AHRI Standard 420 (I-P)

2016 Standard for

Performance Rating of Forced-circulation Free-delivery Unit Coolers for Refrigeration

AIR-CONDITIONING, HEATING, & REFRIGERATION INSTITUTE
we make life better™
2111 Wilson Boulevard, Suite 500
Arlington, VA 22201, USA
www.ahrinet.org
PH 703.524.8800
FX 703.562.1942

IMPORTANT

SAFETY DISCLAIMER

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

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

Note:

This standard supersedes ANSI/AHRI Standard 420-2009.
For SI ratings, see AHRI Standard 421 (SI)-2016.

AHRI CERTIFICATION PROGRAM PROVISIONS

Scope of the Certification Program

This program applies to production models of Unit Coolers, as defined in Section 3.3, and meet the following criteria:

- Use refrigerant R-404A or R-507A for Direct Expansion (DX) Coils, or R-717 for DX and/or liquid overfeed coils
- Single vertical coil with aluminum fin material
- Horizontal only air flow direction (the air flows to or from the inlet face of the coil from or to the fan inlet, with no change in direction)
- Axial fans only

Certified Ratings

The following certification program ratings are verified by test:

1. Rated Power, W or hp
2. Gross Total Cooling Effect, Btu/h

Price $10.00 (Members) $20.00 (Non-Members)
Printed in U. S.A.

TABLE OF CONTENTS

TABLES

APPENDICES

TABLES FOR APPENDICES

FIGURES FOR APPENDICES

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 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.

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 (https://www.ashrae.org/resources--publications/free-resources/ashrae-terminology)* 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.

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. 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. 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.

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. 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 and absolute pressure 29.92 in Hg. Under these conditions, dry air has a mass density of 0.075 lb/ft^3.

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.

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, Table 1, in accordance with one of the methods set forth in Appendix C.

Table 1. Standard Rating Conditions

Condition Number	Coil rating condition	Entering Air				Refrigerant Saturation Temperature[2], ºF	Temperature Difference, ºF
		Dry-bulb Temperature, ºF	Wet-bulb Temperature, ºF	Relative Humidity[1], %	Dew Point Temperature[1], ºF		
1	Wet	50	46.1	75	-	35	15
2	Dry	50	-	< 45	< 30	35	15
3	Dry	35	-	< 50	< 20	25	10
4	Dry	10.0	-	< 46	< -5.0	0.00	10
5	Dry	-10.0	-	< 43	< -25	-20.0	10

Notes:

1. The coil Dry Rating Condition can be confirmed by measuring either the entering air dew point or relative humidity according to the instrumentation requirements of Table 2. At coil Wet Rating 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
Temperature	Air dry-bulb	± 0.10 °F	Resistance temperature device (RTD) thermistor
	Air wet-bulb		
	Refrigerant liquid		
	Refrigerant vapor	± 0.5 °F	Special calibrated thermocouple
	Air Dew Point	± 0.5 °F	Chilled mirror hygrometer
	Others	± 1.0 °F	Liquid-in-glass thermometer
Relative Humidity[1]	Air	± 3 percentage points Rh	Capacitive or resistive Rh sensor
Pressure	Refrigerant	Pressure corresponding to ± 0.2 °F of saturation temperature	Transducer
	Air	± 0.05 inches of mercury	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 from Table 1.

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 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 AHRI Standard 420." All claims to ratings outside the scope of this standard shall include the statement "Outside the scope of AHRI 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:

6.2.1 Model number
6.2.2 Gross Total Cooling Effect, Btu/h
6.2.3 Temperature difference, ºF
6.2.4 Refrigerant designation(s) in accordance with ANSI/ASHRAE Standard 34 with Addenda
6.2.5 Refrigerant saturation temperature, ºF
6.2.6 Rated power, W or hp
6.2.7 Number of motors
6.2.8 Coil fin density, fins per inch or coil fin spacing; Actual fin density or fin spacing shall be within 10% of published values.
6.2.9 Airflow rate, scfm

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:

6.3.1 Type of defrost
6.3.2 Unit cooler motor current, A; voltage, V; and frequency, Hz
6.3.3 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 AHRI 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 AHRI Standard 110-2016, *Air-Conditioning, Heating, and Refrigerating Equipment Nameplate Voltages*, 2016, Air-Conditioning, Heating, and Refrigeration Institute, 2111 Wilson Boulevard, Suite 500, Arlington, VA 22201, U.S.A.

A1.2 ANSI/ASHRAE Standard 34-2013 with Addenda, *Designation and Safety Classification of Refrigerants*, 2013, 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 41.1-2013, *Standard Method for Temperature Measurement*, 2013, 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 41.3-2014, *Standard Method for Pressure Measurement*, 2014, 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 41.4-2015, *Standard Method for Measurement of Proportion of Lubricant in Liquid Refrigerant*, 2015, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., 1791 Tullie Circle, N.E., Atlanta, GA 30329, U.S.A.

A1.6 ANSI/ASHRAE Standard 41.10-2013, *Standard Methods for Refrigerant Mass Flow Measurement Using Flowmeters*, 2013, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., 1791 Tullie Circle, N.E., Atlanta, GA 30329, U.S.A.

A1.7 *ASHRAE Handbook Fundamentals*, 2013, 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 7, 2016, 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, https://www.ashrae.org/resources--publications/free-resources/ashraeterminology, 2016, 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 60038-2009, *IEC Standard Voltages*, 2009, 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 9.1, 2016, 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*, 2014, International Institute of Ammonia Refrigeration, 1001 North Fairfax Street, Suite 503, Alexandria, VA 22314, U.S.A.

B1.2 ANSI/ASHRAE Standard 41.9-2011, *Standard Methods for Volatile-Refrigerant Mass Flow Measurements Using Calorimeters*, 2011, 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 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

C2.1.5 Field testing of Unit Coolers

C3. *Measurements*

C3.1 Refer to AHRI Standard 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 of the first 10.0 ft^2 of airflow area and one additional measuring station is required for each 4.0 ft^2 of airflow area above 10.0 ft^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.

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 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
FS - Fan speed (s), rpm
N - Number of motors
P_b - Barometric pressure, in Hg
T_{db} - Dry-bulb temperature of air at inlet, °F
T_{wb} - Wet-bulb temperature of air at inlet, °F
V - Voltage of each phase, 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*

C4.1.1 Manufacturer name and address
C4.1.2 Identification number (model/serial)
C4.1.3 Size (external dimensions), in × in × in
C4.1.4 Nameplate motor data (for each motor)
C4.1.4.1 Type
C4.1.4.2 Frame size
C4.1.4.3 Power, hp
C4.1.4.4 Speed, rpm
C4.1.4.5 Voltage, V
C4.1.4.6 Amps, A
C4.1.4.7 Phase
C4.1.4.8 Frequency, Hz
C4.1.4.9 Efficiency (NEMA nominal or manufacturer’s certificate for polyphase motors)
C4.1.4.10 Manufacturer
C4.1.4.11 Serial number or manufacturer identification number
C4.1.5 Fan data
C4.1.5.1 Diameter, in
C4.1.5.2 Width (centrifugal fans only), in
C4.1.5.3 Speed, rpm
C4.1.5.4 Number of blades
C4.1.5.5 Manufacturer
C4.1.5.6 Model number or part number
C4.1.5.7 Number of fans

C4.1.6 Cooling coil data

C4.1.6.1 Finned length, in

C4.1.6.2 Fin height and depth, in

C4.1.6.3 Number of rows deep

C4.1.6.4 Number of tubes high

C4.1.6.5 Fin density, fins per inch or fin spacing, mm based on total fin count

C4.1.6.6 If fins are staged, fin density per stage, fins per inch or fin spacing per stage

C4.1.6.7 Measured fin material thickness, in {Note: fin thickness for hot dipped galvanized coils will vary.}

C4.1.6.8 Fin material

C4.1.6.9 Finished fin geometry

C4.1.6.10 Tube material

C4.1.6.11 Tube description {i.e. outside diameter (or equivalent), enhancements}

C4.1.6.12 Number of refrigerant circuits

C4.1.6.13 Coil or fin coatings

C4.1.7 Accessories (e.g. louvers, distributor orifice, grills)

C4.2 *Specific to the test*

C4.2.1 Test location, test company and address

C4.2.2 Method of test

C4.2.3 Date and time of Test Run

C4.2.4 Names of observers – responsible engineers and all data takers

C4.2.5 Published Gross Total Cooling Effect at Standard Rating Conditions, Btu/h

C4.2.6 Refrigerant

C4.2.7 Recirculation Ratio (Method 3) - manufacturer specified

C4.2.8 Refrigerant flow rate, lbm/h (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, see Figure C1.

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, see Figure C2.

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. The Recirculation Ratio and refrigerant flow rate through Unit Cooler shall be specified by the manufacturer, see Figure C3.

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

C6.1 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, per fan section of the Unit Cooler.

C6.2 All other distances correspond to the minimum requirements of the installation instructions provided by the manufacturer.

C6.3 The minimum volume, ft^3, of the test chamber shall be 20 % of the airflow rate, ft^3/min 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:

Table C2. Additional Test Conditions

Method	Condition Number	Inlet Saturation Temperature, ºF		Inlet Subcooling, ºF	Outlet Superheat, ºF
		Excluding R-717	R-717 only		
1, 2	All	105	95	15	6.5
3	1	40	40	3	-
	2	40	40	3	-
	3	30	30	3	-
	4	7.0	7.0	4	-
	5	-10	-10	6	-

Table C3. Test Condition Tolerances

Variable Description	Test Condition Stability Over Test Run Duration, ºF		Allowable Deviation of Average Test Temperatures from Standard Rating Conditions, ºF	
	Dry Condition	Wet Condition	Dry Condition	Wet Condition
Dry-bulb Temperature	-	-	± 1.0	± 1.0
Wet-bulb Temperature	-	± 0.5	-	± 0.5
Dew Point Temperature	-	-	Note 2	-
Temperature Difference	± 0.5[1]	± 0.5[1]	-	-
Refrigerant Flow Rate	± 3.0 %		-	-

Note:

1. The Dry-bulb temperature tolerance is set by the Temperature Difference.
2. The Dew Point Temperature cannot exceed the temperature shown in Table 1.

Table C4. Refrigerant Temperature Tolerances

Variable Description	Test Temperature Stability During the Test Run, ºF		Allowable Deviation of Average Test Temperatures from Standard Rating Conditions, ºF	
	Methods 1, 2	Method 3	Methods 1, 2	Method 3
Inlet Saturation Temperature	± 5.0	± 2.0	± 2.5	± 1.0
Inlet Subcooling	± 5.0	± 1.0 [1]	± 2.0	± 1.0
Outlet Saturation Temperature	-	-	± 0.5	± 0.5
Outlet Superheat	± 1.5	-	± 1.0	-

Note:

1. For Test Condition 5, ± 2.0 ºF.

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

C8.1 *Test Setup and Procedure*. Refer to Section C5, 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
P_b - Barometric pressure, in Hg
rh - Air inlet relative humidity, %
T_{db} - Dry-bulb temperature of air at inlet, °F
T_{dp} - Dew point temperature of air at inlet, °F
T_{wb} - Wet-bulb temperature of air at inlet, °F

C8.2.2 Refrigerant side

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

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 C5, 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 at all sides, top and bottom, except that clearance of any one surface may be reduced to not less than 5.5 in.

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 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, 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 (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 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 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 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.

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:

C.9.1.2.5.1 The average box temperature is not less than 25.0ºF above the test enclosure temperature;
C9.1.2.5.2 Temperature variations do not exceed 5.0ºF between temperature measuring stations; and
C9.1.2.5.3 Temperatures do not vary by more than 2.0ºF 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
FS	-	Fan speed (s), rpm
P_b	-	Barometric pressure, in Hg
rh	-	Air inlet relative humidity
T_{cb}	-	Average dry-bulb temperature of air within the calibrated box, °F
T_{db}	-	Dry-bulb temperature of air at inlet, °F
T_{dp}	-	Dew point temperature of air at inlet, °F
T_{en}	-	Average dry-bulb temperature of air within the temperature controlled enclosure, °F
T_{wb}	-	Wet-bulb temperature of air at inlet, °F

C9.2.2 Heat load provided to calibrated box

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

C9.2.3 Refrigerant Side

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

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 C5, 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
P_b	-	Barometric pressure, in Hg
rh	-	Air inlet relative humidity, %
T_a	-	Local pipe ambient temperature, °F
T_{a1}	-	Condenser calorimeter ambient temperature, °F
T_{a2}	-	Liquid/vapor separator ambient temperature, °F
T_{db}	-	Dry-bulb temperature of air at inlet, °F
T_{dp}	-	Dew point temperature of air at inlet, °F
T_{wb}	-	Wet-bulb temperature of air at inlet, °F

C10.2.2 Refrigerant side

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

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 and mass balance, refer to C12.3.3.1 and C12.3.3.2

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:

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

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

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

C11.2 *Average measured temperatures*

C11.2.1 Dry-bulb temperature (all methods)

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

C11.2.2 Wet-bulb temperature (all methods)

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

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

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

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

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

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

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

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

C11.2.6 Temperature controlled enclosure temperature (method 2)

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

C11.2.7 Calibrated box temperature (method 2)

$$T_{cb} = \frac{\sum_{1}^{n} T_{cb\,n}}{n} \qquad \text{C10}$$

C11.3 *Average measured pressures*

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

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

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

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

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.

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.

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.

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.

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.

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

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

C11.6 *Vapor superheat leaving Unit Cooler* (methods 1, 2)

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

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.

C11.8 *Temperature Difference Correction Factor*

$$TD_{test} = T_{db} - t_{2s} \quad \text{(methods 1, 2)} \quad \text{C15}$$

$$TD_{test} = T_{db} - t_{3s} \quad \text{(method 3)} \quad \text{C16}$$

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

Refer to Table 1 for TD_{rated} values.

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

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

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

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

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

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

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

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

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

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

C12.1.3 Gross Total Cooling Effect

$$q_t = \frac{q_{tr1} + q_{tr2}}{2} \quad \text{C25}$$

C12.1.4 Allowable Cooling Capacity heat balance

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

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

C12.2.1 Heat Leakage Coefficient of Calibrated Box

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

C12.2.2 Air-Side Gross Total Cooling Effect

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

C12.2.3 Refrigerant-Side Gross Total Cooling Effect

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

C12.2.4 Gross Total Cooling Effect

$$q_t = \frac{q_{ta} + q_{tr}}{2} \quad \text{C30}$$

C12.2.5 Allowable Cooling Capacity heat balance

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

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

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

C12.3.1.2 Liquid/vapor separator heat loss or gain

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

C12.3.1.3 Piping heat loss or gain

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

C12.3.1.4 Pump heat gain

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

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

C12.3.2 Recirculation Ratio

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

C12.3.3 Gross Total Cooling Effect

C12.3.3.1 Condenser calorimeter capacity

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

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

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

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

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

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

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

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

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

C12.3.3.4 Gross Total Cooling Effect

$$q_t = \frac{q_{tr1} + q_{tr2}}{2} \quad C45$$

C12.3.3.5 Allowable Cooling Capacity heat balance

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

C12.3.3.6 Allowable system heat loss or gain

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

C13. *Symbols and Subscripts*

A_c	-	Surface area of exposed external area of the condenser calorimeter, ft^2
A_p	-	Pipe surface area, ft^2
A_s	-	Liquid/vapor separator surface area, ft^2
E	-	Total electrical power input to fan motor(s) of Unit Cooler, W
E_c	-	Total electrical power input to heater and auxiliary equipment, W
e_{fm}	-	Fan motor efficiency
FS	-	Fan speed (s), rpm
h_0	-	Enthalpy of refrigerant liquid entering the Unit Cooler, Btu/lb
h_2	-	Enthalpy of refrigerant leaving the Unit Cooler, Btu/lb
h_5	-	Enthalpy of refrigerant vapor entering the condenser, Btu/lb
h_6	-	Enthalpy of refrigerant liquid leaving condenser calorimeter and entering condensate pump, Btu/lb
h_7	-	Enthalpy of refrigerant liquid leaving the condensate pump, Btu/lb
h_8	-	Enthalpy of refrigerant liquid leaving the liquid/vapor separator, Btu/lb
h_9	-	Enthalpy of refrigerant liquid leaving the recirculation pump, Btu/lb
h_{a1}	-	Enthalpy of the air entering the Unit Cooler at Standard Rating Conditions, Btu/lb
h_{a2}	-	Enthalpy of the air entering the Unit Cooler at the test condition, Btu/lb
h_{ar}	-	Enthalpy of saturated air at Standard Rating Refrigerant Saturation Temperature, Btu/lb
h_{at}	-	Enthalpy of saturated air at the test Refrigerant Saturation Temperature, Btu/lb
h_{c1}	-	Enthalpy of fluid entering the condenser, Btu/lb
h_{c2}	-	Enthalpy of fluid leaving the condenser, Btu/lb
HD_{CF}	-	Enthalpy of air correction factor
HD_{rated}	-	Enthalpy difference of air at Rating Conditions, Btu/lb
HD_{test}	-	Enthalpy difference of air at test conditions, Btu/lb
k_c	-	Conductance of condenser calorimeter insulation, Btu/h·°F·ft²
K_{cb}	-	Heat leakage coefficient of calibrated box, Btu/h·°F
k_p	-	Conductance of piping insulation, Btu/h·°F·ft²
k_s	-	Conductance of liquid/vapor separator insulation, Btu/h·°F·ft² add dots between symbols
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
P_{0a}	-	Pressure of subcooled refrigerant liquid entering the expansion valve, psi
P_{0b}	-	Pressure of subcooled refrigerant liquid entering the expansion valve, psi

P_2	-	Pressure of superheated refrigerant vapor leaving the Unit Cooler (method 1 average value), psi
P_{2a}	-	Pressure of superheated refrigerant vapor leaving the Unit Cooler, psi
P_{2b}	-	Pressure of superheated refrigerant vapor leaving the Unit Cooler, psi
P_3	-	Pressure of saturated refrigerant liquid/vapor mixture leaving the Unit Cooler, psi
P_4	-	Pressure of refrigerant in liquid/vapor separator, psi
P_5	-	Pressure of refrigerant entering condenser calorimeter, psi
P_6	-	Pressure of subcooled refrigerant liquid leaving condenser calorimeter and entering condensate pump, psi
P_7	-	Pressure of subcooled refrigerant liquid leaving condensate pump, psi
P_8	-	Pressure of subcooled refrigerant liquid entering recirculation pump, psi
P_9	-	Pressure of subcooled refrigerant liquid leaving recirculation pump, psi
P_b	-	Barometric pressure, in Hg
P_{c1}	-	Pressure of fluid entering condenser calorimeter, psi
P_{c2}	-	Pressure of fluid leaving condenser calorimeter, psi
p_{fmi}	-	Input rated power, W
p_{fmo}	-	Output rated power, hp
q_c	-	Capacity of the condenser calorimeter calculated from the non-volatile side, Btu/h
q_{cl}	-	Heat gain or loss to condenser calorimeter, Btu/h
q_{cp}	-	Heat gain from condensate pump, Btu/h
q_p	-	Total piping heat loss or gain, Btu/h
q_{rp}	-	Heat gain from recirculation pump, Btu/h
q_s	-	Heat gain or loss from liquid/vapor separator, Btu/h
q_t	-	Gross Total Cooling Effect, Btu/h
q_{ta}	-	Air-side Gross Total Cooling Effect, Btu/h
q_{tr}	-	Refrigerant-side Gross Total Cooling Effect, Btu/h
q_{tr1}	-	Refrigerant-side Gross Total Cooling Effect established by first independent measurement, Btu/h
q_{tr2}	-	Refrigerant-side Gross Total Cooling Effect established by second independent measurement, Btu/h
q_v	-	Capacity of the condenser calorimeter calculated from the volatile side, Btu/h
rh	-	Air inlet relative humidity, %
RR	-	Recirculation Ratio
t_0	-	Temperature of subcooled refrigerant liquid entering the expansion valve (method 1 average value), °F
t_{0a}	-	Temperature of subcooled refrigerant liquid entering the expansion valve, °F
t_{0b}	-	Temperature of subcooled refrigerant liquid entering the expansion valve, °F
t_{0s}	-	Temperature of saturated refrigerant entering the expansion valve, °F
t_{0sc}	-	Subcooling entering the expansion valve, °F
t_2	-	Temperature of superheated refrigerant vapor leaving the Unit Cooler (method 1 average value), °F
t_{2a}	-	Temperature of superheated refrigerant vapor leaving the Unit Cooler, °F
t_{2b}	-	Temperature of superheated refrigerant vapor leaving the Unit Cooler, °F
t_{2s}	-	Temperature of saturated refrigerant leaving Unit Cooler, °F
t_{2sh}	-	Amount of superheat leaving test Unit Cooler, °F
t_3	-	Temperature of refrigerant liquid/vapor leaving the Unit Cooler, °F
t_{3s}	-	Temperature of saturated refrigerant leaving Unit Cooler, °F
t_{4s}	-	Temperature of saturated refrigerant in liquid/vapor separator, °F
t_5	-	Temperature of refrigerant entering condenser calorimeter, °F
t_{5s}	-	Temperature of saturated refrigerant entering condenser calorimeter, °F
t_6	-	Temperature of subcooled refrigerant liquid entering condensate pump, °F
t_7	-	Temperature of subcooled refrigerant liquid leaving condensate pump, °F
t_8	-	Temperature of subcooled refrigerant liquid entering recirculation pump, °F
t_9	-	Temperature of subcooled refrigerant liquid leaving recirculation pump, °F
T_a	-	Local pipe ambient temperature, °F
T_{a1}	-	Condenser calorimeter ambient temperature, °F
T_{a2}	-	Liquid/vapor separator ambient temperature, °F
t_{c1}	-	Average temperature of fluid entering condenser calorimeter, °F
t_{c1a}	-	Temperature of fluid entering condenser calorimeter, °F
t_{c1b}	-	Temperature of fluid entering condenser calorimeter, °F
t_{c2}	-	Average temperature of fluid leaving condenser calorimeter, °F
t_{c2a}	-	Temperature of fluid leaving condenser calorimeter, °F
t_{c2b}	-	Temperature of fluid leaving condenser calorimeter, °F

T_{cb}	-	Average dry-bulb temperature of air within the calibrated box, °F
T_{db}	-	Average dry-bulb temperature of air entering Unit Cooler, °F
T_{dp}	-	Dew point temperature of air entering Unit Cooler, °F
T_{en}	-	Average dry-bulb temperature of air within the temperature controlled enclosure, °F
t_s	-	Local pipe refrigerant temperature, °F
T_{wb}	-	Wet-bulb temperature of air entering Unit Cooler, °F
TD_{CF}	-	Temperature Difference correction factor
TD_{rated}	-	Temperature Difference at Rating Conditions, °F
TD_{test}	-	Temperature Difference at test conditions, °F
V	-	Voltage of each phase, V
w_c	-	Mass flow rate of fluid through M1 entering the condenser calorimeter, lbm/h
w_{cc}	-	Calculated mass flow rate of fluid through M1 entering the condenser calorimeter, lbm/h
w_{v1}	-	Mass flow rate of subcooled refrigerant liquid through M1, lbm/h
w_{v2}	-	Mass flow rate of subcooled liquid or superheated refrigerant vapor through M2 or M2ALT, lbm/h
w_{v3}	-	Mass flow rate of subcooled refrigerant liquid through M3, lbm/h

Greek Symbols

ρ_{sa}	-	Density of air at Standard Air Conditions, 0.075 lb/ft^3
ρ_{test}	-	Density of air at test conditions, lb/ft^3

Conversion factors

1 hp = 746 W
1 W = 3.41 Btu/h

FIGURE C1
METHOD 1: DX – DUAL INSTRUMENTATION

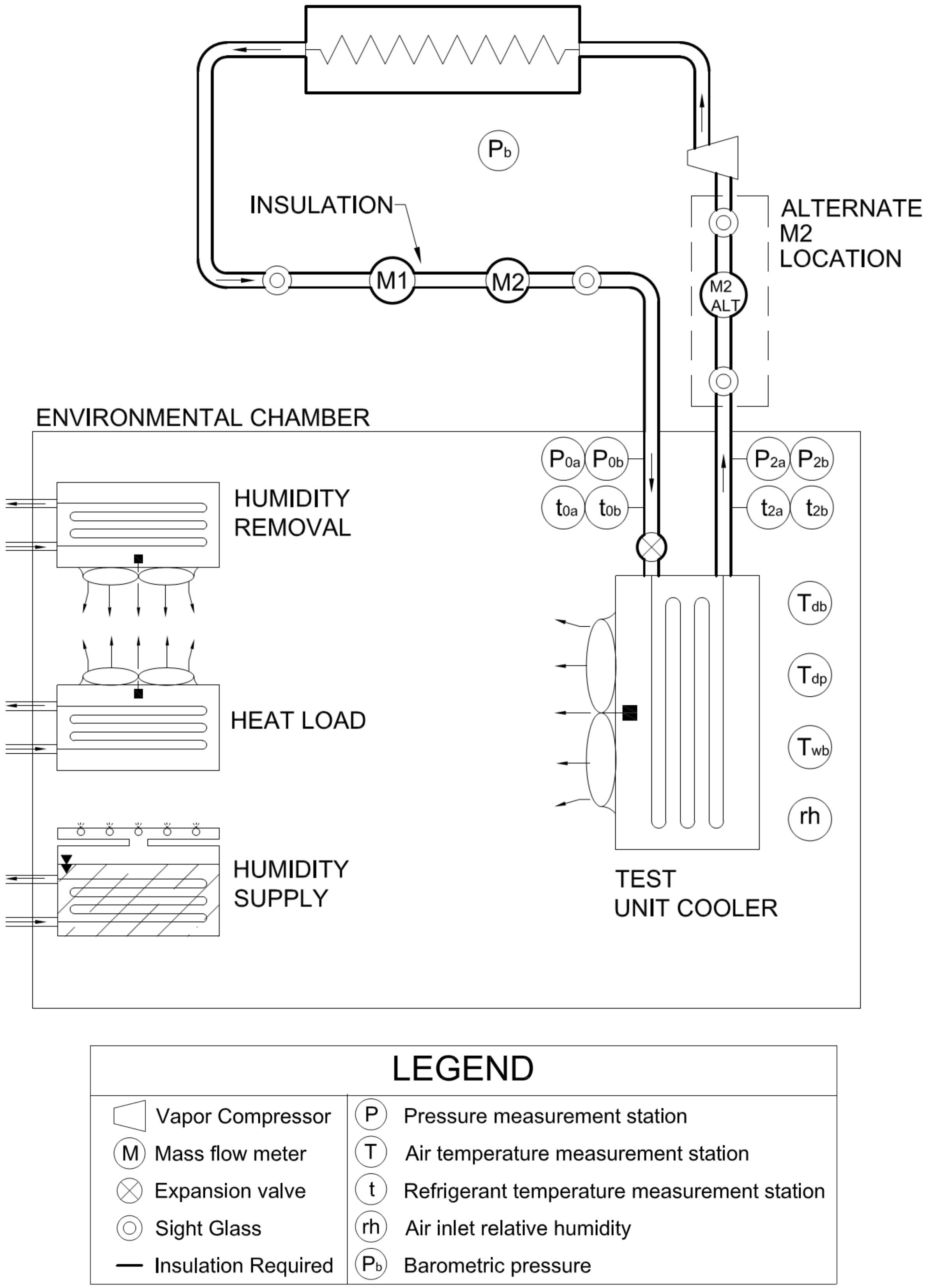


FIGURE C2
METHOD 2: DX – CALIBRATED BOX

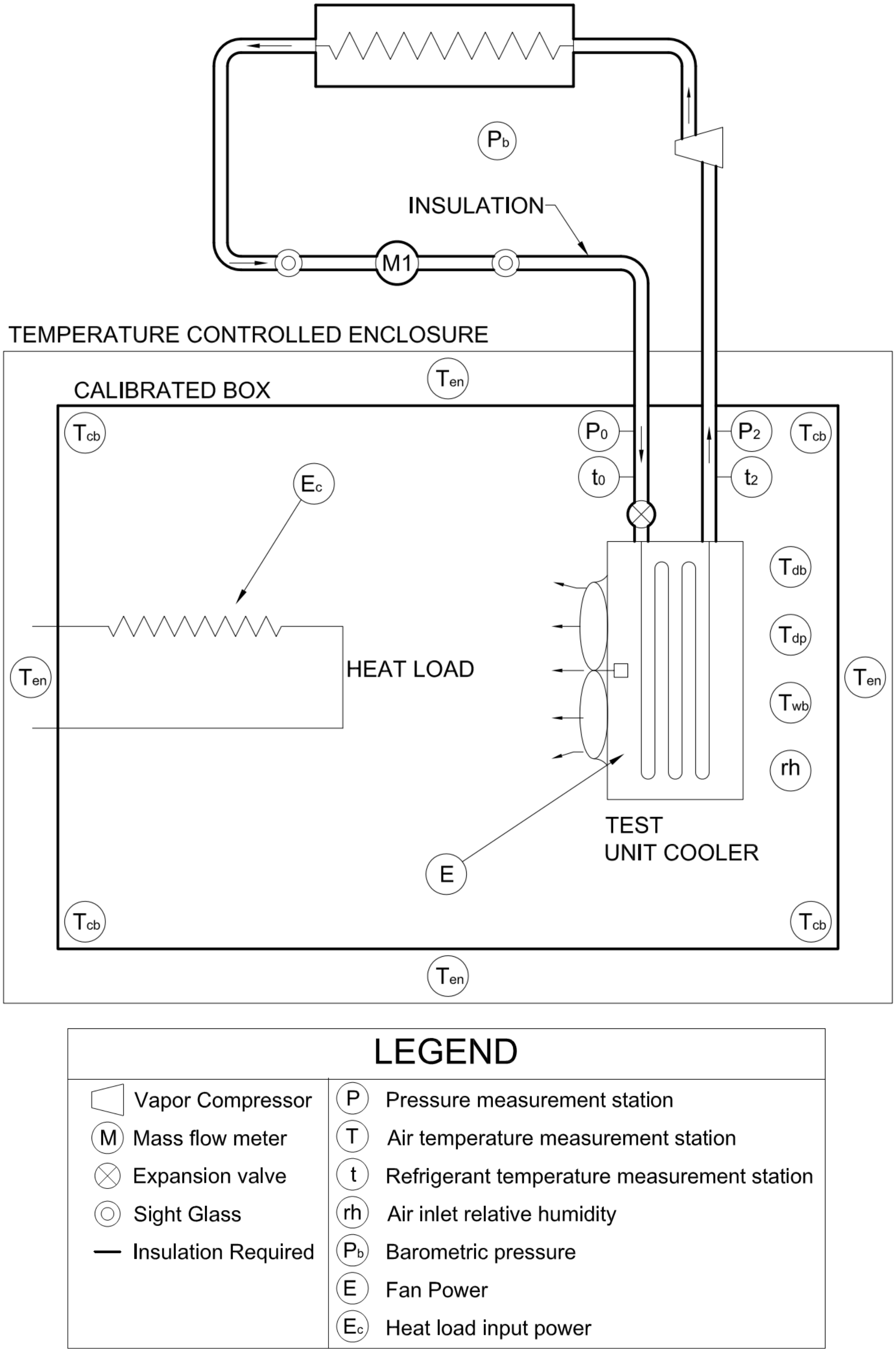
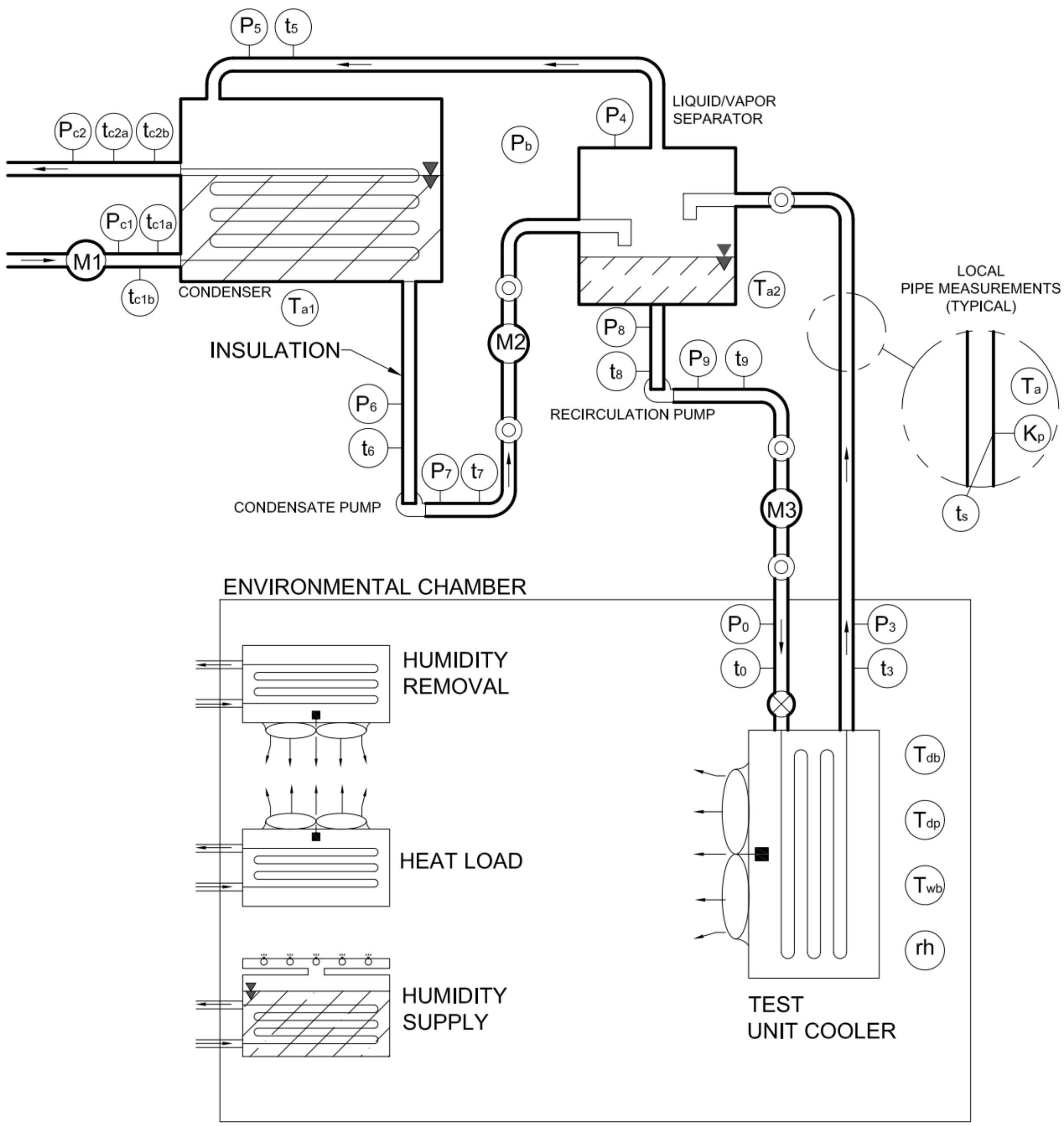


FIGURE C3
METHOD 3: LIQUID OVERFEED



LEGEND

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