor-side data shall be calculated as showing in Equation 23

$$\dot{q}_{thi} = 60 Q_{mi} c_{pa} (t_{a2} - t_{a1}) / [v'_n (1 + W_n)] \quad \textbf{21}$$

The steady-state coefficient of performance shall be determined by

$$COP_{ss} = \dot{q}_{thi} / (3.413 \dot{E}_t) \quad \textbf{22}$$

These relationships shall be used for the low-temperature test and the high-temperature test or tests in the case of two-speed, two-compressor, or variable-speed units. For units without an indoor fan, both the capacity and power shall be corrected as defined in specific test procedures.

Informative Note: During the heat on cycle, the thermal mass, the mixer, will take on heat. This heat is not measured by the thermocouple grid causing a higher C_D. During the no-heat cycle, the thermal mass will give off heat. This procedure is used to create an estimate of this effect.

C3.10. *Full System Psychrometric Round Robin Test*.

C3.10.1. *Selection of Equipment*. In order to qualify the Test Stand for both cooling and heating, a UUT that operates in cooling and heating shall be selected within the scope of the Reference Rating Standard and within the cooling and heating capacity limitations of the Test Stand.

Informative Note: Each lab should select a unit that best meets that lab's individual needs. Selecting a single unit and testing it in multiple rooms will provide the most useful data for trend analysis and correlation between rooms, but little information about the lab's operating range. Selecting different units of different capacities can provide useful data across the lab's operating range, but little data for trend analysis or correlation.

C3.10.2. *Setup*.

C3.10.2.1. *Test System Preparation/Charge*. The UUT shall be charged using the same method and to the same amount within the tolerances defined in the Reference Rating Standard in compliance with the manufacturer's installation instructions requirements and the system state points defined below, whichever is more stringent.

5 psig for any high-side pressure

2 psig for any low-side pressure

1°F superheat at charging location (for piston expansion systems)

1°F subcooling at charging location (for expansion valve systems)

C3.10.2.2. *Secondary Capacity Check Type*. For Split Systems, the refrigerant enthalpy method as outlined in ANSI/ASHRAE Standard 37 Section 7.5 shall be used for the secondary Heat Balance.

For Single Package Units, the outdoor air enthalpy method as outlined in ANSI/ASHRAE Standard 37 Section 7.3 shall be used for the secondary Heat Balance.

If outdoor air enthalpy will be utilized for a split system, then outdoor air enthalpy method equipment shall be verified simultaneously.

C3.10.3. *Procedure*. Only nozzle combinations approved through the Air Flow Measurement Apparatus Verification shall be used in this test.

C3.10.3.1. *Cyclic Testing*. When required, Cyclic Testing shall be conducted using the same time delays as used during the Baseline Test and shall use the mc_{pm} determined in Section C3.7.

C3.10.3.2. *Test Types*. Conduct required tests based on the Correlation Sample type and Reference Standard selected.

C3.10.4. *Data Analysis*. Each Test Type will produce a sensible capacity, latent capacity, and power measurement.

C3.10.4.1. *Sensible Capacity Difference*. Sensible capacity shall be compared using Equation 23.

$$\Delta q_{sci} = \frac{\bar{q}_{sci} - q_{sci}}{\frac{\bar{q}_{sci} + q_{sci}}{2}} \cdot 100 \qquad \textbf{23}$$

Where:

$\bar{q}_{sci}$ = Average sensible capacity of all round robin test results of the same UUT at the same test condition.
q_{sci} = sensible capacity

C3.10.4.2. *Latent Capacity Difference*. Latent capacity shall be compared using Equation 24.

$$\Delta q_{ici} = \frac{\bar{q}_{lci} - q_{lci}}{\frac{\bar{q}_{lci} + q_{lci}}{2}} \cdot 100 \qquad \textbf{24}$$

Where:

$\bar{q}_{lci}$ = Average latent capacity of all round robin test results of the same UUT at the same test condition.

q_{lci} = latent capacity

C3.10.4.3. *Power Difference*. Measured power shall be compared using Equation 25.

$$\Delta E_i = \frac{\bar{E}_i - E_i}{\frac{\bar{E}_i + E_i}{2}} \cdot 100 \qquad \textbf{25}$$

Where:

$\bar{E}_i$ = Average power of all round robin test results of the same UUT at the same test condition.
E_i = power

C3.11. *Alternative Sensible Heat Measurement*.

C3.11.1. *Selection of Equipment*. The UUT and Electric Heat Box shall match those used in the Zero Load testing. This alternative sensible heat measurement shall be used when evaluating systems greater than 5 tons and the Electric Heat Box cannot meet full capacity range. A cooling sample shall be used simultaneously with the Electric Heat Box to allow the air flow to be cooled and then partially reheated to measure sensible heat accuracy. The Heat Box shall be able to provide heating of at least 10% of the cooling capacity of the cooling sample. An ASHRAE duct shall not be required to perform this test.

C3.11.2. *Setup*. Setup shall match the Zero Load Test with the addition of the cooling sample and the ability to measure power supplied to the Electric Heat Box separately from the power supplied to the cooling sample.

C3.11.3. *Procedure.* Only nozzle combinations approved through the Air Flow Measurement Apparatus Verification shall be used in this test.

C3.11.3.1. *Indoor Room Air*. Inlet conditions shall be those specified by the Reference Rating Standard for the full-load heating standard rating condition.

C3.11.3.2. *Electric Heat Box Air Temperature*. Over the tested airflow rates, the voltage to the Electric Heat Box shall be controlled in order to maintain a stable power output from the Electric Heat Box.

C3.11.3.3. *Test Types*.

C3.11.3.3.1. *Cooling Full Load*. During this test, the sample cooling unit shall be run at its low, medium and high-speed settings with the Electric Heat Box 100% on and 100% off. See Table 13.

C3.11.3.3.2. *Mixing Efficiency*. During this test, the cooling sample shall be run at its rated minimum airflow with the cooling turned off and the Electric Heater turned 100% ON with the Left Side Only, the Right Side only, and the entire heater.

Any of the nine grid thermocouples shall conform to the uniform flow tolerance calculated by equation 26:

$$T = T_{avg} \pm 0.75°F \tag{26}$$

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C3.11.4. *Test Conditions*. The UUT and Electric Heat Box shall be operated, at the nine conditions shown in Table 13

Table 13 Sensible Heat Measurement Test Points[1]

Test Condition	Test Type	Target Airflow Setpoint[2]	Electric Heat Box Setpoint[3,4]
1	Cooling Full Load	Cooling Sample Low Speed	100% ON
2		Cooling Sample Low Speed	100% OFF
3		Cooling Sample Medium Speed	100% ON
4		Cooling Sample Medium Speed	100% OFF
5		Cooling Sample High Speed	100% ON
6		Cooling Sample High Speed	100% OFF
7	Mixing Efficiency	Cooling Off Rated Minimum Airflow	100% ON Left Side Only
8		Cooling Off Rated Minimum Airflow	100% ON Right Side Only
9		Cooling Off Rated Minimum Airflow	100% Entire Heater

Notes:
1. Each test shall be run over a minimum 10-minute period.
2. For each test, the Target Airflow shall be selected based on the rated Minimum and Maximum airflow range.
   a. Minimum target is (Rated Minimum up to 1.1 * Rated Minimum)
   b. Maximum target is (Rated Maximum down to 0.9 * Rated Maximum)
   c. Mean target is ((Rated Maximum – Rated Minimum) / 2) ± 10%
3. Electric Heat Box power supply shall have a maximum deviation of 100 W per 1000 SCFM measured.
4. Temperature measurements shall be taken with the heater turned on and the heater turned off. The sensible heat difference shall be calculated and compared to the heater input.

C3.11.5. *Recorded Data*. Refer to C3.4.4 for test conditions 1-6. Refer to 3.5.1 for test conditions 7-9.

C3.11.6. *Data Analysis*. Calculate the following for all tests.

C3.11.6.1. *Sensible Heat Balance, B_{SH}*. Calculate test conditions 1-6 in accordance with Section C3.4.5 for each test.

C3.11.6.2. *Mixing Efficiency*. Calculate test conditions 7-9 in accordance with Section C3.5.2 for each test.

APPENDIX D. DATA ACQUISITION – NORMATIVE

D1. *Purpose*. This appendix prescribes requirements for data acquisition to allow substantive confirmation of accurate repeatable testing.

D2. *Requirements*. All Test Stand tests shall be conducted in accordance with the Reference Rating Standard.

D2.1. *Time Period*. Steady-state operating conditions and performance shall be maintained for a minimum test period of 30 minutes, such that measurement parameters and test results are within both the operating condition tolerances and test tolerances set forth in the Reference Rating Standard.

D2.2. *Simultaneous Measurement*. All measurements should be taken simultaneously. Software or other recording methods shall be used to capture time-stamped data points over the duration of the test time period.

D2.3. *Sampling Rate*. A minimum of 30 data point measurements shall be collected and recorded for each parameter at uniform time intervals. Intervals between time stamps shall not vary more than ± 5% from the average time interval for all data points.

D2.4. *Measured Values*. Measurement values including temperature, pressure, flow, and power shall be calculated as the mean of all measured data over the test time period.

D2.5. *Test Results*. Test results including capacity, efficiency, and pressure drop shall be calculated using the Measured Values.

D2.6. *Period on Conditions*. All tests shall be on conditions for 30 minutes prior to starting data interval.

APPENDIX E. INSTRUMENTATION CALIBRATION – INFORMATIVE

E1. *Purpose*. This appendix prescribes requirements for instrument calibration to allow substantive confirmation of accurate repeatable testing.

E2. *Requirements*. All Test Stand tests should be conducted with calibrated instrumentation in accordance with the Reference Rating Standard.

E2.1. *Calibrated Systems*. Data acquisition systems should be either calibrated as a system, or all individual component calibrations should be documented in a manner that demonstrates the measurement system meets the accuracy requirements specified in the Reference Rating Standard.

E2.2. *Minimum Calibrated Points*. Calibrations should include no less than four points compared to a calibration standard. Calibration standards should be traceable to NIST or laboratories that participate in inter-laboratory audits.

E2.3. *Calibrated Range*. All instruments and measurement systems should be calibrated over a range that meets or exceeds the range of Test Stand data acquisition. For each instrument device in a measurement system, the calibration process should identify the range where the Reference Rating Standard required accuracy can be achieved. All measurements should be taken within the calibrated range for each instrument device measurement. For a given type of measurement, multiple instruments may be required to cover a wide range of testing conditions for a given Test Stand.

To determine the calibrated range a linear regression analysis should be performed on the calibration data.

E2.3.1. *Linear Regression Analysis*. To complete this analysis, calibration data is plotted to show the residual errors versus the calibration reference standard. The standard error of estimate should be calculated for the measurement system indicated values (post calibration) versus the calibration reference standard, then using Equation 27 plot a 95% prediction interval (α=5%) on both sides of the curve fit. The point(s) where the prediction interval curve exceeds the required accuracy should be the limit(s) of the range. Table 14 and Equation 28, Equation 29, Equation 30, Equation 31, Equation 32, and Equation 33 explain the method of calculating the prediction interval. See example using sample data in Figure 7 and Figure 8, where the specified accuracy is ±1% of reading, and the useable range is from 100 to 13.4, or Turn Down Ratio of 7.5:1.

E2.4. *Electrical Measurements*. Accuracy of electrical measurements should include all devices in the measurement system such as power meter or power analyzer, potential transformers, current transformers, and data acquisition signals. UUT that utilize power-altering equipment, such as variable frequency drive or inverter, may require appropriate isolation and precautions to confirm that accurate power measurements are obtained. UUT that utilize power-altering equipment may require the use of instrumentation that is capable of accurately measuring signals containing high frequency and high crest factors, or both. In these cases, the instrumentation used should have bandwidth and crest factor specifications, or both to confirm the electrical power input measurement errors are within the accuracy requirements of the Reference Rating Standard for the quantity measured.

Table 14. Prediction Interval to Determine Range of Acceptable Accuracy

	Reference Standard Value [1] y_j j=1 to n	Corrected (As Left) Indicated Value [2] x_j j=1 to n	Absolute Prediction Interval of Indicated Value	Relative Prediction Interval of Indicated Value %RDG
Calibration Data	y_1	x_1	$x_1 - \hat{y} \pm PI(x_1)$	$\frac{x_1 - \hat{y} \pm PI(x_1)}{x_1}$
	y_2	x_2	$x_2 - \hat{y} \pm PI(x_2)$	$\frac{x_1 - \hat{y} \pm PI(x_2)}{x_2}$
	y_3	x_3	$x_3 - \hat{y} \pm PI(x_3)$	$\frac{x_1 - \hat{y} \pm PI(x_3)}{x_3}$
	y_n	x_n	$x_n - \hat{y} \pm PI(x_n)$	$\frac{x_1 - \hat{y} \pm PI(x_n)}{x_n}$
Regression Statistics	$\bar{x}$ SS_x	s_ε	continuous curve $\hat{x} - \hat{y} \pm PI(\hat{x})$ varying $\hat{x}$ from min to max values of x_j	continuous curve $\frac{\hat{x} - \hat{y} \pm PI(\hat{x})}{\hat{x}}$ varying $\hat{x}$ from min to max values of x_j

Notes:

1. Reference Standard Value is the actual value determined or measured by the calibration standard.
2. Corrected Indicated Value is the value of the measured quantity given directly by a measuring system on the basis of its calibration curve ("as left" when the calibration process has been completed, not "as found" at the beginning of the calibration process).

$$PI(\hat{x}) = s_\varepsilon \cdot t_{\frac{\alpha}{2},n-2} \cdot \sqrt{1 + \frac{1}{n} + \frac{(\hat{x} - \bar{x})^2}{SS_x}} \quad (27)$$

$$\bar{x} = \frac{1}{n}\sum_{j=1}^{n}(x_j) \quad (28)$$

$$SS_x = \sum_{j=1}^{n}(x_j - \bar{x})^2 \quad (29)$$

$$S_{\varepsilon} = \sqrt{\frac{\sum_{j=1}^{n}(y_j - mx_j - c)^2}{n-2}}$$ **30**

$$m = \frac{n\sum_{j=1}^{n} x_j y_j - \sum_{j=1}^{n} x_j \sum_{j=1}^{n} y_j}{n\sum_{j=1}^{n}(x_j)^2 - (\sum_{j=1}^{n} x_j)^2}$$ **31**

$$c = \frac{\sum_{j=1}^{n}(x_j)^2 \sum_{j=1}^{n} y_j - \sum_{j=1}^{n} x_j \sum_{j=1}^{n}(x_j y_j)}{n\sum_{j=1}^{n}(x_j)^2 - (\sum_{j=1}^{n} x_j)^2}$$ **32**

$$\hat{y} = \mathrm{m} \cdot \hat{x} + \mathrm{c}$$ **33**

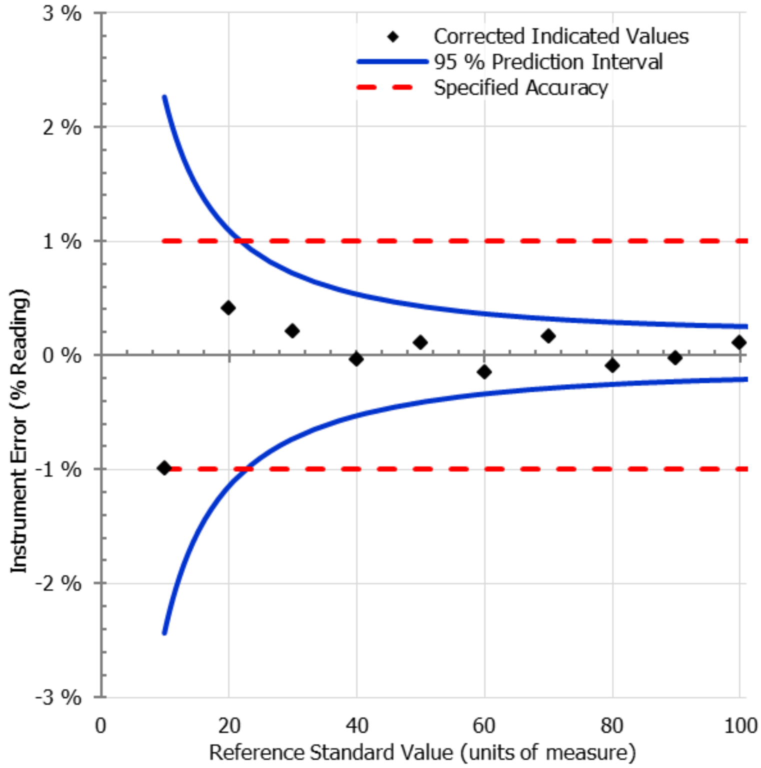

Figure 7. Sample of Relative Calibration Evaluation Data (Percent of Reading)

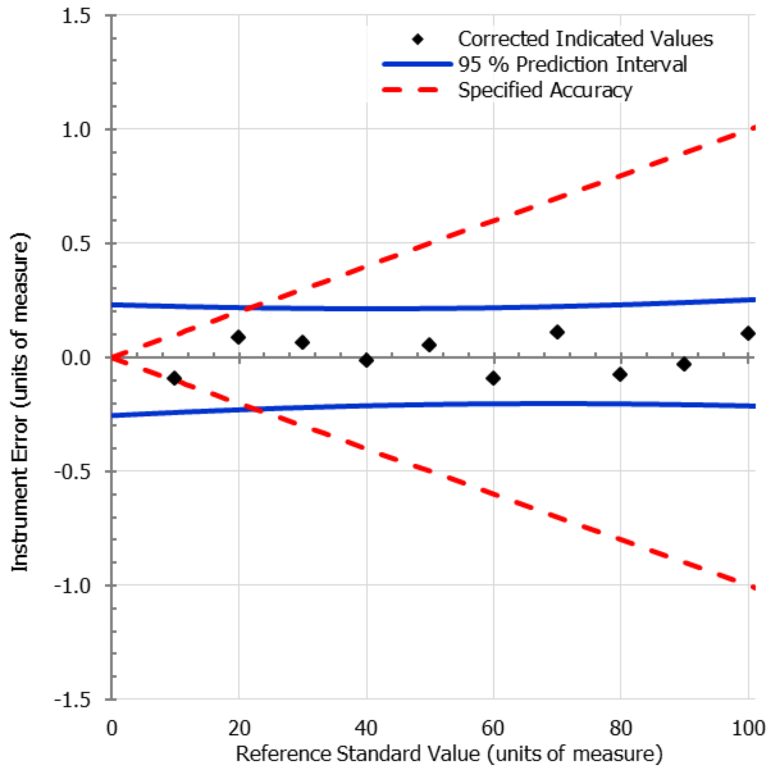

Figure 8. Sample of Absolute Calibration Evaluation Data

APPENDIX F – UNCERTAINTY ANALYSIS – INFORMATIVE

F1. *Purpose*. This appendix provides an example for performing an Uncertainty analysis.

F2. *Methodology*.

F2.1. *Goal*. Uncertainty analysis (referred to as error analysis) is outlined in ASME 19.1. The goal of the Uncertainty analysis is to bound the reported test results such that the true values lie within the specified range with 95% confidence. The Uncertainty of the reported results is found by propagation of error sources in the measurement system.

F2.2. *Overall Uncertainty*. The error analysis applied in this standard is intended for steady state measurements taken from a single system over a period long enough to encompass all system variations. The first step is to assign the Uncertainty in each of the measured variables as shown in Equation 34:

$$U_x = \sqrt{B_x^2 + (tS_x)^2} \tag{34}$$

Where:

U_x = overall Uncertainty in measured variable *x*
B_x = sum of the Systematic Errors associated with variable *x*
S_x = standard deviation of the measurements of variable *x*
t = *t*-value from statistical reference at the 95% confidence level for the degrees of freedom

F2.3. *Systematic Error*. Errors associated with measured variables are those that do not vary randomly during operation of the facility. An example is errors introduced during calibration of the instrumentation. Comparison against a known standard using the instrument in combination with the data acquisition system is the best way to estimate Fixed Errors. If this type of calibration is not viable, the manufacturer's specifications of Uncertainty on instruments and data acquisition system shall be used at a minimum. The total Fixed Error is estimated from its individual contributors as shown in Equation 35,

$$B_x^2 = \sum B_{x,j}^2 \tag{35}$$

F2.4. *Mean and Standard Deviation*. A sequence of measurements made over time of a particular quantity often exhibit random variations or Random Errors. The standard deviation in Equation 36 is a measure of the magnitude of the Random Error and is most meaningful if data is collected on a time scale longer than any naturally occurring variations in the system. The average and standard deviation for each measured variable is calculated by Equation 36 and Equation 37.

$$\bar{x} = \frac{1}{J}\sum_{j=1}^{J} x_j \tag{36}$$

$$S_{\bar{x}} = \left[\frac{1}{J-1}\sum_{j=1}^{J}\left(x_j - \bar{x}\right)^2\right]^{1/2}$$

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where x_j are the individual measurements made of variable *x* over time.

F2.5. *Overall Uncertainty of Y*. Quantities of interest are computed from the measured variables as shown in Equation 38,

$$Y = Y(X_1, X_2, \ldots, X_i) \quad \text{where} \quad X = \bar{x}$$

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The Uncertainty in the computed quantity *Y* can be estimated as shown in Equation 39 from where the partial derivatives represent the sensitivities of the computed quantity Y to variations in the individual (averaged) measurements X_i.

$$U_Y = \left[\left(\frac{\partial Y}{\partial X_1}U_{X_1}\right)^2 + \left(\frac{\partial Y}{\partial X_2}U_{X_2}\right)^2 + \cdots + \left(\frac{\partial Y}{\partial X_i}U_{X_i}\right)^2 + \cdots + \left(\frac{\partial Y}{\partial X_M}U_{X_M}\right)^2\right]^{1/2}$$

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In the following equations, partial derivatives are represented as $\frac{\partial Y}{\partial X_i} = \theta_{Xi}$

F3. *Assumptions*. The following assumptions are made for uncertainties calculated in accordance with this standard.

- Air, water, and refrigerant properties are known perfectly (negligible Uncertainty) when using formulations consistent with those in the Reference Rating Standard.
- As defined in ASHRAE 37, power measurement devices for fans and compressor are accurate within ± 2%.
- As defined in ASHRAE 37, power measurement devices for electric heaters are accurate within ± 1%.

F4. *Requirements*. .

Temperature values used for Uncertainty are in degree Rankin.

F4.1. *Sensible Cooling Capacity*. As defined in ASHRAE 37, sensible cooling capacity (q_{sci}) can be calculated as shown in Equation 40.

$$q_{sci} = \frac{60Q_{mi}(C_{p_{a1}}t_{a1} - C_{p_{a2}}t_{a2})}{v_n'(1 + W_n)} = \frac{60Q_{mi}C_{p_{a1}}t_{a1} - 60Q_{mi}C_{p_{a2}}t_{a2}}{v_n' + v_n'W_n}$$

40

$$U_{q_{sci}} = \sqrt{\begin{matrix}(\theta_{Q_{mi}}U_{Q_{mi}})^2 + (\theta_{C_{p_{a1}}}U_{C_{p_{a1}}})^2 + (\theta_{t_{a1}}U_{t_{a1}})^2 + \\ (\theta_{C_{p_{a2}}}U_{C_{p_{a2}}})^2 + (\theta_{t_{a2}}U_{t_{a2}})^2 + (\theta_{v_n'}U_{v_n'})^2 + (\theta_{W_n}U_{W_n})^2\end{matrix}}$$

$$\frac{U_{q_{sci}}}{q_{sci}} = \sqrt{\begin{matrix}\left(\frac{Q_{mi}}{q_{sci}}\theta_{Q_{mi}}\right)^2\left(\frac{U_{Q_{mi}}}{Q_{mi}}\right)^2 + \left(\frac{C_{p_{a1}}}{q_{sci}}\theta_{C_{p_{a1}}}\right)^2\left(\frac{U_{C_{p_{a1}}}}{C_{p_{a1}}}\right)^2 + \left(\frac{t_{a1}}{q_{sci}}\theta_{t_{a1}}\right)^2\left(\frac{U_{t_{a1}}}{t_{a1}}\right)^2 + \left(\frac{C_{p_{a2}}}{q_{sci}}\theta_{C_{p_{a2}}}\right)^2\left(\frac{U_{C_{p_{a2}}}}{C_{p_{a2}}}\right)^2 \\ + \left(\frac{t_{a2}}{q_{sci}}\theta_{t_{a2}}\right)^2\left(\frac{U_{t_{a2}}}{t_{a2}}\right)^2 + \left(\frac{t_{v_n'}}{q_{sci}}\theta_{v_n'}\right)^2\left(\frac{U_{v_n'}}{v_n'}\right)^2 + \left(\frac{W_n}{q_{sci}}\theta_{W_n}\right)^2\left(\frac{U_{W_n}}{W_n}\right)^2\end{matrix}}$$

$$\theta_{Q_{mi}} = \frac{60(C_{p_{a1}}t_{a1} - C_{p_{a2}}t_{a2})}{v_n'(1 + W_n)}$$

$$\theta_{C_{p_{a1}}} = \frac{60Q_{mi}(t_{a1})}{v_n'(1 + W_n)}$$

$$\theta_{t_{a1}} = \frac{60Q_{mi}(C_{p_{a1}})}{v_n'(1 + W_n)}$$

$$\theta_{C_{p_{a2}}} = -\frac{60Q_{mi}(t_{a2})}{v_n'(1 + W_n)}$$

$$\theta_{t_{a2}} = -\frac{60Q_{mi}(C_{p_{a2}})}{v_n'(1 + W_n)}$$

$$\theta_{v_n'} = -\frac{60Q_{mi}(C_{p_{a1}}t_{a1} - C_{p_{a2}}t_{a2})}{v_n'^2(W_n + 1)}$$

$$\theta_{W_n} = -\frac{60Q_{mi}(C_{p_{a1}}t_{a1} - C_{p_{a2}}t_{a2})}{v_n'(1 + W_n)^2}$$

Where:

indoor UUT measured airflow, cfm

$Q_{mi} = 1097CA_n\sqrt{P_V v_n'}$

$$U_{Q_{mi}} = \sqrt{(\theta_C U_C)^2 + \left(\theta_{A_n} U_{A_n}\right)^2 + \left(\theta_{P_V} U_{P_V}\right)^2 + \left(\theta_{v_n'} U_{v_n'}\right)^2}$$

$$\frac{U_{Q_{mi}}}{Q_{mi}} = \sqrt{\left(\frac{C}{Q_{mi}}\theta_C\right)^2\left(\frac{U_C}{C}\right)^2 + \left(\frac{A_n}{Q_{mi}}\theta_{A_n}\right)^2\left(\frac{U_{A_n}}{A_n}\right)^2 + \left(\frac{P_V}{Q_{mi}}\theta_{P_V}\right)^2\left(\frac{U_{P_V}}{P_V}\right)^2 + \left(\frac{v_n'}{Q_{mi}}\theta_{v_n'}\right)^2\left(\frac{U_{v_n'}}{v_n'}\right)^2}$$

$$\theta_C = 1097 A_n\sqrt{P_V v_n'}$$

$$\theta_{A_n} = 1097 C\sqrt{P_V v_n'}$$

$$\theta_{P_V} = \frac{1097 C A_n\sqrt{v_n'}}{2\sqrt{P_V}}$$

$$\theta_{v_n'} = \frac{1097 C A_n\sqrt{P_V}}{2\sqrt{v_n'}}$$

Nozzle coefficient of discharge, dimensionless

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

$$U_C = \sqrt{(\theta_{Re} U_{Re})^2} = \theta_{Re} U_{Re}$$

$$\frac{U_C}{C} = \frac{\theta_{Re} U_{Re}}{C} = 0$$

$$\theta_{Re} = -\frac{134.6}{Re^2}$$

$U_{Re} = 0$ (see assumptions above)

Nozzle area, ft^2

$$A_n = \pi\left(\frac{\frac{D}{12}}{2}\right)^2 = \pi\left(\frac{D}{6}\right)^2$$

$$U_{A_n} = \sqrt{(\theta_D U_D)^2} = \theta_D U_D$$

$$\frac{U_{A_n}}{A_n} = \frac{\theta_D U_D}{A_n}$$

$$\theta_D = \frac{\pi D}{18}$$

specific volume of air, ft^3/lbm

at nozzle:

$$v_n' = \frac{v_n}{1 + W_n}$$

$$U_{v_n'} = \sqrt{\left(\theta_{v_n} U_{v_n}\right)^2 + \left(\theta_{W_n} U_{W_n}\right)^2}$$

$$\frac{U_{v_n'}}{v_n'} = \sqrt{\left(\frac{v_n}{v_n'}\theta_{v_n}\right)^2\left(\frac{U_{v_n}}{v_n}\right)^2 + \left(\frac{W_n}{v_n'}\theta_{W_n}\right)^2\left(\frac{U_{W_n}}{W_n}\right)^2}$$

$$\theta_{v_n} = \frac{1}{1 + W_n}$$

$$\theta_{W_n} = -\frac{v_n}{(1 + W_n)^2}$$

specific volume of the dry air portion of the mixture, ft^3/lbm_{da}

at nozzle:

$$v_n = \frac{0.370486 \cdot t_n \cdot (1 + 1.607858W_n)}{P_n}$$

$$U_{v_n} = \sqrt{\left(\theta_{t_n} U_{t_n}\right)^2 + \left(\theta_{W_n} U_{W_n}\right)^2 + \left(\theta_{P_n} U_{P_n}\right)^2}$$

$$\frac{U_{v_n}}{v_n} = \sqrt{\left(\frac{t_n}{v_n}\theta_{t_n}\right)^2 \left(\frac{U_{t_n}}{t_n}\right)^2 + \left(\frac{W_n}{v_n}\theta_{W_n}\right)^2 \left(\frac{U_{W_n}}{W_n}\right)^2 + \left(\frac{P_n}{v_n}\theta_{P_n}\right)^2 \left(\frac{U_{P_n}}{P_n}\right)^2}$$

$$\theta_{t_n} = \frac{0.370486(1.607858W_n + 1)}{P_n}$$

$$\theta_{W_n} = \frac{0.595688879t_n}{P_n}$$

$$\theta_{P_n} = -\frac{0.370486t_n(1.607858W_n + 1)}{{P_n}^2}$$

specific heat of air, Btu / (lbm_{da}·°F)

entering UUT:

$$C_{p_{a1}} = 0.24 + 0.444W_1$$

$$U_{C_{p_{a1}}} = \sqrt{\left(\theta_{W_1} U_{W_1}\right)^2} = \theta_{W_1} U_{W_1}$$

$$\frac{U_{C_{p_{a1}}}}{C_{p_{a1}}} = \frac{\theta_{W_1} U_{W_1}}{C_{p_{a1}}}$$

$$\theta_{W_1} = 0.444$$

leaving UUT:

$$C_{p_{a2}} = 0.24 + 0.444W_2$$

$$U_{C_{p_{a2}}} = \sqrt{\left(\theta_{W_2} U_{W_2}\right)^2} = \theta_{W_2} U_{W_2}$$

$$\frac{U_{C_{p_{a2}}}}{C_{p_{a2}}} = \frac{\theta_{W_2} U_{W_2}}{C_{p_{a2}}}$$

$$\theta_{W_2} = 0.444$$

humidity ratio of air, lbm_{wv} / lbm_{da}

at nozzle:

$$W_n = \frac{[(1093 - 0.556t_n^*) \cdot W_{sn}^* - 0.240 \cdot (t_n - t_n^*)]}{1093 + 0.444t_n - t_n^*}$$

$$W_n = \frac{1093W_{sn}^* - 0.556t_n^* W_{sn}^* - 0.240t_n + 0.240t_n^*}{1093 + 0.444t_n - t_n^*}$$

$$U_{W_n} = \sqrt{\left(\theta_{W_{sn}^*} U_{W_{sn}^*}\right)^2 + \left(\theta_{t_n^*} U_{t_n^*}\right)^2 + \left(\theta_{t_n} U_{t_n}\right)^2}$$

$$\frac{U_{W_n}}{W_n} = \sqrt{\left(\frac{W_{sn}^*}{W_n}\theta_{W_{sn}^*}\right)^2 \left(\frac{U_{W_{sn}^*}}{W_{sn}^*}\right)^2 + \left(\frac{t_n^*}{W_n}\theta_{t_n^*}\right)^2 \left(\frac{U_{t_n^*}}{t_n^*}\right)^2 + \left(\frac{t_n}{W_n}\theta_{t_n}\right)^2 \left(\frac{U_{t_n}}{t_n}\right)^2}$$

$$\theta_{W_{sn}^*} = \frac{1093 - 0.556t_n^*}{1093 + 0.444t_n - t_n^*}$$

$$\theta_{t_n^*} = \frac{1093W_{sn}^*}{(1093 + 0.444t_n - t_n^*)^2} - \frac{0.556t_n^* W_{sn}^*}{(1093 + 0.444t_n - t_n^*)^2} - \frac{0.556W_{sn}^*}{1093 + 0.444t_n - t_n^*} + \frac{0.240t_n^*}{(1093 + 0.444t_n - t_n^*)^2} + \frac{0.240}{1093 + 0.444t_n - t_n^*}$$

$$\theta_{t_n^*} = \frac{1093W_{sn}^* - 0.24t_n - 0.556t_n^* W_{sn}^* + 0.240t_n^*}{(1093 + 0.444t_n - t_n^*)^2} + \frac{-0.556W_{sn}^* + 0.240}{1093 + 0.444t_n - t_n^*}$$

$$\theta_{t_n} = -\frac{0.240}{1093 + 0.444t_n - t_n^*} - \frac{0.444(1093W_{sn}^* - 0.24t_n + 0.24t_n^* - 0.556W_{sn}^* t_n^*}{(1093 + 0.444t_n - t_n^*)^2}$$

entering UUT:

$$W_1 = \frac{1093W_{s1}^* - 0.556t_1^* W_{s1}^* - 0.240t_1 + 0.240t_1^*}{1093 + 0.444t_1 - t_1^*}$$

$$U_{W_1} = \sqrt{\left(\theta_{W_{s1}^*} U_{W_{s1}^*}\right)^2 + \left(\theta_{t_1^*} U_{t_1^*}\right)^2 + \left(\theta_{t_1} U_{t_1}\right)^2}$$

$$\frac{U_{W_1}}{W_1} = \sqrt{\left(\frac{W_{s1}^*}{W_1}\theta_{W_{s1}^*}\right)^2 \left(\frac{U_{W_{s1}^*}}{W_{s1}^*}\right)^2 + \left(\frac{t_1^*}{W_1}\theta_{t_1^*}\right)^2 \left(\frac{U_{t_1^*}}{t_1^*}\right)^2 + \left(\frac{t_1}{W_1}\theta_{t_1}\right)^2 \left(\frac{U_{t_1}}{t_1}\right)^2}$$

$$\theta_{W_{s1}^*} = \frac{1093 - 0.556t_1^*}{1093 + 0.444t_1 - t_1^*}$$

$$\theta_{t_1^*} = \frac{1093W_{s1}^* - 0.24t_1 - 0.556t_1^* W_{s1}^* + 0.240t_1^*}{(1093 + 0.444t_1 - t_1^*)^2} + \frac{-0.556W_{s1}^* + 0.240}{1093 + 0.444t_1 - t_1^*}$$

$$\theta_{t_1} = -\frac{0.240}{1093 + 0.444t_1 - t_1^*} - \frac{0.444(1093W_{s1}^* - 0.24t_1 + 0.24t_1^* - 0.556W_{s1}^* t_1^*}{(1093 + 0.444t_1 - t_1^*)^2}$$

leaving UUT:

$$W_2 = \frac{1093W_{s2}^* - 0.556t_2^* W_{s2}^* - 0.240t_2 + 0.240t_2^*}{1093 + 0.444t_2 - t_2^*}$$

$$U_{W_2} = \sqrt{\left(\theta_{W_{s2}^*} U_{W_{s2}^*}\right)^2 + \left(\theta_{t_2^*} U_{t_2^*}\right)^2 + \left(\theta_{t_2} U_{t_2}\right)^2}$$

$$\frac{U_{W_2}}{W_2} = \sqrt{\left(\frac{W_{s2}^*}{W_2}\theta_{W_{s2}^*}\right)^2 \left(\frac{U_{W_{s2}^*}}{W_{s2}^*}\right)^2 + \left(\frac{t_2^*}{W_2}\theta_{t_2^*}\right)^2 \left(\frac{U_{t_2^*}}{t_2^*}\right)^2 + \left(\frac{t_2}{W_2}\theta_{t_2}\right)^2 \left(\frac{U_{t_2}}{t_2}\right)^2}$$

$$\theta_{W_{s2}^*} = \frac{1093 - 0.556t_2^*}{1093 + 0.444t_2 - t_2^*}$$

$$\theta_{t_2^*} = \frac{1093W_{s2}^* - 0.24t_2 - 0.556t_2^* W_{s2}^* + 0.240t_2^*}{(1093 + 0.444t_2 - t_2^*)^2} + \frac{-0.556W_{s2}^* + 0.240}{1093 + 0.444t_2 - t_2^*}$$

$$\theta_{t_2} = -\frac{0.240}{1093 + 0.444t_2 - t_2^*} - \frac{0.444(1093W_{s2}^* - 0.24t_2 + 0.24t_2^* - 0.556W_{s2}^* t_2^*}{(1093 + 0.444t_2 - t_2^*)^2}$$

saturation humidity ratio of air, lbm_{wv} / lbm_{da}

at nozzle:

$$W_{sn}^* = \frac{0.621945 \cdot p_{ws(t_n^*)}}{P_n - p_{ws(t_n^*)}}$$

$$U_{W_{sn}^*} = \sqrt{\left(\theta_{p_{ws(t_n^*)}} U_{p_{ws(t_n^*)}}\right)^2 + \left(\theta_{P_n} U_{P_n}\right)^2}$$

$$\frac{U_{W_{sn}^*}}{W_{sn}^*} = \sqrt{\left(\frac{p_{ws(t_n^*)}}{W_{sn}^*}\theta_{p_{ws(t_n^*)}}\right)^2 \left(\frac{U_{p_{ws(t_n^*)}}}{p_{ws(t_n^*)}}\right)^2 + \left(\frac{P_n}{W_{sn}^*}\theta_{P_n}\right)^2 \left(\frac{U_{P_n}}{P_n}\right)^2}$$

$$\theta_{p_{ws(t_n^*)}} = \frac{0.621945 p_{ws(t_n^*)}}{\left(P_n - p_{ws(t_n^*)}\right)^2} + \frac{0.621945}{P_n - p_{ws(t_n^*)}}$$

$$\theta_{P_n} = -\frac{0.621945 p_{ws(t_n^*)}}{\left(P_n - p_{ws(t_n^*)}\right)^2}$$

entering UUT:

$$W_{s1}^* = \frac{0.621945 \cdot p_{ws(t_1^*)}}{P_1 - p_{ws(t_1^*)}}$$

$$U_{W_{s1}^*} = \sqrt{\left(\theta_{p_{ws(t_1^*)}} U_{p_{ws(t_1^*)}}\right)^2 + \left(\theta_{P_1} U_{P_1}\right)^2}$$

$$\frac{U_{W_{s1}^*}}{W_{s1}^*} = \sqrt{\left(\frac{p_{ws(t_1^*)}}{W_{s1}^*}\theta_{p_{ws(t_1^*)}}\right)^2 \left(\frac{U_{p_{ws(t_1^*)}}}{p_{ws(t_1^*)}}\right)^2 + \left(\frac{P_1}{W_{s1}^*}\theta_{P_1}\right)^2 \left(\frac{U_{P_1}}{P_1}\right)^2}$$

$$\theta_{p_{ws(t_1^*)}} = \frac{0.621945 p_{ws(t_1^*)}}{\left(P_1 - p_{ws(t_1^*)}\right)^2} + \frac{0.621945}{P_1 - p_{ws(t_1^*)}}$$

$$\theta_{P_{\cancel{n}1}} = -\frac{0.621945 p_{ws(t_1^*)}}{\left(P_1 - p_{ws(t_1^*)}\right)^2}$$

leaving UUT:

$$W_{s2}^* = \frac{0.621945 \cdot p_{ws(t_2^*)}}{P_2 - p_{ws(t_2^*)}}$$

$$U_{W_{s2}^*} = \sqrt{\left(\theta_{p_{ws(t_2^*)}} U_{p_{ws(t_2^*)}}\right)^2 + \left(\theta_{P_2} U_{P_2}\right)^2}$$

$$\frac{U_{W_{s2}^*}}{W_{s2}^*} = \sqrt{\left(\frac{p_{ws(t_2^*)}}{W_{s2}^*}\theta_{p_{ws(t_2^*)}}\right)^2 \left(\frac{U_{p_{ws(t_2^*)}}}{p_{ws(t_2^*)}}\right)^2 + \left(\frac{P_2}{W_{s2}^*}\theta_{P_2}\right)^2 \left(\frac{U_{P_2}}{P_2}\right)^2}$$

$$\theta_{p_{ws(t_2^*)}} = \frac{0.621945 p_{ws(t_2^*)}}{\left(P_2 - p_{ws(t_2^*)}\right)^2} + \frac{0.621945}{P_2 - p_{ws(t_2^*)}}$$

$$\theta_{P_{\cancel{n}2}} = -\frac{0.621945 p_{ws(t_2^*)}}{\left(P_2 - p_{ws(t_2^*)}\right)^2}$$

saturation pressure of water vapor (at wet bulb temperature), psia

at nozzle:

$$p_{ws(t_n^*)} = e^{\left[\frac{-10440.397}{t_n^*} - 11.29465 - 0.027022355 * t_n^* + 1.289036 * 10^{-5} * {t_n^*}^2 - 2.4780681 * 10^{-9} * {t_n^*}^3 + 6.5459673 * \ln(t_n^*)\right]}$$

$$U_{p_{ws(t_n^*)}} = \sqrt{\left(\theta_{t_n^*} U_{t_n^*}\right)^2} = \left(\theta_{t_n^*} U_{t_n^*}\right)$$

$$\frac{U_{p_{ws(t_n^*)}}}{p_{ws(t_n^*)}} = \frac{\left(\theta_{t_n^*} U_{t_n^*}\right)}{p_{ws(t_n^*)}}$$

$$\theta_{t_n^*} = e^{\left[-0.027022355 * t_n^* + 6.5459673 * ln(t_n^*) - \frac{10440.397}{t_n^*} + 0.00001289036 * {t_n^*}^2 - 11.29465 - 0.0000000024780681 * {t_n^*}^3\right]} \times (0.00002578072 * t_n^* + \frac{6.5459673}{t_n^*} + \frac{10440.397}{{t_n^*}^2} - 0.0000000074342043 {t_n^*}^2 - 0.027022355$$

entering UUT:

$$p_{ws(t_1^*)} = e^{\left[\frac{-10440.397}{t_1^*} - 11.29465 - 0.027022355 * t_1^* + 1.289036 * 10^{-5} * {t_1^*}^2 - 2.4780681 * 10^{-9} * {t_1^*}^3 + 6.5459673 * \ln(t_1^*)\right]}$$

$$U_{p_{ws(t_1^*)}} = \sqrt{\left(\theta_{t_1^*} U_{t_1^*}\right)^2} = \left(\theta_{t_1^*} U_{t_1^*}\right)$$

$$\frac{U_{p_{ws(t_1^*)}}}{p_{ws(t_1^*)}} = \frac{\left(\theta_{t_1^*} U_{t_1^*}\right)}{p_{ws(t_1^*)}}$$

$$\theta_{t_1^*} = e^{\left[-0.027022355 * t_1^* + 6.5459673 * ln(t_1^*) - \frac{10440.397}{t_1^*} + 0.00001289036 * {t_1^*}^2 - 11.29465 - 0.0000000024780681 * {t_1^*}^3\right]} \times (0.00002578072 * t_1^* + \frac{6.5459673}{t_1^*} + \frac{10440.397}{{t_1^*}^2} - 0.0000000074342043 {t_1^*}^2 - 0.027022355$$

leaving UUT:

$$p_{ws(t_2^*)} = e^{\left[\frac{-10440.397}{t_2^*} - 11.29465 - 0.027022355*t_2^* + 1.289036*10^{-5}*{t_2^*}^2 - 2.4780681*10^{-9}*{t_2^*}^3 + 6.5459673*\ln(t_2^*)\right]}$$

$$U_{p_{ws(t_2^*)}} = \sqrt{\left(\theta_{t_2^*} U_{t_1^*}\right)^2} = \left(\theta_{t_2^*} U_{t_2^*}\right)$$

$$\frac{U_{p_{ws(t_2^*)}}}{p_{ws(t_2^*)}} = \frac{\left(\theta_{t_2^*} U_{t_2^*}\right)}{p_{ws(t_2^*)}}$$

$$\theta_{t_2^*} = e^{\left[-0.027022355*t_2^* + 6.5459673*ln(t_2^*) - \frac{10440.397}{t_2^*} + 0.00001289036*{t_2^*}^2 - 11.29465 - 0.0000000024780681*{t_2^*}^3\right]} \times \left(0.00002578072 * t_2^* + \frac{6.5459673}{t_2^*} + \frac{10440.397}{{t_2^*}^2} - 0.0000000074342043{t_2^*}^2 - 0.027022355\right.$$

saturation pressure of water vapor (at dry bulb temperature), psia

at nozzle:

$$p_{ws(t_n)} = e^{\left[\frac{-10440.397}{t_n} - 11.29465 - 0.027022355*t_n + 1.289036*10^{-5}*{t_n}^2 - 2.4780681*10^{-9}*{t_n}^3 + 6.5459673*\ln(t_n)\right]}$$

$$U_{p_{ws(t_n)}} = \sqrt{\left(\theta_{t_n} U_{t_n}\right)^2} = \left(\theta_{t_n} U_{t_n}\right)$$

$$\frac{U_{p_{ws(t_n)}}}{p_{ws(t_n)}} = \frac{\left(\theta_{t_n} U_{t_n}\right)}{p_{ws(t_n)}}$$

$$\theta_{t_n} = e^{\left[-0.027022355*t_n + 6.5459673*ln(t_n) - \frac{10440.397}{t_n} + 0.00001289036*{t_n}^2 - 11.29465 - 0.0000000024780681*{t_n}^3\right]} \times \left(0.00002578072 * t_n + \frac{6.5459673}{t_n} + \frac{10440.397}{{t_n}^2} - 0.0000000074342043{t_n}^2 - 0.027022355\right.$$

entering UUT:

$$p_{ws(t_1)} = e^{\left[\frac{-10440.397}{t_1} - 11.29465 - 0.027022355*t_1 + 1.289036*10^{-5}*{t_1}^2 - 2.4780681*10^{-9}*{t_1}^3 + 6.5459673*\ln(t_1)\right]}$$

$$U_{p_{ws(t_1)}} = \sqrt{\left(\theta_{t_1} U_{t_1}\right)^2} = \left(\theta_{t_1} U_{t_1}\right)$$

$$\frac{U_{p_{ws(t_1)}}}{p_{ws(t_1)}} = \frac{\left(\theta_{t_1} U_{t_1}\right)}{p_{ws(t_1)}}$$

$$\theta_{t_1} = e^{\left[-0.027022355*t_1 + 6.5459673*ln(t_1) - \frac{10440.397}{t_1} + 0.00001289036*{t_1}^2 - 11.29465 - 0.0000000024780681*{t_1}^3\right]} \times (0.00002578072 * t_1 + \frac{6.5459673}{t_1} + \frac{10440.397}{{t_1}^2} - 0.0000000074342043{t_1}^2 - 0.027022355$$

leaving UUT:

$$p_{ws(t_2)} = e^{\left[\frac{-10440.397}{t_2} - 11.29465 - 0.027022355*t_2 + 1.289036*10^{-5}*{t_2}^2 - 2.4780681*10^{-9}*{t_2}^3 + 6.5459673*\ln(t_2)\right]}$$

$$U_{p_{ws(t_2)}} = \sqrt{\left(\theta_{t_2^*} U_{t_2}\right)^2} = \left(\theta_{t_2} U_{t_2}\right)$$

$$\frac{U_{p_{ws(t_2)}}}{p_{ws(t_2)}} = \frac{\left(\theta_{t_2} U_{t_2}\right)}{p_{ws(t_2)}}$$

$$\theta_{t_2} = e^{\left[-0.027022355*t_2 + 6.5459673*ln(t_2) - \frac{10440.397}{t_2} + 0.00001289036*{t_2}^2 - 11.29465 - 0.0000000024780681*{t_2}^3\right]} \times (0.00002578072 * t_2 + \frac{6.545967}{t_2} + \frac{10440.397}{{t_2}^2} - 0.0000000074342043{t_2}^2 - 0.027022355$$

F4.2. *Total Cooling Capacity*. As defined in ASHRAE 37, sensible cooling capacity (q_{tci}) can be calculated as shown in Equation 42.

$$q_{tci} = q_{sci} + q_{lci} \qquad \textbf{42}$$

Where:
$q_{lci} = 63600 Q_{mi}(W_{i1} - W_{i2})/[v_n'(1 + W_n)]$

The Uncertainty of the total cooling capacity q_{tci} is then defined as

$$U_{q_{tci}} = \sqrt{U_{q_{sci}} + U_{q_{lci}}}$$

Where:

$$U_{q_{lci}} = \sqrt{\left(\theta_{Q_{mi}} U_{Q_{mi}}\right)^2 + \left(\theta_{W_{i1}} U_{W_{i1}}\right)^2 + \left(\theta_{W_{i2}} U_{W_{i2}}\right)^2 + \left(\theta_{v'_n} U_{v'_n}\right)^2 + \left(\theta_{W_n} U_{W_n}\right)^2}$$

$$\theta_{Q_{mi}} = \frac{63600(W_{i1} - W_{i2})}{v'_n(1 + W_n)}$$

$$\theta_{W_{i1}} = \frac{63600Q_{mi}}{v'_n(1 + W_n)}$$

$$\theta_{W_{i2}} = -\frac{63600Q_{mi}}{v'_n(1 + W_n)}$$

$$\theta_{v'_n} = -\frac{63600Q_{mi}(W_{i1} - W_{i2})}{{v'_n}^2(W_n + 1)}$$

$$\theta_{W_n} = -\frac{63600Q_{mi}(W_{i1} - W_{i2})}{(W_n + 1)^2 v'_n}$$

indoor UUT measured airflow, cfm

$$Q_{mi} = 1097CA_n\sqrt{P_V v'_n}$$

$$U_{Q_{mi}} = \sqrt{(\theta_C U_C)^2 + \left(\theta_{A_n} U_{A_n}\right)^2 + \left(\theta_{P_V} U_{P_V}\right)^2 + \left(\theta_{v'_n} U_{v'_n}\right)^2}$$

$$\frac{U_{Q_{mi}}}{Q_{mi}} = \sqrt{\left(\frac{C}{Q_{mi}}\theta_C\right)^2 \left(\frac{U_C}{C}\right)^2 + \left(\frac{A_n}{Q_{mi}}\theta_{A_n}\right)^2 \left(\frac{U_{A_n}}{A_n}\right)^2 + \left(\frac{P_V}{Q_{mi}}\theta_{P_V}\right)^2 \left(\frac{U_{P_V}}{P_V}\right)^2 + \left(\frac{v'_n}{Q_{mi}}\theta_{v'_n}\right)^2 \left(\frac{U_{v'_n}}{v'_n}\right)^2}$$

$$\theta_C = 1097 A_n \sqrt{P_V v'_n}$$

$$\theta_{A_n} = 1097 C \sqrt{P_V v'_n}$$

$$\theta_{P_V} = \frac{1097 C A_n \sqrt{v'_n}}{2\sqrt{P_V}}$$

$$\theta_{v'_n} = \frac{1097 C A_n \sqrt{P_V}}{2\sqrt{v'_n}}$$

Nozzle coefficient of discharge, dimensionless

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

$$U_C = \sqrt{(\theta_{Re} U_{Re})^2} = \theta_{Re} U_{Re}$$

$$\frac{U_C}{C} = \frac{\theta_{Re} U_{Re}}{C} = 0$$

$$\theta_{Re} = -\frac{134.6}{Re^2}$$

$U_{Re} = 0$ (see assumptions above)

Nozzle area, ft^2

$$A_n = \pi \left(\frac{\frac{D}{12}}{2}\right)^2 = \pi \left(\frac{D}{6}\right)^2$$

$$U_{A_n} = \sqrt{(\theta_D U_D)^2} = \theta_D U_D$$

$$\frac{U_{A_n}}{A_n} = \frac{\theta_D U_D}{A_n}$$

$$\theta_D = \frac{\pi D}{18}$$

specific volume of air, ft^3/lbm

at nozzle:

$$v_n' = \frac{v_n}{1 + W_n}$$

$$U_{v_n'} = \sqrt{\left(\theta_{v_n} U_{v_n}\right)^2 + \left(\theta_{W_n} U_{W_n}\right)^2}$$

$$\frac{U_{v_n'}}{v_n'} = \sqrt{\left(\frac{v_n}{v_n'}\theta_{v_n}\right)^2 \left(\frac{U_{v_n}}{v_n}\right)^2 + \left(\frac{W_n}{v_n'}\theta_{W_n}\right)^2 \left(\frac{U_{W_n}}{W_n}\right)^2}$$

$$\theta_{v_n} = \frac{1}{1 + W_n}$$

$$\theta_{W_n} = -\frac{v_n}{(1 + W_n)^2}$$

specific volume of the dry air portion of the mixture, ft^3/lbm$_{da}$

at nozzle:

$$v_n = \frac{0.370486 \cdot t_n \cdot (1 + 1.607858 W_n)}{P_n}$$

$$U_{v_n} = \sqrt{\left(\theta_{t_n} U_{t_n}\right)^2 + \left(\theta_{W_n} U_{W_n}\right)^2 + \left(\theta_{P_n} U_{P_n}\right)^2}$$

$$\frac{U_{v_n}}{v_n} = \sqrt{\left(\frac{t_n}{v_n}\theta_{t_n}\right)^2 \left(\frac{U_{t_n}}{t_n}\right)^2 + \left(\frac{W_n}{v_n}\theta_{W_n}\right)^2 \left(\frac{U_{W_n}}{W_n}\right)^2 + \left(\frac{P_n}{v_n}\theta_{P_n}\right)^2 \left(\frac{U_{P_n}}{P_n}\right)^2}$$

$$\theta_{t_n} = \frac{0.370486(1.607858W_n + 1)}{P_n}$$

$$\theta_{W_n} = \frac{0.595688879t_n}{P_n}$$

$$\theta_{P_n} = -\frac{0.370486t_n(1.607858W_n + 1)}{{P_n}^2}$$

humidity ratio of air, lbm_{wv} / lbm_{da}
at nozzle:

$$W_n = \frac{[(1093 - 0.556t_n^*) \cdot W_{sn}^* - 0.240 \cdot (t_n - t_n^*)]}{1093 + 0.444t_n - t_n^*}$$

$$W_n = \frac{1093W_{sn}^* - 0.556t_n^*W_{sn}^* - 0.240t_n + 0.240t_n^*}{1093 + 0.444t_n - t_n^*}$$

$$U_{W_n} = \sqrt{\left(\theta_{W_{sn}^*}U_{W_{sn}^*}\right)^2 + \left(\theta_{t_n^*}U_{t_n^*}\right)^2 + \left(\theta_{t_n}U_{t_n}\right)^2}$$

$$\frac{U_{W_n}}{W_n} = \sqrt{\left(\frac{W_{sn}^*}{W_n}\theta_{W_{sn}^*}\right)^2\left(\frac{U_{W_{sn}^*}}{W_{sn}^*}\right)^2 + \left(\frac{t_n^*}{W_n}\theta_{t_n^*}\right)^2\left(\frac{U_{t_n^*}}{t_n^*}\right)^2 + \left(\frac{t_n}{W_n}\theta_{t_n}\right)^2\left(\frac{U_{t_n}}{t_n}\right)^2}$$

$$\theta_{W_{sn}^*} = \frac{1093 - 0.556t_n^*}{1093 + 0.444t_n - t_n^*}$$

$$\theta_{t_n^*} = \frac{1093W_{sn}^*}{(1093 + 0.444t_n - t_n^*)^2} - \frac{0.556t_n^*W_{sn}^*}{(1093 + 0.444t_n - t_n^*)^2} - \frac{0.556W_{sn}^*}{1093 + 0.444t_n - t_n^*} + \frac{0.240t_n^*}{(1093 + 0.444t_n - t_n^*)^2} + \frac{0.240}{1093 + 0.444t_n - t_n^*}$$

$$\theta_{t_n^*} = \frac{1093W_{sn}^* - 0.24t_n - 0.556t_n^*W_{sn}^* + 0.240t_n^*}{(1093 + 0.444t_n - t_n^*)^2} + \frac{-0.556W_{sn}^* + 0.240}{1093 + 0.444t_n - t_n^*}$$

$$\theta_{t_n} = -\frac{0.240}{1093 + 0.444t_n - t_n^*} - \frac{0.444(1093W_{sn}^* - 0.24t_n + 0.24t_n^* - 0.556W_{sn}^*t_n^*}{(1093 + 0.444t_n - t_n^*)^2}$$

entering UUT:

$$W_{i1} = \frac{1093W_{si1}^* - 0.556t_1^*W_{si1}^* - 0.240t_1 + 0.240t_1^*}{1093 + 0.444t_1 - t_1^*}$$

$$U_{W_{i1}} = \sqrt{\left(\theta_{W^*_{si1}} U_{W^*_{si1}}\right)^2 + \left(\theta_{t^*_1} U_{t^*_1}\right)^2 + \left(\theta_{t_1} U_{t_1}\right)^2}$$

$$\frac{U_{W_{i1}}}{W_{i1}} = \sqrt{\left(\frac{W^*_{si1}}{W_{i1}} \theta_{W^*_{si1}}\right)^2 \left(\frac{U_{W^*_{si1}}}{W^*_{si1}}\right)^2 + \left(\frac{t^*_1}{W_{i1}} \theta_{t^*_1}\right)^2 \left(\frac{U_{t^*_1}}{t^*_1}\right)^2 + \left(\frac{t_1}{W_{i1}} \theta_{t_1}\right)^2 \left(\frac{U_{t_1}}{t_1}\right)^2}$$

$$\theta_{W^*_{si1}} = \frac{1093 - 0.556t^*_1}{1093 + 0.444t_1 - t^*_1}$$

$$\theta_{t^*_1} = \frac{1093W^*_{si1} - 0.24t_1 - 0.556t^*_1W^*_{si1} + 0.240t^*_1}{(1093 + 0.444t_1 - t^*_1)^2} + \frac{-0.556W^*_{si1} + 0.240}{1093 + 0.444t_1 - t^*_1}$$

$$\theta_{t_1} = -\frac{0.240}{1093 + 0.444t_1 - t^*_1} - \frac{0.444(1093W^*_{si1} - 0.24t_1 + 0.24t^*_1 - 0.556W^*_{si1}t^*_1}{(1093 + 0.444t_1 - t^*_1)^2}$$

leaving UUT:

$$W_{i2} = \frac{1093W^*_{si2} - 0.556t^*_2W^*_{si2} - 0.240t_2 + 0.240t^*_2}{1093 + 0.444t_2 - t^*_2}$$

$$U_{W_{i2}} = \sqrt{\left(\theta_{W^*_{si2}} U_{W^*_{si2}}\right)^2 + \left(\theta_{t^*_2} U_{t^*_2}\right)^2 + \left(\theta_{t_2} U_{t_2}\right)^2}$$

$$\frac{U_{W_{i2}}}{W_{i2}} = \sqrt{\left(\frac{W^*_{si2}}{W_{i2}} \theta_{W^*_{si2}}\right)^2 \left(\frac{U_{W^*_{si2}}}{W^*_{si2}}\right)^2 + \left(\frac{t^*_2}{W_{i2}} \theta_{t^*_2}\right)^2 \left(\frac{U_{t^*_2}}{t^*_2}\right)^2 + \left(\frac{t_2}{W_{i2}} \theta_{t_2}\right)^2 \left(\frac{U_{t_2}}{t_2}\right)^2}$$

$$\theta_{W^*_{si2}} = \frac{1093 - 0.556t^*_2}{1093 + 0.444t_2 - t^*_2}$$

$$\theta_{t^*_2} = \frac{1093W^*_{si2} - 0.24t_2 - 0.556t^*_2W^*_{si2} + 0.240t^*_2}{(1093 + 0.444t_2 - t^*_2)^2} + \frac{-0.556W^*_{si2} + 0.240}{1093 + 0.444t_2 - t^*_2}$$

$$\theta_{t_2} = -\frac{0.240}{1093 + 0.444t_2 - t^*_2} - \frac{0.444(1093W^*_{si2} - 0.24t_2 + 0.24t^*_2 - 0.556W^*_{si2}t^*_2}{(1093 + 0.444t_2 - t^*_2)^2}$$

F4.3. *Power*. As defined in ASHRAE 37, total input power (E_t) can be calculated as shown in Equation 43.

$$E_t = W_{input} + P_{IF} + P_{indoor} \tag{43}$$

Where:

W_{input}	=	compressor power input
P_{IF}	=	fan power input
P_{indoor}	=	indoor input power

$$U_{E_t} = \sqrt{U_{W_{input}}{}^2 + U_{P_{IF}}{}^2 + U_{P_{indoor}}{}^2}$$

Where:

$$U_{W_{input}} = \sqrt{B_{W_{input}}{}^2 + \left(tS_{W_{input}}\right)^2}$$

$$U_{P_{IF}} = \sqrt{B_{P_{IF}}{}^2 + \left(tS_{W_{input}}\right)^2}$$

$$U_{P_{indoor}} = \sqrt{B_{P_{indoor}}{}^2 + \left(tS_{P_{indoor}}\right)^2}$$

Where:

$B_{W_{input}} = B_{P_{IF}} = B_{P_{indoor}} = 0.02$ *OR Value specified by measurement device*

$t = 1.96$

See assumptions above.

F4.4. *Efficiency*. As defined in ASHRAE 37, steady-state energy-efficiency ratio (EER_{ss}) can be calculated as shown in Equation 44.

$$EER_{ss} = q_{tci}/E_t \qquad \textbf{44}$$

$$U_{EER_{ss}} = \sqrt{\left(\frac{1}{E_t}U_{q_{tci}}\right)^2 + \left(\frac{q_{tci}}{E_t^2}U_{E_t}\right)^2}$$

F4.5. *Pressure Drop*. Pressure Drop (ΔP) is defined as Inlet Pressure (P_1) minus Outlet Pressure (P_2). Pressure Drop Uncertainty can be calculated as shown in Equation 45:

$$U_{\Delta P} = \sqrt{{U_{P_{inlet}}}^2 + {U_{p_{outlet}}}^2} \qquad \textbf{45}$$

Where:

$$U_{P_{inlet}} = \sqrt{{B_{P_{inlet}}}^2 + (tS_{P_{inlet}})^2}$$

$$U_{P_{outlet}} = \sqrt{{B_{P_{outlet}}}^2 + (tS_{P_{outlet}})^2}$$

Where:

$B_{P_{inlet}} = B_{P_{outlet}}$ =0.02 OR Value specified by measurement device

$t = 1.96$