2008 Standard for

Performance Rating of Forced-Circulation Free-Delivery Unit Coolers for Refrigeration

Note:

This standard supersedes ARI Standard 420-2000.

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PERFORMANCE RATING OF FORCED-CIRCULATION FREE-DELIVERY UNIT COOLERS FOR REFRIGERATION

Section 1. Purpose

1.1 *Purpose.* The purpose of this standard is to establish for Forced-Circulation Free-Delivery Unit Coolers for Refrigeration: definitions; test requirements; rating requirements; minimum data requirements for Published Ratings; 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.

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 factory-made, Forced-Circulation, Free-Delivery Unit Coolers, as defined in Section 3, operating with a Volatile Refrigerant fed by either direct expansion or liquid overfeed at wet and/or dry conditions.

2.1.1 *Exclusions.* This standard does not apply to:

2.1.1.1 Air-conditioning units used primarily for comfort cooling for which testing methods are given in other standards.

2.1.1.2 Unit Coolers operating at latent load conditions with Refrigerant Saturation Temperature < 32 ºF [0.0 ºC] to prevent frost.

2.1.1.3 Unit Coolers installed in or connected to ductwork.

2.1.1.4 Unit Coolers using zeotropic refrigerants with Glides greater than 2.0 ºF [1.1 ºC].

2.1.1.5 Field testing of Unit Coolers.

Section 3. Definitions

All terms in this document follow the standard industry definitions in the current edition of *ASHRAE Terminology of Heating, Ventilation, Air Conditioning and Refrigeration* unless otherwise defined in this section.

3.1 *Dew Point*. Refrigerant vapor saturation temperature at a specified pressure.

3.2 *Enthalpy Difference (HD).* The difference between the enthalpy of the air entering the Unit Cooler and the calculated enthalpy of saturated air at the Refrigerant Saturation Temperature at the Unit Cooler outlet, Btu/lb [J/kg].

3.3 *Forced-Circulation Free-Delivery Unit Coolers (Unit Coolers).* A factory-made assembly, including means for forced air circulation and elements by which heat is transferred from air to refrigerant without any element external to the cooler imposing air resistance. These may also be referred to as Air Coolers, Cooling Units, Air Units or Evaporators.

3.3.1 *Direct Expansion Unit Cooler.* A Unit Cooler in which the leaving refrigerant vapor is superheated.

3.3.2 *Liquid Overfeed Unit Cooler*. A Unit Cooler in which the refrigerant liquid is supplied at a Recirculation Rate greater than 1.

3.4 *Glide.* The absolute value of the difference between the starting and ending temperatures of a phase-change process (condensation or evaporation) for a zeotropic refrigerant exclusive of any liquid subcooling or vapor superheating.

3.5   *Gross Total Cooling Effect (Cooling Capacity).* The heat absorbed by the refrigerant, Btu/h [W]. This is the sum of the Net Total Cooling Effect and the heat equivalent of the energy required to operate the Unit Cooler. This includes both sensible and latent cooling.

3.6   *Net Total Cooling Effect.* The refrigeration capacity available for space and product cooling, Btu/h [W]. It is equal to the Gross Total Cooling Effect less the heat equivalent of energy required to operate the Unit Cooler. This includes both sensible and latent cooling.

3.7   *Overfeed Ratio.* The mass ratio of liquid to vapor at the outlet of the Liquid Overfeed Unit Cooler. This may also be referred to as overfeed rate.

3.8   *Published Rating.* A statement of the assigned values of those performance characteristics, under stated Rating Conditions, by which a unit may be chosen to fit its application. These values apply to all units of like nominal size and type (identification) produced by the same manufacturer. The term Published Rating includes the rating of all performance characteristics shown on the unit or published in specifications, advertising or other literature, controlled by the manufacturer, at stated Rating Conditions.

> **3.8.1**   *Application Rating.* A rating at conditions other than Standard Rating Conditions.

> **3.8.2**   *Standard Rating.* A rating at one of the Standard Rating Conditions shown in Table 1 that is an accurate representation of test data.

3.9   *Rated Power.*

> **3.9.1**   For single phase motors, total fan motor input power, W or kW.

> **3.9.2**   For polyphase motors, individual fan motor output power, hp [kW].

3.10   *Rating Conditions.* Any set of operating conditions under which a single level of performance results and which causes only that level of performance to occur.

> **3.10.1**   *Standard Rating Conditions.* Rating Conditions listed in Table 1 that can be used as a basis of comparison for performance characteristics.

>> **3.10.1.1**   *Dry Rating Condition.* Rating Condition where latent cooling is not present.

>> **3.10.1.2**   *Wet Rating Condition.* Rating Condition where both sensible and latent cooling are present and the coil surface temperature is above freezing.

3.11   *Recirculation Ratio. (Recirculation Rate)* The mass ratio of liquid circulated to the amount of liquid vaporized.

3.12   *Refrigerant Saturation Temperature.* Refrigerant temperature at the Unit Cooler inlet or outlet determined either by measuring the temperature at the outlet of the two-phase refrigerant flow, for a Liquid Overfeed Unit Cooler, or by measuring refrigerant pressure and determining the corresponding temperature from reference thermodynamic tables or equations for the refrigerant ºF [ºC]. For zeotropic refrigerants, the corresponding temperature to a measured pressure is the refrigerant Dew Point.

3.13   *"Shall" or "Should".* "Shall" or "Should" shall be interpreted as follows:

> **3.13.1**   *Shall.* Where "shall" or "shall not" is used for a provision specified, that provision is mandatory if compliance with the standard is claimed.

> **3.13.2**   *Should.* "Should" is used to indicate provisions which are not mandatory but which are desirable as good practice.

3.14   *Standard Air Conditions.* Dry air at 70 ºF [21 ºC] and absolute pressure 29.92 in Hg [101.3 kPa]. Under these conditions, dry air has a mass density of 0.075 lb/ft^3 [1.2 kg/m^3].

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3.15 *Steady-State Conditions.* An operating state of a system, including its surroundings, in which the extent of change with time is within the limits specified in Tables C3 and C4.

3.16 *Temperature Difference (TD).* The difference between the dry-bulb temperature of the air entering the Unit Cooler and the Refrigerant Saturation Temperature at the unit cooler outlet, ºF [ºC].

3.17 *Test Measurement.* The reading of a specific test instrument at a specific point in time. The Test Measurement may be averaged with other measurements of the same parameter at the same time to determine a Test Reading or averaged over the duration of the test to determine the value for the Test Run.

3.18 *Test Reading.* The recording of one full set of the Test Measurements required to assess the performance of the test unit.

3.19 *Test Run.* Test Readings compiled during Unit Cooler operation during which steady-state conditions have been maintained. It shall last for a minimum of 30 minutes with at least 15 consecutive Test Readings, all of which shall comply with the requirements of Tables C1, C2, C3 and C4. It includes all the information required to determine Unit Cooler performance at a specific rating condition.

3.20 *Test Series.* A group of Test Runs, performed on the same test unit, to determine performance at all required rating conditions.

3.21 *Volatile Refrigerant.* A refrigerant which changes from liquid to vapor in the process of absorbing heat.

Section 4. Test Requirements

4.1 *Test Requirements.* All Standard Ratings of Unit Coolers shall be verified by tests conducted at Standard Rating Conditions in accordance with one of the methods set forth in Appendix C.

Table 1. Standard Rating Conditions												
Condition number	Coil condition	Entering Air								Refrigerant Saturation Temperature[2]		Temperature Difference
		Dry-bulb temperature		Wet-bulb temperature		Relative humidity[1]	Dew Point temperature[1]					
		ºF	ºC	ºF	ºC	%	ºF	ºC	ºF	ºC	ºF	ºC
1	Wet	50	10	46.1	7.83	75	-	-	35	1.7	15	8.3
2	Dry	50	10	-	-	< 45	< 30	< -1.1	35	1.7	15	8.3
3	Dry	35	1.7	-	-	< 50	< 20	< -6.7	25	-3.9	10	5.6
4	Dry	10.0	-12.2	-	-	< 46	< -5.0	< -21	0.00	-17.8	10	5.6
5	Dry	-10.0	-23.3	-	-	< 43	< -25	< 32	-20.0	-28.9	10	5.6

Notes:

1. The dry coil condition can be confirmed by measuring either the entering air dew point or relative humidity according to the instrumentation requirements of Table 2. At wet coil condition, relative humidity is for reference only.

2. Measured at coil outlet.

4.1.1 All regularly furnished equipment that will affect performance shall be in place during the test.

4.1.2 The refrigerant used during the test shall be one that is published for use with the Unit Cooler.

4.1.3 Each Standard Rating test shall be performed at either 50 Hz or 60 Hz and at the highest rated voltage as specified by the manufacturer on the unit or motor nameplate.

4.1.4 *Instrumentation Requirements.* Precision instruments and automated electronic data acquisition equipment shall be used to measure and record temperature, pressure and refrigerant flow rate test parameters. The use of advanced technologies or methods of measurement not described in this appendix are acceptable, provided the accuracy requirements of this appendix are achieved by the alternative method.

4.1.4.1 *Calibration* All measuring instruments and instrument systems (e.g. data acquisition coupled to temperature, pressure, or flow sensors) shall be calibrated by comparison to primary or secondary standards with calibrations traceable to National Institute of Standards and Technology (NIST) measurements, other recognized national laboratories, or derived from accepted values of natural physical constants. All test instruments shall be calibrated annually, whenever damaged, or when the accuracy is called into question.

4.1.4.2 *Selection and Accuracy*. All measuring instruments shall be selected to meet or exceed the accuracy criteria listed in Table 2 for each type of measurement.

Table 2. Instrumentation Accuracy				
Measurement	Medium	Minimum Accuracy		Instrument Examples
		I-P	SI	
Temperature	Air dry-bulb	± 0.10 °F	± 0.06 °C	Resistance Temperature Device (RTD) Thermistor
	Air wet-bulb			
	Refrigerant liquid			
	Refrigerant vapor	± 0.5 °F	± 0.3 °C	Special calibrated thermocouple
	Air Dew Point	± 0.5 °F	± 0.3 °C	Chilled mirror hygrometer
	Others	± 1.0 °F	± 0.6 °C	Liquid-in-glass thermometer
Relative humidity[1]	Air	± 3 % points rh		Capacitive or resistive rh sensor
Pressure	Refrigerant	Pressure corresponding to ± 0.2 °F of saturation temperature	Pressure corresponding to ± 0.1 °C of saturation temperature	Transducer
	Air	± 0.05 inches of mercury	169 Pa	Barometer
Flow	Refrigerant	1 % of reading		Mass flow meter
	Liquids	1 % of reading		Venturi
Electrical	Motor kilowatts/amperes/voltage	1 % of reading		Power meter
	Auxiliary kilowatt input (e.g. heater)			Amp probe
				Multimeter
Speed	Motor / fan shaft	1 % of reading		Tachometer
Weight	Oil / refrigerant solution	0.5 % of reading		Gravimeter (scale or analytical balance)
Specific Gravity	Brine	1 % of reading		Hydrometer
Time	Hours / minutes / seconds	0.5 % of time interval		Electronic clock

Note:

1.   Relative humidity and air dew point measurements are intended to confirm the dry coil condition for test condition numbers 2 through 5.

Section 5. Rating Requirements

5.1 *Standard Ratings.* Standard Ratings shall include Rated Power and Gross Total Cooling Effect established at all applicable Standard Rating Conditions specified in Table 1.

5.2 *Application Ratings*. Application Ratings shall include Rated Power and Gross Total Cooling Effect at conditions other than Standard Rating Conditions. Application Ratings with Refrigerant Saturation Temperatures below 32 °F [0.0 °C]

shall be rated at dry conditions. Application Ratings published by the manufacturer shall be clearly identified as Application Ratings.

5.3 *Tolerances.* To comply with this standard, any representative production unit selected at random, when tested at the Standard Rating Conditions, shall have a Gross Total Cooling Effect not less than 95 % of its published Standard Rating and not exceed 105 % of its Rated Power.

Section 6. Minimum Data Requirements for Published Ratings

6.1 *Minimum Data Requirements for Published Ratings.* As a minimum, Published Ratings shall include all Standard Ratings at which the unit will be produced, marketed or sold. All claims to ratings for products within the scope of this standard shall be accompanied by the statement "Rated in accordance with ARI Standard 420." All claims to ratings outside the scope of this standard shall include the statement "Outside the scope of ARI Standard 420." Wherever Application Ratings are published or printed, they shall include a statement of the conditions at which the ratings apply.

6.2 *Required Published Ratings.* All published Standard Ratings and Application Ratings shall include:

a. Model Number
b. Gross Total Cooling Effect, Btu/h [W]
c. Temperature Difference, °F [°C]
d. Refrigerant designation(s) in accordance with ANSI/ASHRAE Standard 34 with Addenda
e. Refrigerant Saturation Temperature, °F [°C]
f. Rated Power W [kW] or hp [kW]
g. Number of motors
h. Coil fin density, fins per inch or coil fin spacing [mm]; Actual fin density or fin spacing shall be within 10 % of published values.
i. Airflow rate, cfm [m^3/s]

6.3 *Recommended Published Ratings.* It is recommended that the following data be published in addition to the required Published Ratings per Section 6.2:

a. Type of defrost
b. Unit Cooler motor current, A; voltage, V; and frequency, Hz
c. Defrost heater power, W; and voltage, V (if used)

Section 7. Marking and Nameplate Data

7.1 *Marking and Nameplate Data.* As a minimum, the manufacturer name or trade-name; model number; refrigerant(s); current, A; voltage, V; frequency, Hz; and phase shall be shown in a conspicuous place on the unit.

Nameplate voltages for 60 Hertz systems shall include one or more of the equipment nameplate voltage ratings shown in Table 1 of ARI Standard 110. Nameplate voltages for 50 Hertz systems shall include one or more of the utilization voltages shown in Table 1 of IEC Standard Publication 60038.

Section 8. Conformance Conditions

8.1 *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 except where deviations are noted.

A1.1   ANSI/ASHRAE Standard 34-2007, *Designation and Safety Classification of Refrigerants*, 2007, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., 1791 Tullie Circle, N.E., Atlanta, GA 30329, U.S.A.

A1.2   ANSI/ASHRAE Standard 41.1-1986 (RA 2006), *Standard Method for Temperature Measurement*, 2006, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., 1791 Tullie Circle, N.E., Atlanta, GA 30329, U.S.A.

A1.3   ANSI/ASHRAE Standard 41.3-1989, *Standard Method for Pressure Measurement*, 1989, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., 1791 Tullie Circle, N.E., Atlanta, GA 30329, U.S.A.

A1.4   ANSI/ASHRAE Standard 41.4-1996 (RA 2006), *Standard Method for Measurement of Proportion of Lubricant in Liquid Refrigerant*, 2006, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., 1791 Tullie Circle, N.E., Atlanta, GA 30329, U.S.A.

A1.5   ANSI/ASHRAE Standard 41.10-2003, *Flow Meter Test Methods for Mass Flow Measurements of Volatile Refrigerants*, 2003, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., 1791 Tullie Circle, N.E., Atlanta, GA 30329, U.S.A.

A1.6   AHRI Standard 110-2002 (formerly ARI Standard 110-2002), *Air-Conditioning and Refrigerating Equipment Nameplate Voltages,* 2002, Air-Conditioning, Heating, and Refrigeration Institute, 2111 Wilson Boulevard, Suite 500, Arlington, VA 22201, U.S.A.

A1.7   *ASHRAE Handbook Fundamentals*, 2005, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., 1791 Tullie Circle, N.E., Atlanta, GA 30329, U.S.A.

A1.8   ASHRAE *Psychrometric Analysis* software, version 6, 2007, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., 1791 Tullie Circle, N.E., Atlanta, GA 30329, U.S.A.

A1.9   *ASHRAE Terminology of Heating, Ventilation, Air Conditioning and Refrigeration,* Second Edition, 1991, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., 1791 Tullie Circle, N.E., Atlanta, GA, 30329, U.S.A.

A1.10   IEC Standard Publication 60038-2002, *IEC Standard Voltages*, 2002, International Electrotechnical Commission, 3, rue de Varembé, P.O. Box 131, CH - 1211 GENEVA 20, Switzerland.

A1.11   NIST Reference Fluid Thermodynamic and Transport Properties, *REFPROP*, Version 8.0, 2007, National Institute of Standards and Technology, Boulder, CO 80303, USA.

APPENDIX B. REFERENCES – INFORMATIVE

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

B1.1   *Ammonia Refrigeration Piping Handbook*, 2000, International Institute of Ammonia Refrigeration, 1110 North Glebe Road, Suite 250, Arlington, VA 22201, U.S.A.

B1.2   ANSI/ASHRAE Standard 41.9-2000 (RA 2006), *Calorimeter Test Methods for Mass Flow Measurements of Volatile Refrigerants*, 2006, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., 1791 Tullie Circle, N.E., Atlanta, GA 30329, U.S.A.

APPENDIX C. METHODS OF TESTING FORCED-CIRCULATION FREE-DELIVERY UNIT COOLERS FOR REFRIGERATION – NORMATIVE

C1.   *Purpose*. The purpose of this appendix is to provide a method of testing for Forced-Circulation Free-Delivery Unit Coolers for Refrigeration.

C2.   *Scope*. These methods of testing apply to factory-made, Forced-Circulation, Free-Delivery Unit Coolers, as defined in Section 3, operating with a Volatile Refrigerant fed by either direct expansion or liquid overfeed at wet and/or dry conditions.

C2.1   *Exclusions*. These methods of testing do not apply to:

C2.1.1   Air-conditioning units used primarily for comfort cooling for which testing methods are given in other standards.

C2.1.2   Unit Coolers operating at latent load conditions with Refrigerant Saturation Temperature < 32 ºF [0.0 ºC] to prevent frost

C2.1.3   Unit Coolers installed in or connected to ductwork

C2.1.4   Unit Coolers using zeotropic refrigerants with Glides greater than 2.0 ºF [1.1 ºC]

C2.1.5   Field Testing of Unit Coolers

C3.   *Measurements*

C3.1   Refer to ARI 420 Table 2 for required instrumentation accuracy.

C3.2   *Temperature Measurements*

C3.2.1   Temperature measurements shall be made in accordance with ANSI/ASHRAE Standard 41.1.

C3.2.2   Air wet-bulb and dry-bulb temperatures entering the Unit Cooler shall be measured based on the airflow area at the point of measurement. One measuring station is required for each 2.0 ft^2 [0.19 m^2] of the first 10.0 ft^2 [0.93 m^2] of airflow area and one additional measuring station is required for each 4.0 ft^2 [0.27 m^2] of airflow area above 10.0 ft^2 [0.93 m^2]. A minimum of two stations shall be used and the number of measuring stations shall be rounded up to the next whole number.

C3.2.3   The airflow area shall be divided into the required number of equal area rectangles with aspect ratios no greater than 2 to 1. Additional measuring stations may be necessary to meet this requirement. The measuring stations shall be located at the geometric center of each rectangle.

C3.2.4   The maximum allowable deviation between any two air temperature measurement stations shall be 2.0 °F [1.1 °C].

C3.2.5   If sampling tubes are used, each tube opening may be considered a temperature measuring station provided the openings are uniformly spaced along the tube, the airflow rates entering each port are relatively uniform (± 15%) and the arrangement of tubes complies with the location requirements of C3.2.3. Additionally, a one time temperature traverse shall be made over the measurement surface, prior to the test to assess the temperature variation and ensure it complies with the allowable deviation specified in C3.2.4. (Refer to ANSI/ASHRAE Standard 41.1 for more information and diagrams).

C3.2.6   Refrigerant temperatures entering and leaving the Unit Cooler shall be measured by a temperature measuring instrument placed in a thermometer well and inserted into the refrigerant stream. These wells shall be filled with non-solidifying, thermal conducting liquid or paste to ensure the temperature sensing

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instrument is exposed to a representative temperature. The entering temperature of the refrigerant shall be measured within six pipe diameters upstream of the control device.

C3.3   *Pressure Measurements.* Connections for pressure measurements shall be smooth and flush within the pipe wall and shall be located not less than six pipe diameters downstream from fittings, bends, or obstructions. (Refer to ANSI/ASHRAE Standard 41.3 for more information and diagrams).

C3.4   *Volatile Refrigerant Flow Measurement*

C3.4.1   Refrigerant flow meters shall be installed and the flow rate of Volatile Refrigerants shall be measured in accordance with ANSI/ASHRAE Standard 41.10.

C3.4.1.1   Refrigerant liquid must be sub-cooled both upstream and downstream of the meter to ensure the liquid remains single phase.

C3.4.1.2   Refrigerant vapor must be superheated both upstream and downstream of the meter to ensure the vapor remains single phase.

C3.4.1.3   Flow meters shall be installed with at least ten pipe diameters upstream and five diameters downstream of the meter, in straight pipe free of valves and fittings, or in accordance with the manufacturer's instructions.

C3.4.1.4   A direct reading mass-flow-rate measuring device, such as a Coriolis meter, is the preferred instrument for measuring the refrigerant flow rate. Other flow meters that demonstrate the capability to measure flow rate with the specified accuracy are also acceptable.

C3.5   *Oil-in-Refrigerant Mass Ratio Measurement.* The ratio of oil to refrigerant shall be less than 1 % by weight. Unless the system does not contain refrigerant oil, tests for oil concentration shall be made a minimum of once per Test Series per ANSI/ASHRAE Standard 41.4.

C3.6   *Rated Power Measurement.* Prior to conducting a capacity Test Series, the following shall be measured and recorded, refer to Section C11.1.

E	Total electrical power input to fan motor(s) of Unit Cooler, W [W]
FS	Fan speed (s), rpm [rev/s]
N	Number of motors
P_b	Barometric pressure, in Hg [kPa]
T_{db}	Dry-bulb temperature of air at inlet, °F [°C]
T_{wb}	Wet-bulb temperature of air at inlet, °F [°C]
V	Voltage of each phase, V [V]

For a given motor winding configuration, the total power input shall be measured at the highest nameplated voltage. For three-phase power, voltage imbalance shall be no more than 2 %.

C3.7   *Measurement Intervals*. Measurement intervals shall be in accordance with Table C1.

Table C1. Test Readings		
Test Parameter	Minimum Data Collection Rate, Test Readings per Hour	Minimum Number of Test Readings per Test Run [2]
Temperature	30	15
Pressure	30	15
Refrigerant mass flow rate	30	15
Test room barometric pressure	1	1
Fan speed(s)	1	1
Total electrical power input to fan motor(s)[1]	3	2
Total electrical power input to heater and auxiliary equipment [1]	3	2
Notes: 1. For calibrated box only (Method 2) 2. Duration of test run shall be a minimum of 30 minutes		

C4.   *Unit Cooler General Data.* The following data shall be recorded, where applicable, for each unit tested, including the units of measurement used:

C4.1   *Physical data*

   a.   Manufacturer name and address
   b.   Identification number (model/serial)
   c.   Size (external dimensions), in × in × in [mm × mm × mm]
   d.   Nameplate motor data (for each motor)
        1.   Type
        2.   Frame size
        3.   Power, hp [kW]
        4.   Speed, rpm [rev/s]
        5.   Voltage, V
        6.   Amps, A
        7.   Phase
        8.   Frequency, Hz
        9.   Efficiency (NEMA nominal or manufacturer's certificate for polyphase motors)
        10. Manufacturer
        11. Serial number or manufacturer identification number
   e.   Fan data
        1.   Diameter, in [mm]
        2.   Width (centrifugal fans only), in [mm]
        3.   Speed, rpm [rev/s]
        4.   Number of blades
        5.   Manufacturer
        6.   Model number or part number
        7.   Number of fans

       f.   Cooling coil data
1. Finned length, in [mm]
2. Fin height and depth, in [mm]
3. Number of rows deep
4. Number of tubes high
5. Fin density, fins per inch or fin spacing, mm based on total fin count
6. If fins are staged, fin density per stage, fins per inch or fin spacing per stage [mm]
7. Measured fin material thickness, in [mm] {Note: fin thickness for hot dipped galvanized coils will vary.}
8. Fin material
9. Finished fin geometry
10. Tube material
11. Tube description {i.e. outside diameter (or equivalent), enhancements}
12. Number of refrigerant circuits
13. Coil or fin coatings

       g.   Accessories (e.g. louvers, distributor orifice, grills)

    C4.2   *Specific to the test*

       a.   Test location, test company and address
       b.   Method of test
       c.   Date and time of Test Run
       d.   Names of observers – responsible engineers and all data takers
       e.   Published Gross Total Cooling Effect at Standard Rating Conditions, Btu/h [W]
       f.   Refrigerant
       g.   Recirculation Ratio (Method 3) - manufacturer specified
       h.   Refrigerant flow rate, lbm/h [kg/s] (Method 3) - manufacturer specified

C5.   *Methods of Testing.* The Gross Total Cooling Effect of Unit Coolers shall be determined by one of the following methods. In all methods, the reported Gross Total Cooling Effect, q_t, shall be the average of two independent determinations.

    C5.1   *Method 1, DX Dual Instrumentation.* The Cooling Capacity shall be determined by measuring the enthalpy change and the mass flow rate of the refrigerant across the Unit Cooler using two independent measuring systems.

    C5.2   *Method 2, DX Calibrated Box.* The Cooling Capacity shall be determined concurrently by measuring the enthalpy change and the mass flow rate of the refrigerant across the Unit Cooler and the heat input to the calibrated box.

    C5.3   *Method 3, Liquid Overfeed.* The Cooling Capacity shall be determined by measuring the enthalpy change and the mass flow rate of the refrigerant across the Unit Cooler and also measured with a condenser calorimeter. The refrigerant outlet pressure shall be measured and the corresponding Refrigerant Saturation Temperature shall agree with the measured temperature within 0.2 °F [0.1 °C]. The Recirculation Ratio and refrigerant flow rate through Unit Cooler shall be specified by the manufacturer.

C6.   *Test Chamber Dimensions.* The Unit Cooler shall be installed in a room of sufficient size to avoid airflow restrictions or recirculation such that:

    a. No obstacle is positioned within a distance of $2\sqrt{AB}$ from the discharge of the Unit Cooler, where A and B are the air inlet dimensions, in [mm] per fan section of the Unit Cooler.

    b. All other distances correspond to the minimum requirements of the installation instructions provided by the manufacturer.

    c. The minimum volume, ft^3 [m^3], of the test chamber shall be 20 % [1200 %] of the airflow rate, ft^3/min [m^3/s] produced by the Unit Cooler together with all auxiliary air moving devices that operate simultaneously with the Unit Cooler.

C7. *General Test Conditions.* Test acceptance criteria listed in Tables C2, C3 and C4 apply to all methods of test:

Method	Condition Number	Inlet Saturation Temperature				Inlet Subcooling		Outlet Superheat	
		Excluding R-717		R-717 only					
		°F	°C	°F	°C	°F	°C	°F	°C
1, 2	All	105	40.5	95	35	15	8.3	6.5	3.6
3	1	40	4.4	40	4.4	3	1.7	-	-
	2	40	4.4	40	4.4	3	1.7	-	-
	3	30	-1.1	30	-1.1	3	1.7	-	-
	4	7.0	-14.0	7.0	-14.0	4	2.2	-	-
	5	-10	-23	-10	-23	6	3.3	-	-

Table C2. Additional Test Conditions

Variable Description	Test Condition Stability Over Test Run Duration				Allowable Deviation of Average Test Temperatures from Standard Rating Conditions			
	Dry Condition		Wet Condition		Dry Condition		Wet Condition	
	°F	°C	°F	°C	°F	°C	°F	°C
Dry-bulb Temperature	-	-	-	-	± 1.0	± 0.6	± 1.0	± 0.6
Wet-bulb Temperature	-	-	± 0.5	± 0.3	-	-	± 0.5	± 0.3
Dew Point Temperature	-	-	-	-	+ 0.0	+ 0.0	-	-
Temperature Difference	± 0.5[1]	± 0.3[1]	± 0.5[1]	± 0.3[1]	-	-	-	-
Refrigerant Flow Rate	± 3.0 %				-	-	-	-

Table C3. Test Condition Tolerances

Note:

1. The Dry-bulb temperature tolerance is set by the Temperature Difference.

Table C4. Refrigerant Temperature Tolerances								
Variable Description	Test Condition Stability Over Test Run Duration				Allowable Deviation of Average Test Temperatures from Standard Rating Conditions			
	Methods 1, 2		Method 3		Methods 1, 2		Method 3	
	°F	°C	°F	°C	°F	°C	°F	°C
Inlet Saturation Temperature	± 5.0	± 2.8	± 2.0	± 1.1	± 2.5	± 1.4	± 1.0	± 0.6
Inlet Subcooling	± 5.0	± 2.8	± 1.0 [1]	± 0.6 [1]	± 2.0	± 1.1	± 1.0	± 0.6
Outlet Saturation Temperature	-	-	-	-	± 0.5	± 0.3	± 0.5	± 0.3
Outlet Superheat	± 1.5	± 0.8	-	-	± 1.0	± 0.6	-	-

Note:

1. For Test Condition 5, ± 2.0 °F [± 1.1 °C].

C8. *DX Dual Instrumentation Test Procedure (Method 1)*

    C8.1 *Test Setup and Procedure.* Refer to Section C6, C7 and Figure C1 for specific test setup.

    C8.2 *Data to be Measured and Recorded*

        C8.2.1 Air side (as required for dry or wet coil conditions)

FS   Fan speed (s), rpm [rev/s]
P_b Barometric pressure, in Hg [kPa]
rh   Air inlet relative humidity
T_{db} Dry-bulb temperature of air at inlet, °F [°C]
T_{dp} Dew point temperature of air at inlet, °F [°C]
T_{wb} Wet-bulb temperature of air at inlet, °F [°C]

        C8.2.2 Refrigerant side

P_{0a}, P_{0b} Pressure of subcooled refrigerant liquid entering the expansion valve, psi [kPa]
P_{2a}, P_{2b} Pressure of superheated refrigerant vapor leaving the Unit Cooler, psi [kPa]
t_{0a}, t_{0b} Temperature of subcooled refrigerant liquid entering the expansion valve, °F [°C]
t_{2a}, t_{2b} Temperature of superheated refrigerant vapor leaving the Unit Cooler, °F [°C]
w_{v1} Mass flow rate of subcooled refrigerant liquid through M1, lbm/h [kg/s]
w_{v2} Mass flow rate of subcooled refrigerant liquid through M2 or superheated refrigerant vapor through M2ALT, lbm/h [kg/s]

    C8.3 *Calculations (refer to Section C11 for calculated values)*

        C8.3.1 For each independent refrigerant mass flow measurement at a Dry Rating Condition, calculate the Gross Total Cooling Effect, refer to C12.1.1.

        C8.3.2 For each independent refrigerant mass flow measurement at a Wet Rating Condition, calculate the Gross Total Cooling Effect, refer to C12.1.2.

        C8.3.3 Calculate the Gross Total Cooling Effect and heat balance, refer to C12.1.3 and C12.1.4.

C9. *DX Calibrated Box Test Procedure (Method 2)*

C9.1 *Test Setup and Procedure*. Refer to Section C6, C7 and Figure C2 for specific test setup.

C9.1.1 Apparatus Setup for Calibrated Box Calibration and Test

C9.1.1.1 The calibrated box shall be installed in a temperature controlled enclosure in which the temperature can be maintained at a constant level.

C9.1.1.2 The temperature controlled enclosure shall be of a size that will provide clearances of not less than 18 in [457 mm] at all sides, top and bottom, except that clearance of any one surface may be reduced to not less than 5.5 in [140 mm].

C9.1.1.3 In no case shall the heat leakage of the calibrated box exceed 30 % of the Gross Total Cooling Effect of the Unit Cooler under test. The ability to maintain a low temperature in the temperature controlled enclosure will reduce the heat leakage into the calibrated box and may extend its application range.

C9.1.1.4 Refrigerant lines within the calibrated box shall be well insulated to avoid appreciable heat loss or gain.

C9.1.1.5 Instruments for measuring the temperature around the outside of the calibrated box shall be located at the center of each wall, ceiling, and floor at a distance of 6 in [150 mm] from the calibrated box. Exception: in the case where a clearance around the outside of the calibrated box, as indicated above, is reduced to less than 18 in [457 mm], the number of temperature measuring devices on the outside of that surface shall be increased to six, which shall be treated as a single temperature to be averaged with the temperature of each of the other five surfaces. When the clearance is reduced below 12 in [305 mm] (one surface only), the temperature measuring instruments shall be located midway between the outer wall of the calibrated box and the adjacent wall. The six temperature measuring instruments shall be located at the center of six rectangular sections of equal area.

C9.1.1.6 Heating means inside the calibrated box shall be shielded or installed in a manner to avoid radiation to the Unit Cooler, the temperature measuring instruments, and to the walls of the box. The heating means shall be constructed to avoid stratification of temperature, and suitable means shall be provided for distributing the temperature uniformly.

C9.1.1.7 The average air dry-bulb temperature in the calibrated box during Unit Cooler tests and calibrated box heat leakage tests shall be the average of eight temperatures measured at the corners of the box at a distance of 2 in to 4 in [50 mm to 100 mm] from the walls. The instruments shall be shielded from any cold or warm surfaces except that they shall not be shielded from the adjacent walls of the box. The Unit Cooler under test shall be mounted such that the temperature instruments are not in the direct air stream from the discharge of the Unit Cooler.

C9.1.2 *Calibration of the Calibrated Box*. A calibration test shall be made for the maximum and the minimum forced air movements expected in the use of the calibrated box. The calibration heat leakage shall be plotted as a straight line function of these two air quantities and the curve shall be used as calibration for the box.

C9.1.2.1 The heat input shall be adjusted to maintain an average box temperature not less than 25.0 ºF [13.8 ºC] above the test enclosure temperature.

C9.1.2.2 The average dry-bulb temperature inside the calibrated box shall not vary more than 1.0 ºF [0.6 ºC] over the course of the calibration test.

C9.1.2.3 A calibration test shall be the average of eleven consecutive hourly readings when the box has reached a steady-state temperature condition.

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C9.1.2.4 The box temperature shall be the average of all readings after a steady-state temperature condition has been reached.

C9.1.2.5 The calibrated box has reached a steady-state temperature condition when:

1. The average box temperature is not less than 25.0 ℉ [13.8 ℃] above the test enclosure temperature.

2. Temperature variations do not exceed 5.0 ℉ [2.8 ℃] between temperature measuring stations.

3. Temperatures do not vary by more than 2.0 ℉ [1.1 ℃] at any one temperature-measuring station.

C9.2 *Data to be Measured and Recorded*

C9.2.1 Air Side (as required for dry coil conditions)

E   Total electrical power input to fan motor(s) of Unit Cooler, W [W]
FS   Fan speed (s), rpm [rev/s]
P_b Barometric pressure, in Hg [kPa]
rh   Air inlet relative humidity
T_{cb} Average dry-bulb temperature of air within the calibrated box, °F [°C]
T_{db} Dry-bulb temperature of air at inlet, °F [°C]
T_{dp} Dew point temperature of air at inlet, °F [°C]
T_{en} Average dry-bulb temperature of air within the temperature controlled enclosure, °F [°C]
T_{wb} Wet-bulb temperature of air at inlet, °F [°C]

C9.2.2 Heat load provided to calibrated box

E_c Total electrical power input to heater and auxiliary equipment, W [W]

C9.2.3 Refrigerant Side

P_0 Pressure of subcooled refrigerant liquid entering the expansion valve, psi [kPa]
P_2 Pressure of superheated refrigerant vapor leaving the Unit Cooler, psi [kPa]
t_0 Temperature of subcooled refrigerant liquid entering the expansion valve, °F [°C]
t_2 Temperature of superheated refrigerant vapor leaving the Unit Cooler, °F [°C]
w_{v1} Mass flow rate of subcooled refrigerant liquid through M1, lbm/h [kg/s]

C9.3 *Calculations (refer to Section C11 for calculated values)*

C9.3.1 Calculate the heat leakage coefficient of the calibrated box, refer to C12.2.1.

C9.3.2 For each Dry Rating Condition, calculate the air-side Gross Total Cooling Effect, refer to C12.2.2.

C9.3.3 For each Dry Rating Condition, calculate the refrigerant-side Gross Total Cooling Effect, refer to C12.2.3.

C9.3.4 Calculate the Gross Total Cooling Effect and heat balance, refer to C12.2.4 and C12.2.5.

C10. *Liquid Overfeed Test Procedure (Method 3)*

    C10.1 *Test Setup and Procedure.* Refer to Section C6, C7 and Figure C3 for specific test setup.

    C10.2 *Data to be Measured and Recorded*

        C10.2.1 Air side (as required for dry or wet coil conditions)

FS	Fan speed (s), rpm [rev/s]
P_b	Barometric pressure, in Hg [kPa]
rh	Air inlet relative humidity
T_a	Local pipe ambient temperature, °F [°C]
T_{a1}	Condenser calorimeter ambient temperature, °F [°C]
T_{a2}	Liquid/vapor separator ambient temperature, °F [°C]
T_{db}	Dry-bulb temperature of air at inlet, °F [°C]
T_{dp}	Dew point temperature of air at inlet, °F [°C]
T_{wb}	Wet-bulb temperature of air at inlet, °F [°C]

        C10.2.2 Refrigerant side

P_0	Pressure of subcooled refrigerant liquid entering the expansion valve, psi [kPa]
P_3	Pressure of saturated refrigerant liquid/vapor mixture leaving the Unit Cooler, psi [kPa]
P_4	Pressure of refrigerant in liquid/vapor separator, psi [kPa]
P_5	Pressure of refrigerant entering condenser calorimeter, psi [kPa]
P_6	Pressure of subcooled refrigerant liquid leaving condenser calorimeter and entering condensate pump, psi [kPa]
P_7	Pressure of subcooled refrigerant liquid leaving condensate pump, psi [kPa]
P_8	Pressure of subcooled refrigerant liquid entering recirculation pump, psi [kPa]
P_9	Pressure of subcooled refrigerant liquid leaving recirculation pump, psi [kPa]
P_{c1}	Pressure of fluid entering condenser calorimeter, psi [kPa]
P_{c2}	Pressure of fluid leaving condenser calorimeter, psi [kPa]
t_0	Temperature of subcooled refrigerant liquid entering the expansion valve, °F [°C]
t_3	Temperature of saturated refrigerant liquid/vapor mixture at outlet, °F [°C]
t_5	Temperature of refrigerant entering condenser calorimeter, °F [°C]
t_6	Temperature of subcooled refrigerant liquid entering condensate pump, °F [°C]
t_7	Temperature of subcooled refrigerant liquid leaving condensate pump, °F [°C]
t_8	Temperature of subcooled refrigerant liquid entering recirculation pump, °F [°C]
t_9	Temperature of subcooled refrigerant liquid leaving recirculation pump, °F [°C]
t_{c1a}, t_{c1b}	Temperature of fluid entering condenser calorimeter, °F [°C]
t_{c2a}, t_{c2b}	Temperature of fluid leaving condenser calorimeter, °F [°C]
t_s	Local pipe refrigerant temperature, °F [°C]
w_c	Mass flow rate of fluid through M1 entering the condenser calorimeter, lbm/h [kg/s]
w_{v2}	Mass flow rate of subcooled refrigerant liquid through M2, lbm/h [kg/s]
w_{v3}	Mass flow rate of subcooled refrigerant liquid through M3, lbm/h [kg/s]

    C10.3 *Calculations (refer to Section C11 for calculated values)*

        C10.3.1 Calculate system heat losses or gains, refer to C12.3.1.

        C10.3.2 Calculate the Recirculation Ratio, refer to C12.3.2.

        C10.3.3 Calculate the condenser calorimeter capacity, refer to C12.3.3.1

        C10.3.4 Calculate the Independent Gross Total Cooling Effect: Dry Rating Condition, refer to C12.3.3.3.

        C10.3.5 Calculate the Independent Gross Total Cooling Effect: Wet Rating Condition, refer to C12.3.3.4.

        C10.3.6 Calculate the Gross Total Cooling Effect and heat balance, refer to C12.3.3.5 and C12.3.3.6.

C10.3.7 Calculate the system heat loss or gain as a percent of the Gross Total Cooling Effect, refer to C12.3.3.7.

C11. *Calculated values.* Results from these calculations are required for Section C12.

C11.1 *Calculating Rated Power* (all methods)

C11.1.1 Air Density for Rated Power Test

Determine the test air density (ρ_{test}) using dry-bulb temperature (T_{db}), barometric pressure (P_b) and wet-bulb temperature (T_{wb}) by referencing ASHRAE Psychrometric Analysis software.

C11.1.2 Rated Power, for units with single phase motors:

$$p_{fmi} = \frac{(E)(\rho_{sa})}{\rho_{test}} \tag{C1}$$

C11.1.3 Rated Power, for units with polyphase motors:

$$p_{fmo} = \frac{(E)(e_{fm})(\rho_{sa})}{746(\rho_{test})(N)} \tag{C2}$$

$$\left[p_{fmo} = \frac{(E)(e_{fm})(\rho_{sa})}{(\rho_{test})(N)} \right]$$

C11.2 *Average measured temperatures*

C11.2.1 Dry-bulb temperature (all methods)

$$T_{db} = \frac{\sum_{1}^{n} T_{db_n}}{n} \tag{C3}$$

C11.2.2 Wet-bulb temperature (all methods)

$$T_{wb} = \frac{\sum_{1}^{n} T_{wb_n}}{n} \tag{C4}$$

C11.2.3 Temperature of subcooled refrigerant liquid entering the expansion valve (Method 1)

$$t_0 = \frac{t_{0a} + t_{0b}}{2} \tag{C5}$$

C11.2.4 Temperature of refrigerant vapor leaving the Unit Cooler (Method 1)

$$t_2 = \frac{t_{2a} + t_{2b}}{2} \tag{C6}$$

C11.2.5   Temperature of fluid entering and leaving condenser calorimeter (Method 3)

$$t_{c1} = \frac{t_{c1a} + t_{c1b}}{2} \qquad\qquad\qquad (C7)$$

$$t_{c2} = \frac{t_{c2a} + t_{c2b}}{2} \qquad\qquad\qquad (C8)$$

C11.2.6   Temperature controlled enclosure temperature (Method 2)

$$T_{en} = \frac{\sum_{1}^{n} T_{en_n}}{n} \qquad\qquad\qquad (C9)$$

C11.2.7   Calibrated box temperature (Method 2)

$$T_{cb} = \frac{\sum_{1}^{n} T_{cb_n}}{n} \qquad\qquad\qquad (C10)$$

C11.3   *Average measured pressures*

C11.3.1   Pressure of subcooled refrigerant liquid entering the expansion valve (Method 1)

$$P_0 = \frac{P_{0a} + P_{0b}}{2} \qquad\qquad\qquad (C11)$$

C11.3.2   Pressure of refrigerant vapor leaving the Unit Cooler (Method 1)

$$P_2 = \frac{P_{2a} + P_{2b}}{2} \qquad\qquad\qquad (C12)$$

C11.4   *Calculated Saturation Temperatures*

C11.4.1   Refrigerant Liquid Saturation Temperature entering the expansion valve (all methods)

Determine t_{0s} for P_0 by referencing thermophysical properties in texts from ASHRAE Handbook Fundamentals or NIST REFPROP Software.

C11.4.2   Unit Cooler Outlet Saturation Temperature (Methods 1, 2)

Determine t_{2s} for P_2 by referencing thermophysical properties in texts from ASHRAE Handbook Fundamentals or NIST REFPROP Software.

C11.4.3   Unit Cooler Outlet Saturation Temperature (Method 3) for comparison to measured t_3.

Determine t_{3s} for P_3 by referencing thermophysical properties in texts from ASHRAE Handbook Fundamentals or NIST REFPROP Software..

C11.4.4   Liquid/Vapor Separator Saturation Temperature (Method 3)

Determine t_{4s} for P_4 by referencing thermophysical properties in texts from ASHRAE Handbook Fundamentals or NIST REFPROP Software..

C11.4.5   Condenser Calorimeter Saturation Temperature (Method 3)

Determine t_{5s} for P_5 by referencing thermophysical properties in texts from ASHRAE Handbook Fundamentals or NIST REFPROP Software..

C11.5   *Liquid Subcooling entering expansion valve* (all methods)

$$t_{0sc} = t_{0s} - t_0 \tag{C13}$$

C11.6   *Vapor Superheat leaving Unit Cooler* (Methods 1, 2)

$$t_{2sh} = t_2 - t_{2s} \tag{C14}$$

C11.7   *Enthalpies*

C11.7.1   Air Enthalpies (Methods 1, 3)

Determine enthalpies using dry-bulb (T_{db}), barometric pressure (P_b) and wet-bulb (T_{wb}) by referencing ASHRAE Psychrometric Analysis software.

C11.7.2   Refrigerant Enthalpies

Determine enthalpies for the appropriate refrigerant by using average pressure and temperature measured at each location and referencing thermodynamic software or texts from ASHRAE Handbook Fundamentals or NIST REFPROP Software..

C11.8   *Temperature Difference Correction Factor*

$$TD_{test} = T_{db} - t_{2s} \qquad \text{(Methods 1, 2)} \tag{C15}$$

$$TD_{test} = T_{db} - t_{3s} \qquad \text{(Method 3)} \tag{C16}$$

$$TD_{CF} = \left(\frac{TD_{rated}}{TD_{test}} \right) \tag{C17}$$

Refer to Table 1 for TD_{rated} values.

C11.9   *Air Enthalpy Correction Factor* (Methods 1, 3)

$$HD_{rated} = h_{a1} - h_{ar} \tag{C18}$$

$$HD_{test} = h_{a2} - h_{at} \tag{C19}$$

$$HD_{CF} = \left(\frac{HD_{rated}}{HD_{test}} \right) \tag{C20}$$

C12.   *Capacity Calculations for each Method*

C12.1   *Gross Total Cooling Effect* (Method 1)

C12.1.1   Independent Measurement Gross Total Cooling Effect: Dry Rating Condition

$$q_{tr1} = w_{v1}(h_2 - h_0)(TD_{CF})$$ (C21)

$$q_{tr2} = w_{v2}(h_2 - h_0)(TD_{CF})$$ (C22)

C12.1.2   Independent Measurement Gross Total Cooling Effect: Wet Rating Condition

$$q_{tr1} = w_{v1}(h_2 - h_0)(HD_{CF})$$ (C23)

$$q_{tr2} = w_{v2}(h_2 - h_0)(HD_{CF})$$ (C24)

C12.1.3   Gross Total Cooling Effect

$$q_t = \frac{q_{tr1} + q_{tr2}}{2}$$ (C25)

C12.1.4   Allowable Cooling Capacity heat balance

$$+5\% \geq \frac{100(q_{tr1} - q_{tr2})}{q_t} \geq -5\%$$ (C26)

C12.2   *Gross Total Cooling Effect – Dry Rating Condition only* (Method 2)

C12.2.1   Heat Leakage Coefficient of Calibrated Box

$$K_{cb} = 3.41\frac{E_c}{(T_{en} - T_{cb})}$$ (C27)

$$\left[K_{cb} = \frac{E_c}{(T_{en} - T_{cb})}\right]$$

C12.2.2   Air-Side Gross Total Cooling Effect

$$q_{ta} = [K_{cb}(T_{en} - T_{cb}) + 3.41(E_c + E)](TD_{CF})$$ (C28)

$$\left[q_{ta} = \{K_{cb}(T_{en} - T_{cb}) + E_c + E\}(TD_{CF})\right]$$

C12.2.3   Refrigerant-Side Gross Total Cooling Effect

$$q_{tr} = w_{v1}(h_2 - h_0)(TD_{CF})$$ (C29)

C12.2.4   Gross Total Cooling Effect

$$q_t = \frac{q_{ta} + q_{tr}}{2}$$ (C30)

C12.2.5   Allowable Cooling Capacity heat balance

$$+5\% \geq \frac{100(q_{ta} - q_{tr})}{q_t} \geq -5\%$$ (C31)

C12.3 *Gross Total Cooling Effect Calculation.* (Method 3)

C12.3.1 System heat loss or gain

C12.3.1.1 Condenser Heat Loss or Gain

$$q_{c1} = A_c k_c \left[T_{a1} - \frac{t_{5s} + t_6}{2} \right] \tag{C32}$$

C12.3.1.2 Liquid/Vapor Separator Heat Loss or Gain

$$q_s = A_s k_s \left(T_{a2} - t_{4s} \right) \tag{C33}$$

C12.3.1.3 Piping heat loss or gain

$$q_p = \sum_{1}^{n} A_{Pn} k_{Pn} \left(T_{a_n} - t_{s_n} \right) \tag{C34}$$

C12.3.1.4 Pump heat gain

$$q_{cp} = w_{v2} \left(h_7 - h_6 \right) \tag{C35}$$

$$q_{rp} = w_{v3} \left(h_9 - h_8 \right) \tag{C36}$$

C12.3.2 Recirculation Ratio

$$RR = \left(\frac{w_{v3}}{w_{v2}} \right) \tag{C37}$$

C12.3.3 Gross Total Cooling Effect

C12.3.3.1 Condenser Calorimeter Capacity

$$q_c = w_c \left(h_{c2} - h_{c1} \right) \tag{C38}$$

$$q_v = w_{v2} \left(h_5 - h_6 \right) + q_{c1} \tag{C39}$$

$$w_{cc} = \frac{w_{v2} \left(h_5 - h_6 \right) + q_{c1}}{\left(h_{c2} - h_{c1} \right)} \tag{C40}$$

C12.3.3.2 Independent Gross Total Cooling Effect: Dry Rating Condition

$$q_{tr1} = w_c(h_{c2} - h_{c1})(TD_{CF}) - (q_p + q_s + q_{cp} + q_{rp}) \qquad (C41)$$

$$q_{tr2} = w_{cc}(h_{c2} - h_{c1})(TD_{CF}) - (q_p + q_s + q_{cp} + q_{rp}) \qquad (C42)$$

C12.3.3.3 Independent Gross Total Cooling Effect: Wet Rating Condition

$$q_{tr1} = w_c(h_{c2} - h_{c1})(HD_{CF}) - (q_p + q_s + q_{cp} + q_{rp}) \qquad (C43)$$

$$q_{tr2} = w_{cc}(h_{c2} - h_{c1})(HD_{CF}) - (q_p + q_s + q_{cp} + q_{rp}) \qquad (C44)$$

C12.3.3.4 Gross Total Cooling Effect

$$q_t = \frac{q_{tr1} + q_{tr2}}{2} \qquad (C45)$$

C12.3.3.5 Allowable Cooling Capacity heat balance

$$+5\% \geq \frac{100(q_{tr1} - q_{tr2})}{q_t} \geq -5\% \qquad (C46)$$

C12.3.3.6 Allowable system heat loss or gain

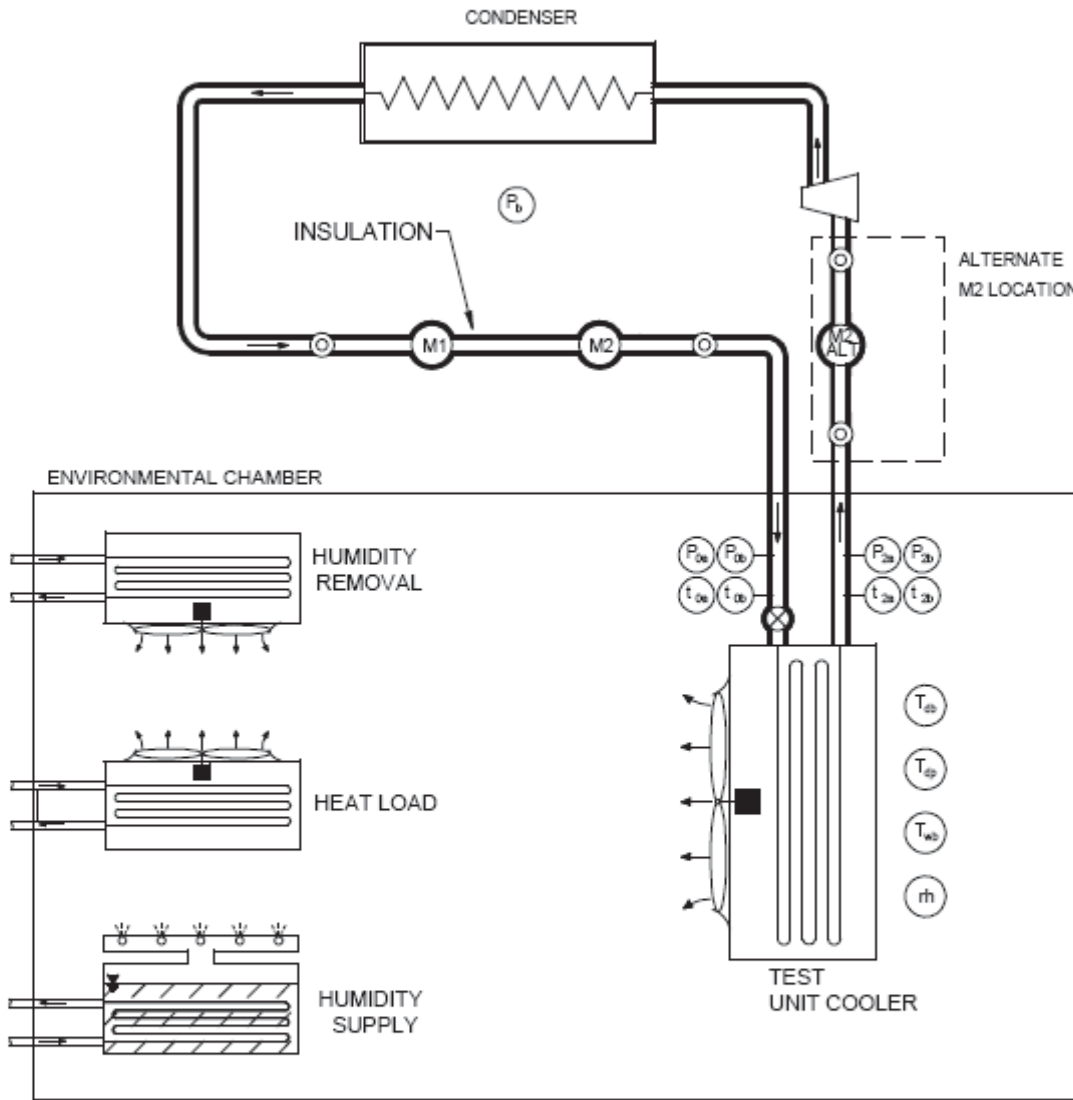$$+5\% \geq \frac{100(q_{cl} + q_s + q_p + q_{cp} + q_{rp})}{q_t} \geq -5\% \qquad (C47)$$

C13. *Symbols and Subscripts*

A_c Surface area of exposed external area of the condenser calorimeter, ft^2 [m^2]
A_p Pipe surface area, ft^2 [m^2]
A_s Liquid/vapor separator surface area, ft^2 [m^2]
E Total electrical power input to fan motor(s) of Unit Cooler, W [W]
E_c Total electrical power input to heater and auxiliary equipment, W [W]
e_{fm} Fan motor efficiency
FS Fan speed (s), rpm [rev/s]
h_0 Enthalpy of refrigerant liquid entering the Unit Cooler, Btu/lb [W/kg]
h_2 Enthalpy of refrigerant leaving the Unit Cooler, Btu/lb [W/kg]
h_5 Enthalpy of refrigerant vapor entering the condenser, Btu/lb [W/kg]
h_6 Enthalpy of refrigerant liquid leaving condenser calorimeter and entering condensate pump, Btu/lb [W/kg]
h_7 Enthalpy of refrigerant liquid leaving the condensate pump, Btu/lb [W/kg]
h_8 Enthalpy of refrigerant liquid leaving the liquid/vapor separator, Btu/lb [W/kg]
h_9 Enthalpy of refrigerant liquid leaving the recirculation pump, Btu/lb [W/kg]
h_{a1} Enthalpy of the air entering the Unit Cooler at Standard Rating Conditions, Btu/lb [J/kg]
h_{a2} Enthalpy of the air entering the Unit Cooler at the test condition, Btu/lb [J/kg]
h_{ar} Enthalpy of saturated air at Standard Rating Refrigerant Saturation Temperature, Btu/lb [J/kg]
h_{at} Enthalpy of saturated air at the test Refrigerant Saturation Temperature, Btu/lb [J/kg]
h_{c1} Enthalpy of fluid entering the condenser, Btu/lb [W/kg]
h_{c2} Enthalpy of fluid leaving the condenser, Btu/lb [W/kg]
HD_{CF} Enthalpy of air correction factor
HD_{rated} Enthalpy difference of air at Rating Conditions, Btu/lb [W/kg]
HD_{test} Enthalpy difference of air at test conditions, Btu/lb [W/kg]
k_c Conductance of condenser calorimeter insulation, Btu/h·°F·ft² [W/°C·m²]

|	
K_{cb}	Heat leakage coefficient of calibrated box, Btu/h·°F [W/°C]
k_p	Conductance of piping insulation, Btu/h·°F·ft² [W/°C·m²]
k_s	Conductance of liquid/vapor separator insulation, Btu/h·°F·ft² [W/°C·m²]
n	Number of measurement stations
N	Number of motors
P_0	Pressure of subcooled refrigerant liquid entering the expansion valve (method 1 average value), psi [kPa]
P_{0a}	Pressure of subcooled refrigerant liquid entering the expansion valve, psi [kPa]
P_{0b}	Pressure of subcooled refrigerant liquid entering the expansion valve, psi [kPa]
P_2	Pressure of superheated refrigerant vapor leaving the Unit Cooler (method 1 average value), psi [kPa]
P_{2a}	Pressure of superheated refrigerant vapor leaving the Unit Cooler, psi [kPa]
P_{2b}	Pressure of superheated refrigerant vapor leaving the Unit Cooler, psi [kPa]
P_3	Pressure of saturated refrigerant liquid/vapor mixture leaving the Unit Cooler, psi [kPa]
P_4	Pressure of refrigerant in liquid/vapor separator, psi [kPa]
P_5	Pressure of refrigerant entering condenser calorimeter, psi [kPa]
P_6	Pressure of subcooled refrigerant liquid leaving condenser calorimeter and entering condensate pump, psi [kPa]
P_7	Pressure of subcooled refrigerant liquid leaving condensate pump, psi [kPa]
P_8	Pressure of subcooled refrigerant liquid entering recirculation pump, psi [kPa]
P_9	Pressure of subcooled refrigerant liquid leaving recirculation pump, psi [kPa]
P_b	Barometric pressure, in Hg [kPa]
P_{c1}	Pressure of fluid entering condenser calorimeter, psi [kPa]
P_{c2}	Pressure of fluid leaving condenser calorimeter, psi [kPa]
p_{fmi}	Input rated power, W [kW]
p_{fmo}	Output rated power, hp [kW]
ρ_{sa}	Density of air at Standard Air Conditions, 0.075 lb/ft^3 [1.201 kg/m^3]
ρ_{test}	Density of air at test conditions, lb/ft^3 [kg/m^3]
q_c	Capacity of the condenser calorimeter calculated from the non-volatile side, Btu/h [W]
q_{cl}	Heat gain or loss to condenser calorimeter, Btu/h [W]
q_{cp}	Heat gain from condensate pump, Btu/h [W]
q_p	Total piping heat loss or gain, Btu/h [W]
q_{rp}	Heat gain from recirculation pump, Btu/h [W]
q_s	Heat gain or loss from liquid/vapor separator, Btu/h [W]
q_t	Gross Total Cooling Effect, Btu/h [W]
q_{ta}	Air-side Gross Total Cooling Effect, Btu/h [W]
q_{tr}	Refrigerant-side Gross Total Cooling Effect, Btu/h [W]
q_{tr1}	Refrigerant-side Gross Total Cooling Effect established by first independent measurement, Btu/h [W]
q_{tr2}	Refrigerant-side Gross Total Cooling Effect established by second independent measurement, Btu/h [W]
q_v	Capacity of the condenser calorimeter calculated from the volatile side, Btu/h [W]
rh	Air inlet relative humidity
RR	Recirculation Ratio
t_0	Temperature of subcooled refrigerant liquid entering the expansion valve (method 1 average value), °F [°C]
t_{0a}	Temperature of subcooled refrigerant liquid entering the expansion valve, °F [°C]
t_{0b}	Temperature of subcooled refrigerant liquid entering the expansion valve, °F [°C]
t_{0s}	Temperature of saturated refrigerant entering the expansion valve, °F [°C]
t_{0sc}	Subcooling entering the expansion valve, °F [°C]
t_2	Temperature of superheated refrigerant vapor leaving the Unit Cooler (method 1 average value), °F [°C]
t_{2a}	Temperature of superheated refrigerant vapor leaving the Unit Cooler, °F [°C]
t_{2b}	Temperature of superheated refrigerant vapor leaving the Unit Cooler, °F [°C]
t_{2s}	Temperature of saturated refrigerant leaving Unit Cooler, °F [°C]
t_{2sh}	Amount of superheat leaving test Unit Cooler, °F [°C]
t_3	Temperature of refrigerant liquid/vapor leaving the Unit Cooler, °F [°C]
t_{3s}	Temperature of saturated refrigerant leaving Unit Cooler, °F [°C]
t_{4s}	Temperature of saturated refrigerant in liquid/vapor separator, °F [°C]
t_5	Temperature of refrigerant entering condenser calorimeter, °F [°C]
t_{5s}	Temperature of saturated refrigerant entering condenser calorimeter, °F [°C]
t_6	Temperature of subcooled refrigerant liquid entering condensate pump, °F [°C]
t_7	Temperature of subcooled refrigerant liquid leaving condensate pump, °F [°C]
t_8	Temperature of subcooled refrigerant liquid entering recirculation pump, °F [°C]
t_9	Temperature of subcooled refrigerant liquid leaving recirculation pump, °F [°C]

T_a	Local pipe ambient temperature, °F [°C]
T_{a1}	Condenser calorimeter ambient temperature, °F [°C]
T_{a2}	Liquid/vapor separator ambient temperature, °F [°C]
t_{c1}	Average temperature of fluid entering condenser calorimeter, °F [°C]
t_{c1a}	Temperature of fluid entering condenser calorimeter, °F [°C]
t_{c1b}	Temperature of fluid entering condenser calorimeter, °F [°C]
t_{c2}	Average temperature of fluid leaving condenser calorimeter, °F [°C]
t_{c2a}	Temperature of fluid leaving condenser calorimeter, °F [°C]
t_{c2b}	Temperature of fluid leaving condenser calorimeter, °F [°C]
T_{cb}	Average dry-bulb temperature of air within the calibrated box, °F [°C]
T_{db}	Average dry-bulb temperature of air entering Unit Cooler, °F [°C]
T_{dp}	Dew point temperature of air entering Unit Cooler, °F [°C]
TD_{CF}	Temperature Difference correction factor
TD_{rated}	Temperature Difference at Rating Conditions, °F [°C]
TD_{test}	Temperature Difference at test conditions, °F [°C]
T_{en}	Average dry-bulb temperature of air within the temperature controlled enclosure, °F [°C]
t_s	Local pipe refrigerant temperature, °F [°C]
T_{wb}	Wet-bulb temperature of air entering Unit Cooler, °F [°C]
V	Voltage of each phase, V [V]
w_c	Mass flow rate of fluid through M1 entering the condenser calorimeter, lbm/h [kg/s]
w_{cc}	Calculated mass flow rate of fluid through M1 entering the condenser calorimeter, lbm/h [kg/s]
w_{v1}	Mass flow rate of subcooled refrigerant liquid through M1, lbm/h [kg/s]
w_{v2}	Mass flow rate of subcooled liquid or superheated refrigerant vapor through M2 or M2ALT, lbm/h [kg/s]
w_{v3}	Mass flow rate of subcooled refrigerant liquid through M3, lbm/h [kg/s]

FIGURE C1
METHOD 1: DX - DUAL INSTRUMENTATION

CONDENSER

P_b

INSULATION

ALTERNATE
M2 LOCATION

M1   M2   M2 ALT

ENVIRONMENTAL CHAMBER

HUMIDITY REMOVAL

HEAT LOAD

HUMIDITY SUPPLY

P_{0a} P_{0b} P_{2a} P_{2b}

t_{0a} t_{0b} t_{2a} t_{2b}

T_{db}

T_{dp}

T_{wb}

rh

TEST UNIT COOLER

	LEGEND	
◁	Vapor Compressor	(P) Pressure measurement station
(M)	Mass flow meter	(T) Air temperature measurement station
⊗	Expansion valve	(t) Refrigerant temperature measurement station
◎	Sight Glass	(rh) Air inlet relative humidity
—	Insulation Required	(P_b) Barometric pressure

FIGURE C2
METHOD 2: DX - CALIBRATED BOX
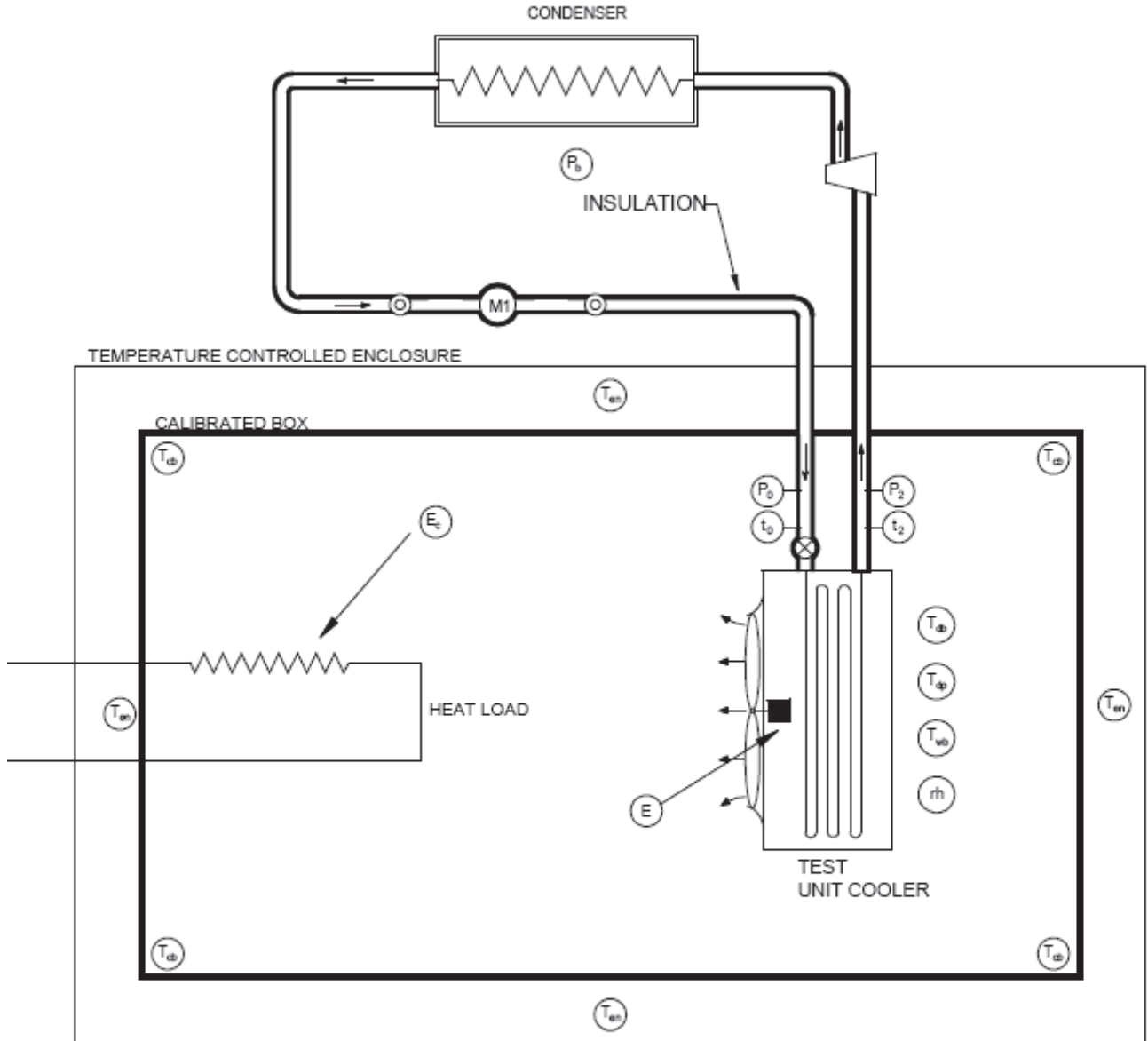
LEGEND

◁	Vapor Compressor	(P)	Pressure measurement station
(M)	Mass flow meter	(T)	Air temperature measurement station
⊗	Expansion valve	(t)	Refrigerant temperature measurement station
◎	Sight Glass	(rh)	Air inlet relative humidity
▬	Insulation Required	(P_b)	Barometric pressure
		(E)	Fan power
		(E_c)	Heat load input power

FIGURE C3
METHOD 3: LIQUID OVERFEED