ANSI/AHRI Standard 1520-2022 (SI/I-P)

2022 Standard for

Performance Rating of Centrifugal Refrigerant Compressors

Approved American National Standard
ANSI

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ICS Code: 23.140

Note:

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

This standard was approved as an American National Standard (ANS) on 8 June 2023.

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PERFORMANCE RATING OF CENTRIFUGAL REFRIGERANT COMPRESSORS

Section 1. Purpose

1.1 *Purpose.* The purpose of this standard is to establish for Centrifugal Compressors: definitions, test requirements, rating requirements, minimum data requirements for Published Ratings, operating requirements, marking and nameplate data, and conformance conditions.

1.1.1 *Intent.* This standard is intended for the guidance of the industry, including manufacturers, engineers, installers, contractors and users. The standard defines the minimum amount of information, in a standard form to enable the evaluation and comparison of different Centrifugal Compressors for use in an application.

1.1.2 *Review and Amendment.* This standard is subject to review and amendment as technology advances.

Section 2. Scope

2.1 *Scope.* This standard applies to Centrifugal Compressors and their presentation of performance in heating, ventilation, and air-conditioning applications. The manufacturer is solely responsible for the determination of values to be used in published product information. This standard stipulates the minimum amount of information to be provided and suggests a method to be used to verify the accuracy of that information.

2.2 Exclusions.

2.2.1 This standard does not apply to compressors intended for use in:

a. Household refrigerators and freezers
b. Automotive air-conditioners
c. Household dehumidifiers
d. Industrial products other than heating and cooling
e. Compressed air applications

2.2.2 This standard does not apply to compressors when contained within a package or system.

Section 3. Definitions

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

3.1 *Flow.* Volumetric flow rate through the compressor expressed in ft^3/min, m^3/sec.

3.2 *Individual Published Rating.* A data table used to represent the nominal performance of a Compressor at a single Step.

3.3 *Interstage Port.* An inlet port for vapor or liquid between two stages of compression.

3.4 *Model Number*. The identifier for a product containing one or more Compressors and any accessories that are supplied by the manufacturer, required to sustain operation of the Compressor(s) at the rating conditions or that impact the Published Rating.

Note: Accessories may include, but are not limited to, interconnecting piping, fans, liquid receivers, desuperheaters, strainers, service valves, check valves, suction filters, lubricant separators, motors, motor starters, and unloaders, as supplied or specified by the compressor manufacturer.

3.4.1 *Centrifugal Compressor*. A dynamic compression machine in which an increase in refrigerant vapor pressure is attained by imparting velocity to the refrigerant and then increasing static pressure by a reduction in the velocity through work applied to the compressor's mechanism. For clarity of this standard, the term Compressor implies Centrifugal Compressor.

3.4.2 *Compressor Housing Types*

3.4.2.1 *Hermetic Refrigerant Compressor*. A Compressor and motor assembly, both of which are contained within a gas tight housing that is permanently sealed by welding or brazing with no access for servicing internal parts in the field.

3.4.2.2 *Open Type Refrigerant Compressor*. A Compressor with a shaft or other moving part extending through its casing to be driven by an outside source of power thus requiring a shaft seal or equivalent rubbing contact between fixed and moving parts.

3.4.2.3 *Semi-hermetic Refrigerant Compressor*. A Compressor and motor assembly contained within a gas-tight housing that is sealed by gasketed joints to provide access for servicing internal parts.

3.5 *Population of Compressors*. Compressors intended to perform the same function, produced in quantity, manufactured to the same technical specifications and characterized by the same Published Rating.

3.6 *Power Input.* The time rate of energy usage of the Compressor (compressor power) plus any accessories required to sustain operation of the compressor at the Rating Condition.

3.7 *Published Operating Range.* The applicable boundaries of head and flow coefficients for which ratings are published.

3.8 *Published Rating.* Composed of Individual Published Ratings used to represent the nominal performance of a Compressor.

3.8.1 *Individual Published Rating.* A data table used to represent the nominal performance of a Compressor at a single Step.

3.9 *Rating Condition*. A saturated suction temperature and saturated discharge temperature point used to determine the number of Steps required to be published per Section 5.

3.10 *Rating Uncertainty Limit (Tolerance).* The limit within which the measured performance of an individual Compressor falls relative to the Published Rating.

3.11 *Reference Rating Conditions.* A specific operating condition selected from Table 4 for quick reference or comparison.

3.12 *Refrigerant Mass Flow Rate*. The mass flow rate of the volatile refrigerant, which is potentially mixed with lubricant.

3.13 *Refrigerating Capacity*. The capacity associated with the increase in total enthalpy between the refrigerant entering the evaporator and the superheated return gas entering the Compressor. The calculation of Refrigeration Capacity does not include parasitic heat transfer effects., expressed in Btu/h, W.

Terms used to determine the number of Steps required to be published per Section 5:

3.13.1 *Maximum Capacity*. The rated Refrigerating Capacity of the modulating Compressor operating at the Maximum Step for a manufacturer defined Rating Condition, expressed in Btu/h, W.

3.13.2 *Minimum Capacity*. The rated Refrigerating Capacity of the modulating Compressor operating at the Minimum Step for a manufacturer defined Rating Condition, expressed in Btu/h, W.

3.13.3 *% Capacity.* A percentage of the Maximum Capacity based on the manufacturer defined Rating Condition at a specific Step (Maximum Capacity is 100% Capacity).

3.14 *Step.* A level of modulation achieved by changing the Flow not limited to the examples listed below:

3.14.1 *Step Method*

a. VFD frequency, Hz
b. Compressor speed, RPM
c. Mechanical unloading setting (fixed or time weighted average) (%).

Note: This "%" is a representation or name of the Step and not necessarily an actual % Capacity.

3.14.2 *Maximum Step*. The Step producing the highest Flow of the modulating Compressor.

3.14.3 *Minimum Step*. The Step producing the lowest Flow of the modulating Compressor.

3.15 *"Shall"* or *"Should," shall be interpreted as follows:*

3.15.1 *Shall.* Where "shall" or "shall not" is used for a provision specified, that provision is mandatory if compliance with the standard is claimed.

3.15.2 *Should.* "Should" is used to indicate provisions which are not mandatory, but which are desirable as good practice.

3.16 *Vapor Injection.* A method of increasing evaporator capacity using an economizer to sub-cool liquid refrigerant exiting the condenser and reducing discharge temperature. Refrigerant vapor or wet vapor that exits the economizer enters an intermediate port or an interstage port on the compressor.

3.17 *Variable Frequency Drive (VFD)*. A power electronic device that regulates the speed of an alternating current (AC) motor by adjusting the frequency and the voltage of the electrical power supplied to the motor.

Section 4. Test Requirements

4.1 *Test Requirements*. All Published Ratings shall be verified by tests conducted in accordance with ANSI/ASHRAE Standard 225.

4.2 *Ambient Temperature*. Published Ratings shall be established with an ambient temperature around the Compressor and its accessories of 95.0°F, 35.0°C. If Published Ratings are established at ambient temperatures other than 95.0°F, 35.0°C, the actual ambient temperature used to establish the Published Ratings shall be stated by the manufacturer.

4.3 *Airflow*. Published Ratings shall be established with no airflow across the Compressor. If Published Ratings are established with airflow across the compressor, the details of the airflow over the Compressor used to establish Published Ratings shall be stated by the manufacturer.

4.4 *Nameplate Voltages for Rating*. Published Ratings shall be established using the nameplate rated voltage and frequency. For dual nameplate voltage ratings, Published Ratings shall be established using both voltages, or using the higher of the two voltages, if only a single rating is to be published.

4.5 *Power Input*. For Hermetic or Semi-hermetic Refrigerant Compressors with a factory integrated or factory specified VFD, the Power Input is measured at the VFD input terminals. If accessories are not included, it shall be explicitly stated.

Section 5. Rating Requirements

5.1 *Published Rating.* A Published Rating is one or more Individual Published Ratings that represents Flow coefficient, head coefficient, and isentropic efficiency parameters across the Published Operating Range of the Compressor.

5.1.1 *Reference Rating Condition*. Superheat, Subcooling, Saturation Temperatures, and/or return gas temperature conditions specified in Table 4 shall be used for reference rating conditions. The intent of the reference rating conditions is for manufacturers to publish performance for the ease of comparing to other compressors.

5.1.2 *Continuous Modulating Compressor*. The Published Rating of a continuous modulating Compressor shall be provided per the following requirements to comprise each set of Individual Published Ratings.

5.1.2.1 An Individual Published Rating of the Compressor at the Maximum Rated Step.

5.1.2.2 An Individual Published Rating of the Compressor at the Minimum Rated Step.

5.1.2.3 At least two Individual Published Ratings of the Compressor between the Maximum and Minimum Rated Step.

5.1.2.3.1 Each Step shall be evenly spaced between the Maximum and Minimum Rated Step within ± 5%.

5.1.2.4 An individual published rating of the Compressor shall contain sufficient points such that interpolation between the points produces a representation within the specified uncertainty found in Table 4 and Figure 1.

5.1.3 *Operating map***.**

5.1.3.1 *Surge definition.* The lowest flow point along an Individual Published Rating will be considered the last stable operating point prior to surge at that step.

5.1.3.2 *Choke definition.* The highest flow point along an Individual Published Rating will be considered the choke point.

5.5 *Rating Methods*. Compressors or compressor units shall be rated in one of four ways shown in Table 1. Manufacturers shall declare which rating method is used when providing Published Ratings. If no method is referenced it is assumed that AHRI Standard 1520 Method 1 is used.

Table 1. Rating Methods[1,]

Method	Economizer	Liquid Leaving Condenser	Liquid Exiting Economizer	Vapor Exiting Economizer
1	None	N/A	N/A	N/A
2	Manufacturer Specified Heat Exchanger	Note 2	Note 3	Stated by manufacturer
3	Non-Specified Heat Exchanger	Note 2	Note 3	Note 4
4	Flash Tank	Note 2	Note 3	Note 5

Notes:

1. For all methods, other than mechanical sub-cooling in the economizer, there is no parasitic heat gain or loss in the liquid line.
2. Liquid temperature leaving the condenser shall be assumed to have 0 ºR, 0 K subcooling unless otherwise stated by the manufacturer.
3. Manufacturer shall specify the outlet liquid temperature of the Economizer or the approach temperature.
4. Vapor temperature leaving the economizer shall be 9 ºR, 5 K above the dew point temperature corresponding to the pressure at the Intermediate or Interstage Port of the compressor.
5. Vapor temperature leaving the economizer shall be equal to the dew point temperature corresponding to the pressure at the Intermediate or Interstage Port of the compressor.

5.6 *Rating Uncertainty Limits of Published Ratings.* To comply with this standard, single sample product verification test results, conducted at conditions within the Application Envelope defined in Table 2. and Table 3, shall meet the Published Ratings of the Compressor within the Rating Uncertainty Limits defined in Table 4, unless uncertainty is specified differently by the manufacturer for each rating point.

Table 2. Application Envelope (I-P)

Rating Conditions	Region 1	Region 2	Region 3
Suction Dew Point, °F	≥-40 and <0	≥0 and <30	≥30 and ≤70
Discharge Dew Point, °F Subcritical Condensing Applications	≥-5 and <140	≥20 and ≤140	≥50 and ≤140

Table 3. Application Envelope (SI)

Rating Conditions	Region 1	Region 2	Region 3
Suction Dew Point, °C	≥-40 and <-20	≥-20 and <-1	≥-1 and ≤21
Discharge Dew Point, °C Subcritical Condensing Applications	≥-20 and <55	≥-6.5 and ≤60	≥50 and ≤60

Table 4. Rating Uncertainty Limits

Published Rating		Region 1	Region 2	Region 3
Refrigerant Mass Flow, lb/min Refrigerating Capacity, Btu/hr EER, Btu/W*h COP, W/W	Full Load	Tested Rating ≥ 90.0% x Published Rating	Tested Rating ≥ 92.5% x Published Rating	Tested Rating ≥ 95.0% x Published Rating
	Part Load	Tested Rating ≥ (100% - UL_{R2}) x Published Rating	Tested Rating ≥ (100% - UL_{R2}) x Published Rating	Tested Rating ≥ (100% - UL_{R3}) x Published Rating
Input Power, kW	Full Load	Tested Rating ≤ 110.0% x Published Rating	Tested Rating ≤ 107.5% x Published Rating	Tested Rating ≤ 105.0% x Published Rating
	Part Load	Tested Rating ≤ (100% + UL_{R2}) x Published Rating	Tested Rating ≤ (100% + UL_{R2}) x Published Rating	Tested Rating ≤ (100% + UL_{R3}) x Published Rating

Rating Uncertainty Limits are calculated as follows as follows in equations 1-3:

$$UL_{R1} = (\%\ Capacity) \times (-0.0625) + 0.1625 \quad (1)$$

$$UL_{R2} = (\%\ Capacity) \times (-0.0625) + 0.1375 \quad (2)$$

$$UL_{R3} = (\%\ Capacity) \times (-0.0625) + 0.1125 \quad (3)$$

Where:
UL_{R1} = Rating Uncertainty Limit in Region 1
UL_{R2} = Rating Uncertainty Limit in Region 2
UL_{R3} = Rating Uncertainty Limit in Region 3

Figure 1 is a graphical representation of the Rating Uncertainty Limits for minimum Refrigerating Capacity, Refrigerant Mass Flow Rate, EER, COP, and Input Power shown in Table 4.

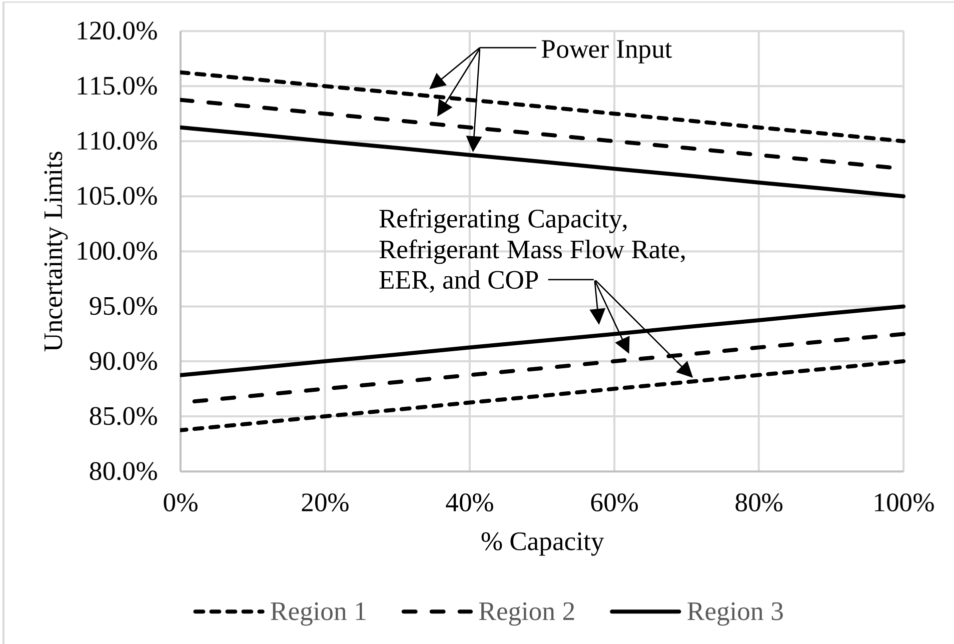

Figure 1. Rating Uncertainty Limits

Figure 2, Figure 3, are graphical representations of the Application Envelopes shown in Table 2 and Table 3.

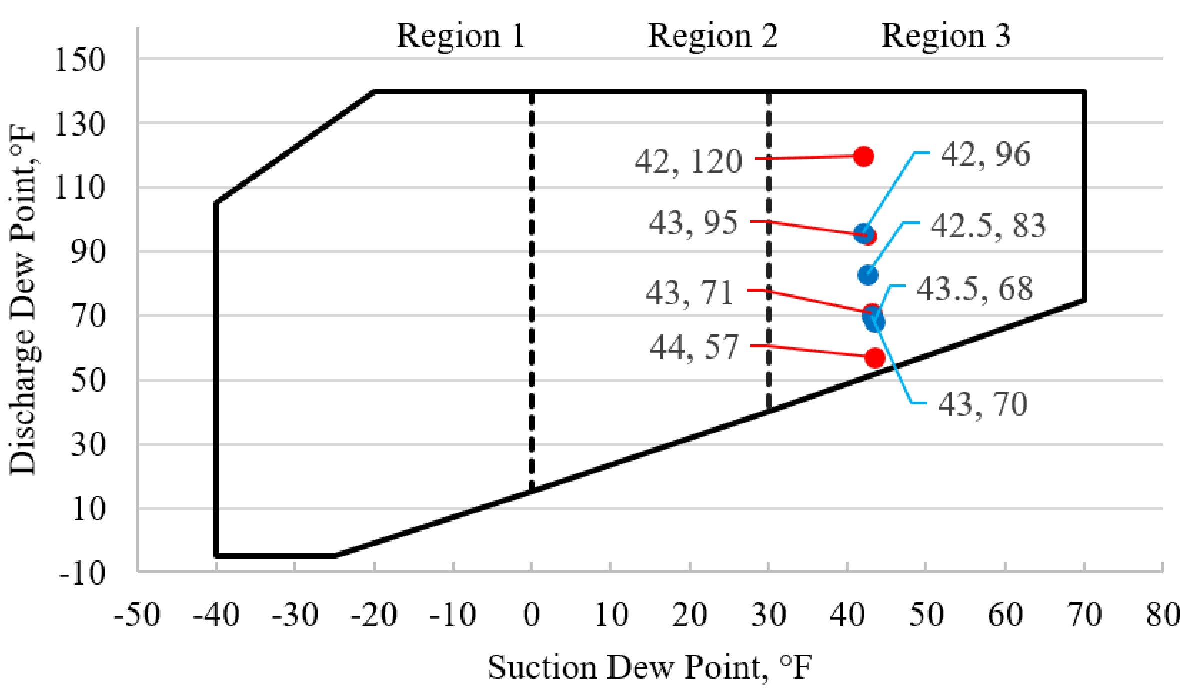

Figure 2. Application Envelope with Reference Rating Conditions Shown (I-P)

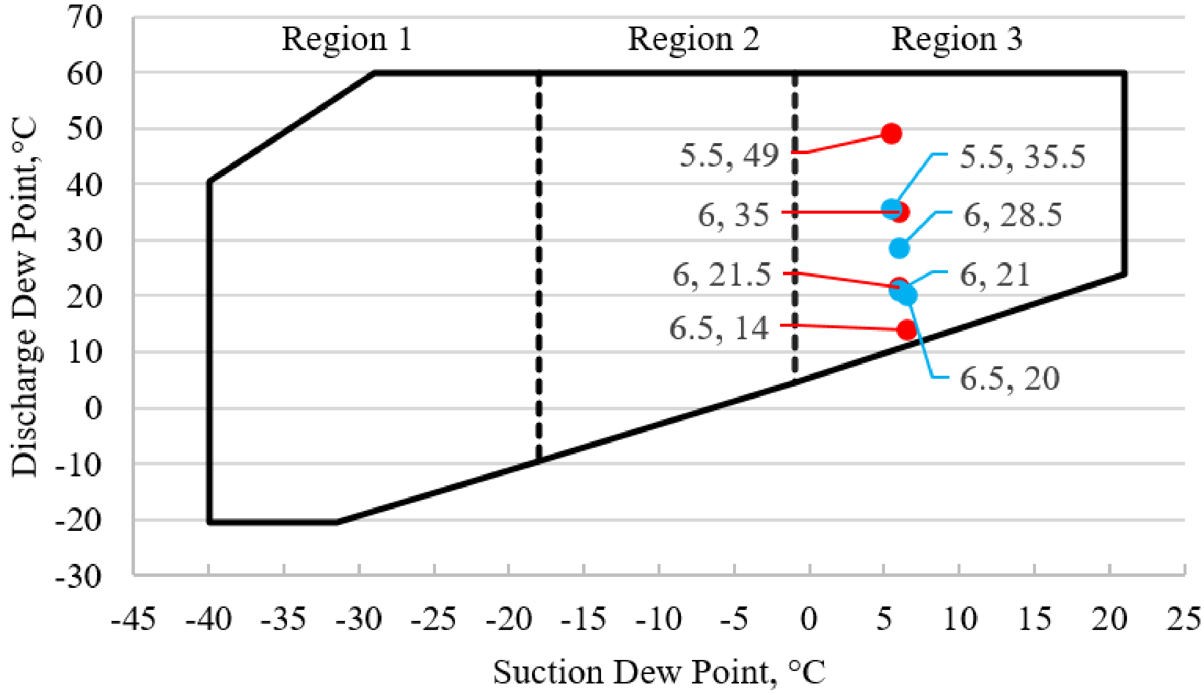

Figure 3. Application Envelope with Reference Rating Conditions Shown (SI)

5.7 *Reference Rating Conditions.* The manufacturer shall identify the operating condition when publishing single point rating information. Reference rating conditions are shown in Table 5 and Table 6.

Table 5. Reference Rating Conditions (I-P)[2]

Temperature Points	% Capacity			
	100	**75**	**50**	**25**
Suction Dew Point, °F	43	43	43	43
Discharge Dew Point (air-cooled), °F	124	102	82	66
Discharge Dew Point (water-cooled), °F	97	84	72	68
Suction Return Gas Temperature, °F or	63	63	63	63
Superheat[1], R	20	20	20	20
SubcoolinE3, R	0	0	0	0

Notes:
1) The manufacturer shall clearly state which superheat is published.
2) Refer to Figure 2 graphical representation of the Reference Rating Conditions.
3) Refer to Appendix C for subcooling calculation for capacity.

Table 6. Reference Rating Conditions (SI)[2]

Temperature Points	% Capacity			
	100	**75**	**50**	**25**
Suction Dew Point, °C	6	6	6	6
Discharge Dew Point (air-cooled), °C	51	39	28	19
Discharge Dew Point (water-cooled), °C	36	29	22	20
Suction Return Gas Temperature, °C	17	17	17	17
or Superheat[1], K	11	11	11	11
SubcoolinE3, K	0	0	0	0

Notes:

1) The manufacturer shall clearly state which superheat is published.
2) Refer to Figure 3 graphical representation of the Reference Rating Conditions.
3) Refer to Appendix C for subcooling calculation for capacity.

Section 6. Minimum Data Requirements for Published Ratings

6.1 *Minimum Data Requirements for Published Ratings.* Table 7 provides minimum data requirements for published ratings. At a minimum a data point at the 100% Reference Rating Condition shall be published. Any exceptions to the ambient temperature and airflow per Section 4.2 and 4.3 shall be stated.

Table 7. Published Ratings

Published Values	Units
General	
Model Number	-
Refrigerant Designation per ANSI/ASHRAE Standard 34	-
Voltage	V
Phase	-
Frequency	Hz
Rating Method	-
Performance Data	
Overall Compressor Efficiency[1, 2, 3, 4]	-
Refrigerant flow coefficient (suction) of each Stage	-
Head coefficient of each Stage	-
Refrigerating Capacity at 100% reference point	
Power at 100% reference point	
Additional Information	
Step	Hz, RPM, %, Hz
Step Method	VFD frequency, Compressor speed, Mechanical unloading (IGV and/or diffuser setting)

Notes:

1. If a compressor package includes a motor and/or VFD, the motor and/or VFD shall be included as part of the published efficiency rating.
2. Motor and/or VFD part number shall be published if motor and/or VFD efficiency is included in ratings and the motor and/or VFD is not shipped with the Compressor.
3. In the case of open drive compressors, efficiency will be relative to shaft input power.
4. If Published Ratings include the efficiency of the motor and/or VFD and are established with additional cooling means, or an ambient temperature other than defined in Section 4, the details of the cooling fluid, fluid flow rate and entering fluid temperature cooling the motor and/or VFD shall be stated by the manufacturer.

6.2 *Claims to Ratings.* All claims to ratings within the scope of this standard shall include the statement "Rated in accordance with AHRI Standard 1520". All claims to ratings outside the scope of this standard shall include the statement "Outside the scope of AHRI Standard 1520". Wherever ratings are published or printed, they shall include a statement of the conditions at which the ratings apply. If no Rating Method is explicitly identified, Rating Method 1 is assumed.

Section 7. Operating Requirements

7.1 *Loading Requirements*. The Compressor shall be capable of operating continuously at all operating points in the Published Operating Range for a minimum period of two hours at the minimum and maximum utilization voltage as described in ANSI/AHRI Standard 110, Table 1. There is no expectation that the Compressor will meet the Published Rating at the maximum or minimum utilization voltage.

Section 8. Marking and Nameplate Data

8.1 *Compressor Nameplate Marking*. As a minimum, each Compressor shall have a nameplate, affixed on which the following information shall be marked:

8.1.1 Compressor manufacturer's name and/or symbol
8.1.2 Compressor Model Number
8.1.3 Electrical Information, Input (For Hermetic and Semi-hermetic Refrigerant Compressors)

8.1.3.1 Voltage, V
8.1.3.2 Phase
8.1.3.3 Frequency, Hz

8.1.4 Maximum Permissible Speed (For Open Type Refrigerant Compressors)

Section 9. Conformance Conditions

9.1 *Conformance*. While conformance with this standard is voluntary, conformance shall not be claimed or implied for products or equipment within the standard's Purpose (Section 1) and Scope (Section 2) unless such product claims meet all of the requirements of the standard and all of the testing and rating requirements are measured and reported in complete compliance with the standard. Any product that has not met all the requirements of the standard shall not 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 standard. All references in this appendix are considered as part of the standard.

A1.1 ANSI/AHRI Standard 110-2016, *Air-Conditioning, Heating, and Refrigerating Equipment Nameplate Voltages*, 2016, Air-Conditioning, Heating, and Refrigeration Institute, 2311 Wilson Boulevard, Suite 400, Arlington, VA 22201, U.S.A.

A1.2 ANSI/ASHRAE Standard 225-2020, *Methods for Performance Testing Centrifugal Refrigerant Compressors and Condensing Units*, 2020, ASHRAE, 180 Technology Parkway, Peachtree Corners, GA 30092.

A1.3 ASHRAE Terminology. ASHRAE. Accessed August 27, 2021. https://www.ashrae.org/resources–publications/free-resources/ashrae-terminology.

APPENDIX B. REFERENCES – INFORMATIVE

B1 Listed here are all standards, handbooks, and other publications not essential to the formation and implementation of the standard and intended for referenced only.

B1.1 AHRI/ASERCOM White Paper: January 2017, *Tolerances and Uncertainties in Performance Data of Refrigerant Compressors,* Air- Conditioning, Heating, and Refrigeration Institute, 2311 Wilson Boulevard, Suite 500, Arlington, VA 22201, U.S.A., Association of European Refrigeration Component Manufacturers, Rue du Congrès 35, 1000 Brussels, Belgium.

B1.2 Brasz, J.J., *A Proposed Centrifugal Refrigeration Compressor Rating Method*, International Compressor Engineering Conference, 2010.

B1.3 PTC 10-1997 (R2014), *Performance Test Code on Compressors and Exhausters*, 1997 (R2014), ASME International, Two Park Avenue, New York, NY 10016, U.S.A.

B1.4 AHRI Standard 550/590, *Standard for Performance Rating of Water-chilling and Heat Pump Water-heating Packages Using the Vapor Compression Cycle*, 2020, Air-Conditioning, Heating, and Refrigeration Institute, 2311 Wilson Boulevard, Suite 400, Arlington, VA 22201, U.S.A.

APPENDIX C. VERIFICATION OF PUBLISHED RATINGS FOR A POPULATION OF COMPRESSORS – INFORMATIVE

C1 The purpose of this appendix is to provide additional information and a proposed method to verify Published Ratings for a Population of Compressors using a sample of a normally distributed population.

C2 *General Discussion*. To comply with this standard, single sample product verification test results shall meet the Published Rating of the Compressor within the Rating Uncertainty Limits defined in Table 4 Therefore, to publish the performance rating of a Population of Compressors, it is necessary to provide a nominal value representing the average performance of the compressor, and to also provide information on the uncertainty that can be expected for that representative rating. This uncertainty is the result of factors including measurement uncertainty, lab to lab testing reproducibility uncertainty, manufacturing uncertainty, performance prediction uncertainty, and tested vs rated condition uncertainty, all of which are described in the AHRI/ASERCOM White Paper.

C3 *Rating Uncertainty Limits*. For verification purposes, it is necessary to specify both an uncertainty limit and the size of the portion that can be expected to fall within the limit. The uncertainty limits are given in Table C1 and it can be assumed that 95% of a Population of Compressors will fall within these limits.

C4 *Rating Uncertainty Limits of Published Ratings for a Population of Compressors Using a Sample Size of 3*. Rating Uncertainty Limits of Published Ratings for a Population of Compressors using a sample size of three are determined with the following method.

A sample size of n=3 is taken at random from the Population of Compressors. The measured performance values are each measured to calculate an averaged test value (V_{avg}).

If V_{avg} is within the Rating Uncertainty Limits for the average of three samples as given in Table C1, the Published Rating is verified. Note that for this case when the sample size is larger than one, the Rating Uncertainty Limits (Table C1) are less than the Rating Uncertainty Limits in Table 4. This is due to the decreased uncertainty of the rating due to the increased sample size of the measurement.

Table C1. Rating Uncertainty Limits Using a Sample Size of 3

Published Rating		Region 1	Region 2	Region 3
Refrigerant Mass Flow, lb/min Refrigerating Capacity, Btu/hr EER, Btu/W*h COP, W/W	Full Load	Tested Rating ≥ 94.5% x Published Rating	Tested Rating ≥ 95.5% x Published Rating	Tested Rating ≥ 97.0% x Published Rating
	Part Load	Tested Rating ≥ (104.5% - UL_{R1}) x Published Rating	Tested Rating ≥ (103% - UL_{R2}) x Published Rating	Tested Rating ≥ (102% - UL_{R3}) x Published Rating
Input Power, kW	Full Load	Tested Rating ≤ 105.5% x Published Rating	Tested Rating ≤ 104.5% x Published Rating	Tested Rating ≤ 103.0% x Published Rating
	Part Load	Tested Rating ≤ (100% + UL_{R1}) x Published Rating	Tested Rating ≤ (100% + UL_{R2}) x Published Rating	Tested Rating ≤ (100% + UL_{R3}) x Published Rating

C5 *Examples*.

C5.1 *Example 1 (I-P)*.

A Population of Compressors has a published value for Power Input of 10.000 kW at 43/124°F.

A single compressor is selected for verification and tested at 43/124°F as outlined in Section 4. The tested value is 10.4 kW. The ratio of the tested value to the published value is 104%. For this case, the published value is verified.

Three compressors are selected for verification and tested at 43/124°F as outlined in Section 4. The tested values are 10.292 kW, 10.400 kW, and 10.358 kW respectively. The average for the three samples is 10.35 kW. The ratio of the average value to the published value is 103.5%. For this case the published value is not verified.

C5.2 *Example 2 (SI)*.

A Population of Compressors has a published Refrigerating Capacity of 8.200 kW at 10/46°C.

A single compressor is selected for verification and tested at 10/46°C as outlined in Section 4. The tested value is 7.878 kW. The ratio of the tested value to the published value is 96.1%. For this case, the published value is verified.

Three compressors are selected and tested at 10/46°C as outlined in Section 4. The tested values are 7.878 kW, 8.294 kW, and 7.913 kW respectively. The average for the three samples is 8.028 kW. The ratio of the average value to the published value is 97.9%. For this case the published value is verified.

APPENDIX D. DERIVATION OF REFERENCE RATING CONDITIONS – INFORMATIVE

D1 The purpose of this appendix is to provide the explanation for the derivation of the reference rating conditions.

Table D1. Sample Compressor Rating Conditions based on AHRI 550/590 Standard Water-Cooled Chiller Rating Conditions*

Rating Values	Units	Point A	Point B	Point C	Point D
% Load (400 ton Chiller)		100	75	50	25
Entering Condenser Water Temp	°F	85.0	75.0	65.0	65.0
Leaving Condenser Water Temp	°F	95.0	82.5	71.0	67.5
Condenser Approach Temp (includes fouling)	°F	2.0	1.5	1.0	0.5
SDT	°F	97.0	84.0	72.0	68.0
Condenser Subcooling Approach Temp	°F	0.0	0.0	0.0	0.0
Condenser Subcooled Liquid Temp	°F	97.0	84.0	72.0	68.0
Leaving Evaporator Water Temp	°F	44.0	44.0	44.0	44.0
Evaporator Approach Temperature (includes fouling)	°F	1.0	1.0	1.0	1.0
SST	°F	43.0	43.0	43.0	43.0

*Assumes flooded shell and tube evaporators and condensers

Table D2. Sample Compressor Rating Conditions based on AHRI 550/590 Standard Air-Cooled Chiller Rating Conditions*

Rating Values	Units	Point A	Point B	Point C	Point D
% Load (150 ton Chiller)		100	75	50	25
Ambient Air Temp	°F	95.0	80.0	65.0	55.0
Leaving Condenser Air Temp	°F	115.0	95.0	75.0	65.0
Condenser Approach Temp	°F	10.0	8.0	6.0	4.0
SDT	°F	125.0	103.0	81.0	69.0
Condenser Subcooling Approach Temp	°F	0.0	0.0	0.0	0.0
Condenser Subcooled Liquid Temp	°F	125.0	103.0	81.0	69.0
Leaving Evaporator Water Temp	°F	44.0	44.0	44.0	44.0
Evaporator Approach Temperature (includes fouling)	°F	1.0	1.0	1.0	1.0
SST	°F	43.0	43.0	43.0	43.0

* Assumes Microchannel Condenser and Flooded Shell and Tube Evaporator

APPENDIX E. METHODS FOR CALCULATING CENTRIFUGAL COMPRESSORS PERFORMANCE - INFORMATIVE

E1. *Compressor Performance Parameters*

Centrifugal Compressor thermodynamic performance is historically represented with dimensionless parameters for flow, head, and efficiency as in B1.3. For refrigeration compressor, we will adopt variations on the parameters used by Brasz in B1.2 shown in Equations E1, E2, and E3 below.

Flow Factor: $$FF = \frac{\dot{m}_0}{\rho_0 a_0}$$ E1

Head Factor: $$HF = \frac{\Delta h_s}{a_0^2}$$ E2

Isentropic Efficiency: $$\eta_{is} = \frac{\Delta h_s}{\Delta h_a}$$ E3

Where $\dot{m}_0$ is suction mass flow, ρ_0 is suction density, a_0 is suction sonic velocity, Δh_s is isentropic enthalpy rise, and Δh_a is the actual enthalpy rise. With the exception of FF the other two parameters are dimensionless. The impeller diameter squared term (D^2), inB.1.2, has been taken out of the denominator for proprietary reasons and it is a constant throughout the operating range.

E1.1 *Parasitic Losses*

The above compressor performance parameter only pertains to the aerodynamic or thermodynamic performance. There are other losses to be accounted for including but not restricted to bearings, motor windage, motor electrical, and variable frequency drives. Efficiency will be defined based on input power of the unit under test (UUT) to account for the parasitic losses. The calculation method is outlined below.

E1.2 *Method*

Figure E1 is a schematic of a two-stage compressor with economizer injection. State points are defined at the compressor flanges for all inlets and exits. Mass flow is defined at two of the three state points.

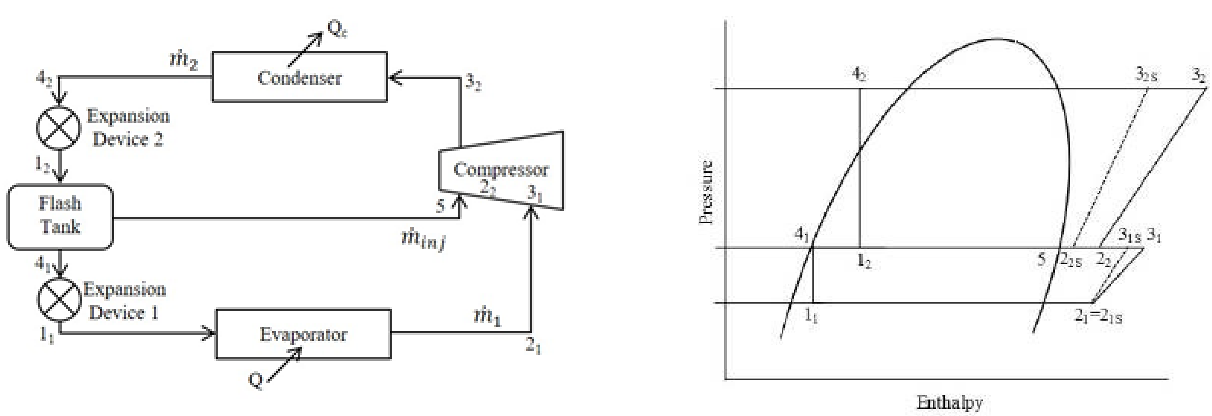

Figure E1: **Cycle schematic and pressure-enthalpy diagram for a two-stage compressor with vapor injection using a flash tank economizer**

State point 2_{2s} which is at the injection flow inlet pressure represents a mixed-out flow condition of the primary flow and injection flow. The mixed-out state point 2_{2s} is at the same pressure as the exit of the first stage and the economizer. However, the enthalpy of state point 2_{2s} is calculated by Equation E10. The isentropic state point at the exit of the first stage is used and does not require measurement of first stage exit temperature. This is consistent with ASHRAE Standard 225. Equations E4, E6 and E8 are in SI units and E5, E7 and E9 are in I-P units.

Flow factor, shall be calculated using Equation E4 for SI units or Equation E5 for I-P units:

$$FF_{2_1} = \frac{\dot{m}_1}{\rho_{2_1} a_{2_1}} \quad \text{E4}$$

$$FF_{2_1} = \frac{\dot{m}_1}{3600\ \rho_{2_1} a_{2_1}} \quad \text{E5}$$

$$HF_i = \frac{(h_{3_{is}} - h_{2_{is}})}{a_{2_1}^2} \cdot 1000 \quad \text{E6}$$

$$HF_i = \frac{(h_{3_{is}} - h_{2_{is}})}{a_{2_1}^2} \cdot 25{,}037 \quad \text{E7}$$

$$\eta = \frac{\left[\dot{m}_1\left(h_{3_{1s}} - h_{2_{1s}}\right) + \dot{m}_2\left(h_{3_{2s}} - h_{2_{2s}}\right)\right]}{P} \times 100 \quad \text{E8}$$

$$\eta = \frac{\left[\dot{m}_1\left(h_{3_{1s}} - h_{2_{1s}}\right) + \dot{m}_2\left(h_{3_{2s}} - h_{2_{2s}}\right)\right]}{P} \times 0.02931 \quad \text{E9}$$

$$h_{2_{2s}} = \frac{\left(\dot{m}_1 h_{3_{1s}} + \dot{m}_5 h_5\right)}{\dot{m}_2} \quad \text{E10}$$

E1.3 *Extension to different number of stages*

For more than two stages, the method outlined in E1.2 can be extended. For multi-stage compressors, the flow factor shall be calculated for the first stage only. Equations E11-E14outline the estimation of head factor and overall efficiency. Equations E13 and E14 are similar to E8 and E9 and will be used for estimating the mixed-out conditions for the stage receiving the economized flow.

$$HF_i = \frac{(h_{3_{is}} - h_{2_{is}})}{a_{2_1}^2} \cdot 1000 \quad \text{E11}$$

$$HF_i = \frac{(h_{3_{is}} - h_{2_{is}})}{a_{2_1}^2} \cdot 25{,}037 \quad \text{E12}$$

$$\eta = \frac{\left[\sum_{i=1}^{NS} \dot{m}_i (h_{3_{is}} - h_{2_{is}})\right]}{P} \times 100 \quad \text{E13}$$

$$\eta = \frac{\left[\sum_{i=1}^{NS} \dot{m}_i (h_{3_{is}} - h_{2_{is}})\right]}{P} \times 0.02931 \quad \text{E14}$$

E2. *Example for calculation of Performance*

The compressor manufacturer should provide performance parameters in a tabular format for both stages segmented by inlet guide vane (IGV), speed, etc. Table E1 is an example of a fixed speed R134a compressor with IGVs. Table E2 is an example calculation using the data in Table E1.

Table E1. Stage Performance Data

1st Stage	**IGV** (deg)	*(Surge)* *90*	*90*	*90*	*90*	*90*	*(Choke)* *90*
	FF_{2_1}	0.0154	0.0175	0.0190	0.0208	0.0216	0.0219
	HF_1	0.5543	0.5284	0.4972	0.4280	0.3669	0.3109
	EFF_{OA}	0.7147	0.7297	0.7359	0.7008	0.6490	0.5669
	IGV (deg)	*(Surge)* *75*	*75*	*75*	*75*	*75*	*(Choke)* *75*
	FF_{2_1}	0.0149	0.0164	0.0179	0.0198	0.0206	0.0210
	HF_1	0.5394	0.5181	0.4887	0.4118	0.3483	0.2927
	EFF_{OA}	0.7126	0.7231	0.7305	0.6878	0.6378	0.5480
2nd Stage	**IGV** (deg)	*(Surge)* *90*	*90*	*90*	*90*	*90*	*(Choke)* *90*
	FF_{2_1}	0.0154	0.0175	0.0190	0.0208	0.0216	0.0219
	HF_2	0.5075	0.4909	0.4794	0.4291	0.3766	0.3027
	IGV (deg)	*(Surge)* *75*	*75*	*75*	*75*	*75*	*(Choke)* *75*
	FF_{2_1}	0.0149	0.0164	0.0179	0.0198	0.0206	0.0210
	HF_2	0.5070	0.4915	0.4766	0.4197	0.3623	0.2836

Table E2. Two Stage Performance Parameters Segmented by IGV

			R134a		
Step 1	*Inputs*				
	Parameter	Variable	Value	Unit	Notes
	Saturated Suction Temperature	$T_{sat, suct}$	37.76	°F	
	Suction Superheat	SH	0.78	R	
	Saturated Discharge Temperature	$T_{sat, disch}$	95.73	°F	
	Subcooling	SC	0.00	R	
	Refrigerating Capacity	Q	207.73	Tons	
Step 2	*Calculate Flange Conditions*				
	Suction Pressure	P_{21s}	47.615	Psia	
	Suction Temperature	T_{21s}	38.54	°F	
	Suction Density	ρ_{21s}	1.0035	lb/ft³	

	Suction Enthalpy	H_{21s}	172.35	Btu/lb	
	Suction Entropy	S_{21s}	0.4125	Btu/lb	
	Suction Sonic Velocity	A_{21s}	482.4	ft/s	
	Discharge Pressure	P_{31}	130.10	psia	
	Lvg Condenser Enthalpy	H_{42}	107.30	Btu/lb	
Step 3	*Goal Seek on FF to meet P_4*				
	Flow Factor for 90 deg IGV	FF_{90}	0.01895	ft²	Goal Seek on FF along the 90 deg IGVuntil discharge pressure meets user input
	Discharge Pressure Difference	$\Delta P_{32, 90}$	0.0000		
Step 4	*Table Lookup*				
	First Stage				
	HF 1 at 90 deg IGV for FF = 0.019	$HF_{1, 90}$	0.4977		
	EFF OA at 90 deg IGV for FF = 0.019	$EFF_{OA, 90}$	0.7358		
	Second Stage				
	HF2 at 90 deg IGV for FF = 0.019	$HF_{2, 90}$	0.4801		
Step 5	*Calculate Cycle and Mass Flow with Economizer Pressure*				
	First Stage, 90deg IGV				
	Mass Flow for 90 deg IGV	$m_{21, 90}$	9.174	lb/s	
	Isentropic Enthapy Rise	$\Delta h_{31s-21, 90}$	4.626	Btu/lb	
	Discharge Isentropic Enthalpy	$H_{31s, 90}$	176.97	Btu/lb	
	Discharge Pressure	$P_{31, 90}$	80.1	psia	
	Economizer Saturation Temperaure	$T_{5, 90}$	66.01	°F	
	Entering Evaporator Enthalpy	$h_{11, 90}$	97.13	Btu/lb	
	Economizer Lvg Vapor Enthalpy	$h_{5, 90}$	175.93	Btu/lb	
	Economizer Lvg Vapor Density	$\rho_{5, 90}$	1.676	lb/ft³	
	Economizer Lvg Vapor Sonic Velocity	$a_{5, 90}$	476.8	ft/s	
	Vapor Quality Entering Economizer	$x_{12, 90}$	0.1290		
	Economizer Injection Mass Flow	$m_{5, 90}$	1.359	lb/s	
	Second Stage, 90deg IGV				
	Ent 2nd Stage Isentropic Enthalpy	$h_{22s,90}$	176.84	Btu/lb	Eq. E10
	Ent 2nd Stage Isentropic Entropy	$s_{22s, 90}$	0.4122	Btu/lb	
	Isentropic Enthalpy Rise	$\Delta h_{32s-22s, 90}$	4.360	Btu/lb	
	Discharge Isentropic Enthalpy	$H_{32s, 90}$	181.20	Btu/lb	

	Discharge Pressure	$P_{32, 90}$	130.1	psia	Goal Seek to meet specified outlet pressure (sat temp)
	<u>First Stage, 75deg IGV</u>				
	Mass Flow for 75 deg IGV	$m_{21, 75}$	8.54	lb/s	
	Isentropic Enthalpy Rise	$\Delta h_{31s\text{-}21, 75}$	4.589	Btu/lb	
	Discharge Isentropic Enthalpy	$H_{31s, 75}$	176.94	Btu/lb	
	Discharge Pressure	$P_{31, 75}$	79.8	psia	
	Economizer Saturation Temperature	T_5	65.77	°F	
	Entering Evaporator Enthalpy	$h_{11, 75}$	97.05	Btu/lb	
	Economizer Lvg Vapor Enthalpy	$h_{5, 75}$	175.90	Btu/lb	
	Economizer Lvg Vapor Density	$\rho_{5, 75}$	1.669	lb/ft³	
	Economizer Lvg Vapor Sonic Velocity	$a_{5, 75}$	476.9	ft/s	
	Vapor Quality Entering Economizer	$x_{12, 75}$	0.1300		
	Economizer Injection Mass Flow	$m_{5, 75}$	1.276	lb/s	
	<u>Second Stage, 75deg IGV</u>				
	Ent 2nd Stage Isentropic Enthalpy	$h_{22s, 75}$	176.80	Btu/lb	Eq. 11
	Ent 2nd Stage Isentropic Entropy	$s_{22s, 75}$	0.4122	Btu/lb	
	Isentropic Enthalpy Rise	$\Delta h_{32s, 75}$	4.397	Btu/lb	
	Discharge Isentropic Enthalpy	$h_{32s, 75}$	181.20	Btu/lb	
	Discharge Pressure	$P_{32, 75}$	130.1	psia	Goal Seek to meet specified outlet pressure (sat temp)
	<u>IGV 90</u>				
	Refrigerating Capacity	Q	207.0	Tons	
	<u>IGV 75</u>				
	Refrigerating Capacity	Q	192.9	Tons	
	<u>IGV 90.8</u>				
	Inlet Guide Vane to Meet Discharge Pressure	IGV	90.77	deg	Interpolate between IGVs to meet input Refrigerating Capacity
	Suction Mass Flow	m_{21}	9.206	lb/s	
Step 6	*Calculation of Compressor Thermodynamic Performance*				
	<u>IGV 90.8</u>				
	Flow Factor (eq. 3)	FF	0.0190	ft²	

	HF 1 at 90.8 deg IGV for FF = 0.019	HF_1	0.4979		
	EFF OA at 90.8 deg IGV for FF = 0.019	EFF_{OA}	0.7362		
	HF 2 at 90.8 deg IGV for FF = 0.019	HF_2	0.4799		
	Isentropic Enthalpy Rise of First Stage	Δh_{31s-21}	4.628	Btu/lb	
	Isentropic Enthalpy Lvg. First Stage	H_{31s}	176.98	Btu/lb	
	Pressure Leaving First Stage	P_{31}	80.1	psia	
	Economizer Saturation Temperaure	T_5	66.03	°F	
	Economizer Injection Enthalpy	h_5	175.93	Btu/lb	
	Density Leaving First Stage	ρ_{31s}	1.676	lb/ft³	
	Sonic Velocity Leaving First Stage	a_{31s}	476.8	ft/sec	
	Vapor Quality Entering Economizer	x_{12}	0.1290		
	Economizer Injection Mass Flow	m_5	1.363	lb/s	
	Enthalpy Entering Second Stage	h_{22s}	176.84	Btu/lb	Eq. 11
	Isentropic Enthalpy Rise of Second Stage	$\Delta h_{32s-22s}$	4.358	Btu/lb	
	Total Power	P	127.1	kW	0.28% from measured power

E3. *Symbols and Subscripts*

NS	=	number of compressor stages
HF_i	=	head factor for compressor stage *i*
$a_{2_{1s}}$	=	refrigerant sonic velocity entering the first compressor stage, m/s (ft/s)
η	=	isentropic efficiency, % (%), for a two-stage stage compressor with Vapor Injection
$\dot{m}_1$	=	refrigerant mass flow rate entering the compressor, kg/s (lb_m/h)
$\dot{m}_2$	=	refrigerant mass flow rate after mixing the injection flow and inlet flow, kg/s (lb_m/h)
$\dot{m}_i$	=	refrigerant mass flow rate entering the compressor stage *i*, kg/s (lb_m/h)
$\dot{m}_5$	=	refrigerant mass flow rate injected into compressor at intermediate pressure, kg/s (lb_m/h)
$h_{2_{1s}}$	=	specific enthalpy of refrigerant vapor at suction pressure and temperature entering the compressor, kJ/kg (Btu/lb_m)
$h_{2_{2s}}$	=	specific enthalpy of refrigerant vapor after mixing the intermediate pressure flow at state point 5 with the flow at state point 3_{1s} shall be calculated using Equation E10, kJ/kg (Btu/lb_m)
$h_{3_{1s}}$	=	specific enthalpy of refrigerant vapor at intermediate pressure following an isentropic compression of the refrigerant from compressor suction pressure and temperature, kJ/kg (Btu/lb_m)
$h_{3_{2s}}$	=	specific enthalpy of refrigerant vapor at compressor discharge pressure following an isentropic compression of the refrigerant from state point 2_{2s}, kJ/kg (Btu/lb_m)
h_5	=	specific enthalpy of refrigerant injected into compressor calculated based on measured pressure P5 and temperature T5, kJ/kg (Btu/lbm)
$h_{2_{is}}$	=	specific enthalpy of refrigerant vapor at suction pressure and temperature entering the compressor stage *i*, kJ/kg (Btu/lb_m)
$h_{3_{is}}$	=	specific enthalpy of refrigerant vapor at the discharge pressure for stage *i* following an isentropic compression of the refrigerant from compressor stage suction pressure and temperature, kJ/kg (Btu/lb_m)
P	=	total power input to the UUT (unit under test), kW (kW)