AHRI Standard 901 (SI)

2014 Standard for

Performance Rating of Thermal Storage Equipment Used for Cooling

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Note:

This standard supersedes AHRI 900-2010.
For IP ratings, see AHRI Standard 900 (I-P) – 2014.

Price $25.00 (M) $50.00 (NM)
Printed in U.S.A.

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PERFORMANCE RATING OF THERMAL STORAGE EQUIPMENT USED FOR COOLING

Section 1. Purpose

1.1 *Purpose.* The purpose of this standard is to establish for Thermal Storage Equipment used for cooling: definitions; classifications; test requirements; rating requirements; minimum data requirements for Published Ratings; operating requirements; marking and nameplate data; and conformance conditions.

1.1.1 *Intent.* This standard is intended for the guidance of the industry, including manufacturers, engineers, installers, contractors, and users.

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

Section 2. Scope

2.1 *Scope.* This standard applies to Thermal Storage Equipment used for cooling which may be charged and discharged with any of a variety of heat transfer fluids. The equipment, as further described in Sections 3 and 4, may be fully factory assembled; assembled on site from factory supplied components; or field erected in accordance with pre-established design criteria.

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

2.2.1 Thermal Storage Equipment with storage capacities of 25 kWh or less
2.2.2 Thermal Storage Equipment used solely for heating

Section 3. Definitions

All terms in this document shall follow the standard industry definitions in the current edition of *ASHRAE Terminology* website (https://www.ashrae.org/resources--publications/free-resources/ashrae-terminology) unless otherwise defined in this section. For the convenience of users of this standard, definitions for the more important terms employed in this standard are provided below:

3.1 *Ambient Air.* The air in the space surrounding the thermal energy storage device.

3.2 *Ambient Heat Load.* The load (typically expressed in kW) imposed on the storage device due to heat gain from the ambient.

3.3 *Charge Fluid.* The heat transfer fluid used to remove heat from a Thermal Storage Device

3.4 *Charge Period/Cycle.* The Period of time when energy (heat) is removed from the storage device.

3.5 *Charge Rate.* The rate (typically expressed in kW) at which energy (heat) is removed from the storage device during the Charge Period.

3.6 *Discharge Fluid.* The heat transfer fluid used to add heat to the Thermal Storage Device.

3.7 *Discharge Period/Cycle.* The Period of time when energy (heat) is added to the storage device.

3.8 *Discharge Rate.* The rate (typically expressed in kW) at which energy (heat) is added to the storage device during the Discharge Period.

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3.9 *Fouling Factor Allowance.* A thermal resistance included in heat transfer calculations to account for the fouling expected over time on the air, refrigerant, or water side area of a heat transfer surface.

3.10 *Hermetic Compressor.* A motor-compressor assembly contained within a gas-tight casing which uses the refrigerant as the motor coolant. This includes semi-hermetic compressors.

3.11 *Kilowatt-hour (kWh).* The quantity of thermal energy equal to 1 kW of refrigeration provided for one hour.

3.12 *Interval.* The time span between individual test readings.

3.13 *Load Intensity.* The ratio of the instantaneous load imposed upon the storage device to the Net Usable Storage Capacity of the unit, typically expressed in kW/kWh.

3.14 *Net Storage Inventory.* Net accumulated measured Storage Capacity at a given period of time during a 24 hour cycle.

3.15 *Open-type Compressor.* A refrigerant compressor with a shaft or other moving part extending through the casing to be driven by an outside source of power.

3.16 *Period.* The one hour time segments into which the total duty cycle of a thermal storage system is divided for the purpose of analysis and evaluation.

3.17 *Phase Change Material (PCM).* A substance that undergoes changes of state while absorbing or rejecting thermal energy, normally at a constant temperature.

3.18 *Published Ratings.* Published Ratings for Thermal Storage Equipment are the data and methodology by which the "Supplier Specified Data", as set forth in Table 3 of this standard, are developed for a specified duty cycle. They may take the form of tables, graphs, or computer programs, as elected by the manufacturer, and shall apply to all units of like nominal size and type (identification) produced by the same manufacturer.

3.18.1 *Standard Rating.* A rating based on tests performed at standard rating conditions.

3.18.2 *Mapped Rating(s).* Mapped Ratings are ratings falling within certain specified limits that are provided for products which do not have a standard rating condition. They are based upon tests performed across a range of operating conditions as defined by the product manufacturer.

3.18.3 *Application Rating.* A rating, based on tests performed at application rating conditions (other than standard or mapped rating conditions).

3.19 *Saturated Evaporator Temperature (SET).* The dew point temperature of the refrigerant corresponding to the saturation pressure at the outlet connection of the evaporator.

3.20 *Saturated Return Temperature.* The temperature of the refrigerant corresponding to the saturation pressure at the return connection of a Unitary Thermal Storage System.

3.21 *Secondary Coolant.* Any liquid cooled by a refrigerant and used for heat transmission without a change in state, having no flash point or a flash point above 65.0°C.

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

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

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

3.23 *Storage Capacity***.** Storage Capacity, as used in this standard, shall be defined as follows:

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3.23.1 *Measured Storage Capacity***.** The Storage Capacity of a *Unitary Thermal Storage System* (UTSS) determined during a given Storage Cycle in the charge cycle test, typically expressed in kWh.

3.23.2 *Net Usable Storage Capacity.* The amount of stored cooling that can be supplied from the storage device at or below the specified cooling supply temperature for a given Charge and Discharge Cycle, typically expressed in kWh.

3.23.3 *Nominal Storage Capacity.* A theoretical capacity of the storage device as defined by the storage device manufacturer (which in many cases is greater than the Net Usable Storage Capacity), typically expressed in kWh.

3.24 *Thermal Storage Device.* Equipment which stores cooling capacity using sensible and/or latent heat. This equipment may consist solely of a storage means or be packaged with one or more components of a mechanical refrigeration system.

3.25 *Thermal Storage Equipment.* Any one of, or a combination of, Thermal Storage Devices and/or Unitary Thermal Storage Systems, that may include various other components of a mechanical refrigeration package (Section 4).

3.26 *Unitary Thermal Storage System (UTSS).* An assembly of components including a thermal storage device and refrigeration equipment for charging, whose overall performance as a Unitary Thermal Storage System is rated by the manufacturer.

Section 4. Classifications

4.1 *Classification.* Thermal Storage Equipment is broadly classified as either "sensible" or "latent", with further delineations as shown in Table 1 and explained in subsequent paragraphs.

4.1.1 *Sensible Thermal Storage Equipment.* Sensible Thermal Storage Equipment used for cooling typically employs water as the storage medium. During the Charge Period, warm water from the storage device is chilled to the desired temperature by a water chiller and returned to the storage vessel. During the Discharge (cooling) Period, the chilled water is pumped from the storage vessel to the load and the resultant warm water returned to storage. Any of several methods may be used to keep the warm return water separated from the stored chilled water, including separate or compartmentalized tanks or where only one tank is employed, labyrinths, membranes, or thermal stratification.

4.1.2 *Latent Thermal Storage Equipment.* Latent Thermal Storage Equipment is further categorized as ice-on-coil, encapsulated ice or Phase Change Material, ice harvester/chiller, ice slurry, or unitary.

4.1.2.1 *Ice-on-Coil.* A Thermal Storage Device consisting of coils, plates, or other heat transfer surface submerged in a water filled tank. During the Charge Period, an evaporating refrigerant or cold Secondary Coolant is circulated through the coils/plates causing ice to form on the external surfaces. During the Discharge (cooling) Period, either of two methods is typically employed:

4.1.2.1.1 *External Melt.* With external melt, warm, return water is circulated through the tank, external to the ice formation, whereby it is cooled by the melting ice.

Some ice-on-coil devices may also serve as water chillers by circulating warm return water through the tank and over the external surface of the heat exchanger where it is cooled by Secondary Coolant or refrigerant circulating within the exchanger.

4.1.2.1.2 *Internal Melt.* With internal melt, typically a warm, return, Secondary Coolant is circulated through the coils/plates and cooled as the ice external to the coils/plates is melted.

4.1.2.2 *Encapsulated Ice or Phase Change Material.* Thermal Storage Equipment consisting of a tank or vessel densely packed with numerous, relatively small containers in which the storage medium (water-ice or other Phase Change Material such as eutectic salt) is encapsulated. During the Charge Period, water or Secondary Coolant, at a temperature below the phase change temperature of the storage media, is circulated through the tank/vessel to effect a phase change (freezing) in the storage medium. During the Discharge

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Period, warm return water or Secondary Coolant is circulated through the tank/vessel and cooled as the encapsulated storage media changes phase (melts).

4.1.2.3 *Unitary.* An assembly of components including a thermal storage device and refrigeration equipment for charging, which is rated by the manufacturer as a UTSS. The Thermal Storage Device consists of a heat exchanger submerged in a water filled tank. During the Charge Period, an evaporating refrigerant or cold Secondary Coolant is circulated through the heat exchanger causing ice to form on the external surface. During the Discharge (cooling) Period, a condensing refrigerant or warm Secondary Coolant is cooled by internal and/or external melt processes.

Table 1. Classification of Thermal Storage Equipment

Classification	Type	Storage Media	Charge Fluid	Discharge Fluid
Sensible	Chilled Water	Water or other Aqueous Solution	Water or other Aqueous Solution	Water or other Aqueous Solution
Latent	Ice-on-Coil (External Melt)	Ice or other Phase Change Material	Secondary Coolant	Water or Secondary Coolant
			Refrigerant	
	Ice-on-Coil (Internal Melt)	Ice or other Phase Change Material	Secondary Coolant	Secondary Coolant
	Encapsulated Ice or Phase Change Material	Ice or other Phase Change Material	Water	Water
			Secondary Coolant	Secondary Coolant
	Unitary	Ice or other Phase Change Material	Refrigerant or Secondary Coolant	Refrigerant, Water or Secondary Coolant

Section 5. Test Requirements

5.1 *Test Requirements.* All Standard and Mapped Ratings shall be verified by tests conducted in accordance with the methods, procedures, and instrumentation set forth in Appendices C, D, E or F of this standard, as applicable.

5.2 *Tolerances for Thermal Storage Devices.* Published Mapped Ratings shall be such that any production Thermal Storage Device, upon test, shall have a Net Usable Storage Capacity of not less than 100% of its rated Net Usable Storage Capacity, with:

5.2.1 Fluid side pressure drop values no greater than 15% above the rated values.

5.2.2 Average fluid temperatures (or saturated suction temperatures) for each Period during the Charge Cycle no lower than 0.3°C below the values predicted by the Published Rating methodology for the specified charge duration.

5.2.3 Average fluid temperatures for each Period during the Discharge Cycle no higher than 0.3°C above those predicted by the Published Rating methodology for the specified load profile.

5.2.4 Where applicable, a full load power input at any point during the cycle not more than 5% greater than its power input rating.

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5.3 *Tolerances for Unitary Thermal Storage Systems.* Published Mapped Ratings shall be such that any production Unitary Thermal Storage System, upon test, shall have an average charging power input no greater than 5% above the rated value for each outdoor ambient rating condition and a Net Usable Storage Capacity of not less than 100% of its rated value with average fluid temperatures for each Period during the Discharge Cycle no higher than 0.3°C above those predicted by the published rating methodology for the specified load profile.

Section 6. Rating Requirements

6.1 *Rating Conditions.* The type of equipment shall determine the form of the Published Ratings, as specified below:

6.1.1 *Thermal Storage Devices.* Published Ratings of Thermal Storage Devices shall include Mapped Ratings (Table 2) and Application Ratings consisting of the Net Usable Storage Capacity of the device and the auxiliary power input rating accompanied by the performance data as specified in Table 3 of this standard.

6.1.1.1 *Mapped Ratings*. The Mapped Ratings for each type of Thermal Storage Device shall be limited to the range of conditions set forth in Table 2.

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Table 2. Limits of Mapped Rating Conditions and Method of Testing

Equipment Type	Method of Testing	Discharge Cycle				Charge Cycle
		Load Intensity, kW/kWh	Period, h	Entering Fluid Temperature, °C	Leaving Fluid Temperature, °C	Period, h
Chilled Water	Appendix E	0.08 to 0.25	4 to 12	8 to 18	4 to 10	8 to 12
Ice-on-Coil External Melt	Appendix F	0.08 to 0.25	4 to 12	5 to 15	1.5 to 10.0	8 to 12
Ice-on-Coil Internal Melt	Appendix C	0.08 to 0.25	4 to 12	5 to 15	3.5 to 10.0	8 to 12
Encapsulated Ice	Appendix C or E	0.08 to 0.25	4 to 12	5 to 15	3.5 to 10.0	6 to 12
Phase Change Material (PCM)	Appendix C or E	0.08 to 0.25	4 to 12	5 to 15 above Phase Change Temperature	3.5 to 10 above Phase Change Temperature	8 to 12
Unitary	Appendix D	0.08 to 0.25	4 to 12	3.5 to 15	3.5 to 10.0	6 to 14

6.1.1.2 *Auxiliary Power Input Rating.* Published auxiliary power input ratings for Thermal Storage Devices shall be the power required from the customer's power source by all auxiliary components of the Thermal Storage Device that shall operate during the Charge Cycle and/or Discharge Cycle to produce the Net Usable Storage Capacity, including any motors, motor starters, frequency converters, and controls furnished by the manufacturer. Power required by pumps circulating Secondary Coolants to the thermal storage system load external to the Thermal Storage Device shall be excluded.

6.1.2 *Unitary Thermal Storage Systems.* Published Ratings of UTSS shall include the Mapped Ratings of the Net Usable Storage Capacity accompanied by the performance data as specified in Table 3b and the average charge rate and power input ratings when operating at the charge cycle rating conditions specified in Table 4 of this standard.

6.1.2.1 *Mapped Ratings.* The Mapped Ratings for UTSS shall be limited to the range of conditions set forth in Table 2.

6.1.2.2 *Power Input Rating.* Published power input ratings for a UTSS shall be the power required from the customer's power source by all components of the UTSS that shall operate during the Charge Cycle and/or Discharge Cycle to produce the Net Usable Storage Capacity, including, but not limited to the compressor motor(s), condenser fan motor(s), pump(s), motor starters, frequency converters and controls furnished by the manufacturer. Power required by pumps circulating Secondary Coolants or water to the thermal storage system load external to the Unitary Thermal Storage System shall be excluded.

6.1.2.3 *Fouling Factor Allowance*. Calculation of results shall not include Fouling Factor Allowances to determine Published Ratings of a UTSS.

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6.2 *Application Ratings.* Application Ratings are ratings at conditions falling outside the boundaries of mapped rating conditions or at other than standard rating conditions, as may be elected by the manufacturer to facilitate the selection of equipment.

6.3 *Specific Conditions.* Ratings prepared by the manufacturer to address a specific job requirement should include the performance data set forth in Table 3 of this standard, over the Charge and Discharge Cycle.

Section 7. Minimum Data Requirements for Published Ratings

7.1 *Published Ratings.* As a minimum, Published Ratings shall include, or be capable of generating, unit designation(s), Mapped or Standard Ratings for each such unit, and any additional Application Ratings as the manufacturer may elect to include. Ratings shall be accompanied by the following information:

7.1.1 *Thermal Storage Devices.*

7.1.1.1 The Net Usable Storage Capacity, kWh
7.1.1.2 Auxiliary power input rating, kW
7.1.1.3 Type of heat transfer fluid used during the Charge and Discharge Cycles
7.1.1.4 Performance data specified in Table 3a
7.1.1.5 Initial Charge Period, h,
7.1.1.6 Minimum entering temperature of the heat transfer fluid over the duration of the Charge Cycle, °C
7.1.1.7 Pressure drop of heat transfer fluid across the Thermal Storage Device, kPa, at the maximum flow rate encountered during the Charge and Discharge Cycles, l/s
7.1.1.8 Design working pressure(s), kPa

7.1.2 *Unitary Thermal Storage Systems.*

7.1.2.1 Power input requirements during the Charge and Discharge Periods, kW
7.1.2.2 Nominal voltages, V
7.1.2.3 Frequencies for which the rating is valid, Hz
7.1.2.4 Net Usable Storage Capacity, kWh
7.1.2.5 Average charge rate during each Charge Period of the charge cycle test, kW
7.1.2.6 Designation of the refrigerant used during the Charge Cycle, in accordance with ANSI/ASHRAE Standard 34 with Addenda
7.1.2.7 Type of refrigerant or heat transfer fluid used during the Discharge Cycle
7.1.2.8 Performance data specified in Tables 3b & 4

Section 8. Marking and Nameplate Data

8.1 *Marking and Nameplate Data*. As a minimum, the unit nameplate shall display:

8.1.1 The name of the manufacturer and/or the supplier responsible for the performance ratings
8.1.2 The model number of the equipment and a serial number uniquely identifying the product
8.1.3 Where applicable, the refrigerant designation used during the charge cycle, in accordance with ANSI/ASHRAE Standard 34 with Addenda
8.1.4 Where applicable, the electrical characteristics and power consumption of auxiliaries, motors, and controls included in the device or package

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

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Section 9. Conformance Conditions

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

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Table 3A. Supplier Specified Data – Example Design Day

Hour	Thermal Storage System Load, kW	Refrigeration Equipment Load, kW	Storage Device Charge or Discharge Rate[1], kW	Parasitic and Accessory Heat Load into Storage, kW	Ambient Heat Load into Storage Device, kW	Net Storage Inventory[2], kWh	Saturated Evaporator Temperature[3] (If Applicable), °C
0-1							
1-2							
2-3							
3-4							
4-5							
5-6							
6-7							
7-8							
8-9							
9-10							
10-11							
11-12							
12-13							
13-14							
14-15							
15-16							
16-17							
17-18							
18-19							
19-20							
20-21							
21-22							
22-23							
23-0							
TOTALS			N/A			N/A	N/A

Net Usable Storage Capacity	Heat Transfer Fluid	Specific Gravity	Specific Heat	Other Refrigeration Energy Inputs are Required?
_____kWh	_____	_____@ _____°C	_____kJ/kg/°C @ _____ °C	☐ YES ☐ NO

Notes:
1. Greater Discharge Rates may not be possible at the defined discharge temperature
2. Net Storage Inventory Values are not available for instantaneous discharge
3. Applicable where refrigerant is the Charge Fluid.

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Table 3A. Supplier Specified Data – Example Design Day (continued)

Hour	Load Supply Temperature - T1, °C	Load Return Temperature - T2, °C	Flow Rate to Load, L/s	Fluid Temperature Entering Storage Device - T3, °C	Fluid Temperature Leaving Storage Device - T4, °C	Flow Rate through Storage Device, L/s	Pressure Drop Across Storage Device, kPa	Storage Device Refrigeration Energy Input, kWh	Condenser Load, kW or Water Flow, L/s	Refrigeration Condensing or Heat Sink Temp.[4], °C	Power Input to Storage Device, kW
0-1											
1-2											
2-3											
3-4											
4-5											
5-6											
6-7											
7-8											
8-9											
9-10											
10-11											
11-12											
12-13											
13-14											
14-15											
15-16											
16-17											
17-18											
18-19											
19-20											
20-21											
21-22											
22-23											
23-0											
TOTAL	N/A	N/A	N/A	N/A	N/A	N/A	N/A			N/A	

Notes:
4. Specify the type of Heat Sink and the Temperature (Entering Condenser Water Temperature, Entering Air Dry-bulb Temperature, Entering Air Wet-bulb Temperature).

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Table 3B. Supplier Specified Discharge Data for Unitary Thermal Storage Systems

Discharge Hour	Thermal Storage System Load, kW	Refrigeration Equipment Load, kW	Storage Device Discharge Rate[1] kW	Parasitic and Accessory Heat Load into Storage, kW	Ambient Heat Load into Storage Device, kW	Net Storage Inventory[2] kWh	Saturated Return Temperature[3], °C	Power Input to UTSS, kW
0-1								
1-2								
2-3								
3-4								
4-5								
5-6								
6-7								
7-8								
8-9								
9-10								
10-11								
11-12								
TOTALS			N/A			N/A	N/A	

Notes:
1. Greater Discharge Rates may not be possible at the defined discharge temperature
2. Net Storage Inventory Values are not available for instantaneous discharge
3. For a UTSS using a Secondary Coolant as the Discharge Fluid, use the leaving fluid temperature in place of the Saturated Return Temperature

Table 4. Charge Cycle Rating Conditions for Unitary Thermal Storage Systems

Ambient, °C	Charge Rate, kW	Charge Duration, h	Power Input, kW
13.0			
18.5			
24.0			
29.5			
35.0			

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APPENDIX A. REFERENCES – NORMATIVE

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

A1.1 AHRI Standard 900 (I-P)-2014, *Performance Rating of Thermal Storage Equipment Used for Cooling*, 2014, Air-Conditioning, Heating and Refrigerating Institute, 2111 Wilson Boulevard, Suite 500, Arlington, VA 22201, U.S.A.

A1.2 ANSI/AHRI Standard 110-2012, *Air-Conditioning and Refrigerating Equipment Nameplate Voltages*, 2012, Air-Conditioning, Heating and Refrigerating Institute, 2111 Wilson Boulevard, Suite 500, Arlington, VA 22201, U.S.A.

A1.3 ANSI/ASHRAE Standard 34 – 2013 with Addenda, *Designation and Safety Classification of Refrigerants*, 2013, American Society of Heating, Refrigerating and Air-Conditioning Engineers, 1791 Tullie Circle N.E., Atlanta, GA 30329, U.S.A.

A1.4 ANSI/ASHRAE Standard 37 - 2009, *Methods of Testing for Rating Electrically Driven Unitary Air-Conditioning and Heat Pump Equipment*, 2009, American Society of Heating, Refrigerating and Air-Conditioning Engineers, 1791 Tullie Circle N.E., Atlanta, GA 30329, U.S.A.

A1.5 ANSI/ASHRAE Standard 41.1 – 2013 (RA 2001), *Standard Method for Temperature Measurement*, 2013, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, 1791 Tullie Circle N.E., Atlanta, GA 30329, U.S.A.

A1.6 ANSI/ASHRAE Standard 41.3 - 1989, *Standard Method for Pressure Measurement*, 1989, American Society of Heating, Refrigerating and Air-Conditioning Engineers, 1791 Tullie Circle N.E., Atlanta, GA 30329, U.S.A.

A1.7 ANSI/ASHRAE Standard 41.8 - 1989, *Standard Methods for Measurement of Flow of Liquids in Pipes Using Orifice Flowmeters*, 1989, American Society of Heating, Refrigerating and Air-Conditioning Engineers, 1791 Tullie Circle N.E., Atlanta, GA 30329, U.S.A.

A1.8 ANSI/ASHRAE Standard 41.9 - 2011, *A Standard Calorimeter Test Method for Flow Measurement of a Volatile Refrigerant*, 2011, American Society of Heating, Refrigerating and Air-Conditioning Engineers, 1791 Tullie Circle N.E., Atlanta, GA 30329, U.S.A.

A1.9 *ASHRAE Handbook Fundamentals*, Chapter 30, "Thermophysical Properties of Refrigerants" and Chapter 31, "Physical Properties of Secondary Coolants (Brines)", 2013, American Society of Heating, Refrigerating and Air-Conditioning Engineers, 1791 Tullie Circle N.E., Atlanta, GA 30329, U.S.A.

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A1.16 ASME MFC-16-2014 *Measurement of Fluid Flow in Closed Conduits with Electromagnetic Flowmeters*, 2014, American Society of Mechanical Engineers (ASME), 345 E. 47th St., New York, NY 10017, U.S.A.

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A1.18 IEC Standard 60038, *IEC Standard Voltages*, 2009, International Electrotechnical Commission, 3, rue de Varembe, P. O. Box 131, 1211 Geneva 20, Switzerland.

A1.19 NIST Standard Reference Database 23, 2013, *NIST Reference Fluid Thermodynamic and Transport Properties – REF PROP 9.1*, National Institute of Standards and Technology, Gaithersburg, MD 20899, U.S.A.

APPENDIX B. REFERENCES – INFORMATIVE

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

B1.1 AHRI Guideline T (SI) – 2013, *Specifying the Thermal Performance of Cool Storage Equipment*, 1994, Air-Conditioning, Heating and Refrigeration Institute, 2111 Wilson Boulevard, Suite 500, Arlington, VA 22201, U.S.A.

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APPENDIX C. METHOD OF TESTING FOR RATING THERMAL STORAGE DEVICES WHICH EMPLOY THE SAME SECONDARY COOLANT FOR THE CHARGE AND DISCHARGE CYCLES – NORMATIVE

C1 *Purpose*. The purpose of this appendix is to prescribe a method of testing to verify the performance and capacity of Thermal Storage Devices which employ the same Secondary Coolant to both charge and discharge the device.

C1.1 *Intent*. The procedures set forth in this appendix are intended for use where adequate facilities, equipment, instrumentation and load stability can be provided.

Cl.2 *Exemptions*. This procedure is not intended for testing typical field installations where facilities, equipment, and instrumentation differ from those specified in this standard and steady state conditions are virtually impossible to achieve.

C2 *Scope*. This method of test applies only to sensible (chilled water) and latent (ice on coil-internal melt, encapsulated ice, and Phase Change Materials) Thermal Storage Devices, as defined in Section 4 of this standard, where the same heat transfer fluid is used both to charge and discharge the device. (See other appendices for methods of testing applicable to other equipment classifications.)

C3 *Definitions*. Definitions for this appendix are identical to those in Section 3 of this standard.

C4 *Method of Testing.*

C4.1 *Test Method*. The complete test shall include three individual test runs; the initial charge cycle test to determine the time required to initially charge the Thermal Storage Device, the discharge cycle test to verify the temperatures at which the Net Usable Storage Capacity of the device can be delivered, and the charge cycle test to verify the temperatures of the heat transfer fluid and the refrigeration capacity required to recharge the device. The approximate duration of the charge cycle test, the general profile of the load to be imposed on the Thermal Storage Device during the discharge cycle test, and the Net Usable Storage Capacity of the unit for that load profile shall be determined prior to the start of the test.

C4.1.1 The initial charge cycle test shall determine the elapsed time required to bring the storage device to its fully charged condition and the minimum temperature of the heat transfer fluid attained during the cycle. It shall also determine the time weighted average inlet temperature ($\overline{T_3}$), the time weighted average outlet temperature ($\overline{T_4}$), the average charging rate ($\overline{q_{IC}}$), and the total heat removal required (Q_{IC}) to bring the storage device to its fully charged condition.

C4.1.1.1 At the beginning of the initial charge test, the Thermal Storage Device shall be in a fully discharged, steady state condition as defined in Section C7.3.1.

C4.1.1.2 The initial charge test shall employ the same average heat removal rate (Charge Rate) as the charge test (see Section C7.2.3).

C4.1.1.3 The initial charge cycle test shall be complete when the storage device has reached the fully charged condition as defined by the manufacturer's published criteria.

C4.1.2 The discharge cycle test shall verify that the coolant temperatures delivered by the Thermal Storage Device agree, Period by Period, with those predicted by the manufacturer's rating methodology when using as input the load profile actually imposed on the device during the test.

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C4.1.2.1 At the beginning of the discharge cycle test, the storage device shall be in its fully charged condition in accordance with the manufacturer's published criteria.

C4.1.2.2 The discharge cycle test shall be conducted with the mixed temperature, as measured at sensor TS-1, held essentially constant ±1°C by the temperature mixing valve TMV-1 (Figure C1) at a preset value as determined by the parties to the test, prior to the test.

C4.1.2.3 The discharge cycle test shall be complete when the Net Usable Storage Capacity (Q_D) claimed for the test load profile has been removed from the device. Note that as discussed in Section C9.12, some residual cooling may still remain in the Thermal Storage Device at this point since the duration of the discharge cycle test is solely a function of the Net Usable Storage Capacity, not the state of charge of the Thermal Storage Device.

C4.1.3 The charge cycle test shall verify that the temperatures of the heat transfer fluid required to recharge the device agree, Period by Period, with those predicted by the manufacturer's rating methodology when using as input the chiller capacity actually delivered during the test. It shall also determine the time weighted average inlet temperature ($\overline{T_3}$), the time weighted average outlet temperature ($\overline{T_4}$), the average charging rate ($\overline{q_{Ch}}$), and the total heat removal required (Q_{Ch}) to bring the storage device to its fully charged condition.

C4.1.3.1 At the beginning of the charge cycle test, the storage device shall be in the state of discharge reached at the end of the discharge cycle test as described in Section C4.1.2.3 above.

C4.1.3.2 The charge cycle test shall be complete when the storage device has been returned to its initial fully charged condition as defined in Section C4.1.1.3.

C4.2 *Data to be Taken*. The following data shall be measured and recorded at Intervals not exceeding five minutes over the duration of the above described initial charge, charge, and discharge cycle tests.

C4.2.1 The flow rate of the heat transfer fluid (Secondary Coolant) flowing through:

C4.2.1.1 The test apparatus as measured at FM-1 (Figure C1)
C4.2.1.2 The storage device as measured at FM-2 (Figure C1)

C4.2.2 The temperatures of the heat transfer fluid (Secondary Coolant):

C4.2.2.1 As it enters and leaves the Thermal Storage Device at TS-3 and TS-4 (Figure C1)
C4.2.2.2 At confirming measurement points TS-1 and TS-2 (Figure C1)

C4.2.3 The temperature of the Ambient Air (T_{amb}) surrounding the Thermal Storage Device.

C4.2.4 The pressure drop of the heat transfer fluid across the Thermal Storage Device (ΔPS-1 Figure C1).

C4.2.5 The power input to any auxiliary equipment such as air pumps, agitators, etc. that are required by the storage device to produce the rated capacity during the charge or discharge cycle test.

C4.2.6 One measurement of the refractive index of any Secondary Coolant during each discharge and charge cycle test.

C5 *Instruments.*

C5.1 *General*. Instruments and multi-component measurement systems shall be selected and calibrated to meet the requirements and accuracies specified in the following subsections.

C5.1.1 Instrument calibrations shall be traceable to primary or secondary standards calibrated by the National Institute of Standards and Technology. The indicated corrections shall be applied to obtain the required accuracy. Instruments shall be calibrated on a regular schedule appropriate for the respective instruments, and full calibration records shall be maintained.

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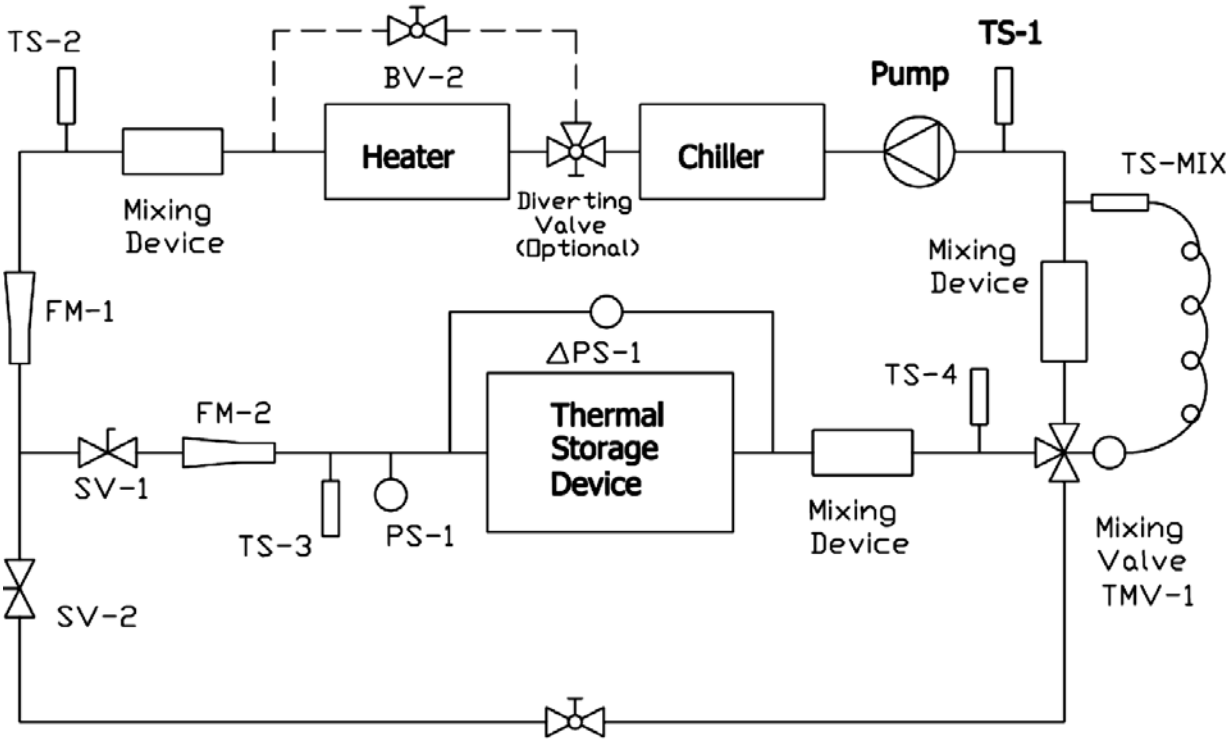


Figure C1. Thermal Storage Device Test Apparatus

Legend:

BV	=	Balancing Valve	SV	=	Shut-Off Valve
ΔPS	=	Differential Pressure Sensor	TMV	=	Temperature Actuated Mixing Valve
FM	=	Flow meter	TS	=	Temperature Sensor
PS	=	Pressure Sensor			

C5.1.2 All instruments shall be applied and used in accordance with the standards specified for that type of instrument and in a manner that ensures compliance with the specified accuracy.

C5.2 *Temperature Measurements.* Temperature measurements shall be made in accordance with ANSI/ASHRAE Standard 41.1 with instruments having accuracies within the limits specified for the following measurements:

C5.2.1 Individual temperatures of water and other heat transfer fluids, or air dry-bulb temperatures: ±0.05°C

C5.2.2 Temperature differences in heat transfer fluids within 2% of the numerical value of the difference being measured

C5.3 *Pressure Measurements*. Pressure measurements shall be made in accordance with ANSI/ASHRAE Standard 41.3 and ASME PTC 19.2. The accuracy of instruments for measuring the pressure of fluids and the pressure differential across the Thermal Storage Device shall permit determination of the pressure or pressure differential within 2% of the numerical value of the quantity being measured.

C5.4 *Electrical Measurements and Instruments.* Electrical measurements shall be made at a location such that the instrumentation can accurately measure the total power input to the device. Instrumentation used shall measure the true rms power within an accuracy of 1% of the quantity measured. Test facilities that utilize power-altering equipment may require appropriate isolation and precautions between the measurement point and the load device to ensure that accurate power measurements are obtained.

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C5.5 *Flow Measurements.* Flow rates of heat transfer fluids (including refrigerants) shall be measured in accordance with ASHRAE Standard 41.8 and the standard listed below for the instrument being used. Instruments shall have accuracies within 1 % of the quantity measured. The instruments that may be used to measure the flow of heat transfer fluids include the following:

Coriolis Meters	ASME MFC-11M
Electromagnetic Meters	ASME MFC-16
Flow Nozzles	ASME MFC-3M
Orifices	ASME MFC-3M
Turbine Meters	ASME MFC-4M
Ultrasonic Meters	ASME MFC-5M
Venturi Meters	ASME MFC-3M
Vortex Meters	ASME MFC-6M

C5.6 *Time Measurements.* Time measurements shall be made with instruments having accuracies within 0.5% of the elapsed time measured. This accuracy will include any uncertainty errors associated with starting and stopping the instrument.

C5.7 *Physical and Thermodynamic Properties.* The physical and thermodynamic properties of fluids shall be determined from the following sources:

C5.7.1 The heat transfer and thermodynamic properties of water shall be taken from the *ASHRAE Handbook Fundamentals.*

C5.7.2 The heat transfer and thermodynamic properties of Secondary Coolants shall be taken from the *ASHRAE Handbook Fundamentals,* based on the refractive index measurements taken during the test(s).

C5.7.2.1 Refractive index measurements shall be converted to concentration (in percent by volume) of the heat transfer fluid using standard conversion tables.

C5.7.2.2 The properties shall be interpolated from the data published in *ASHRAE Handbook Fundamentals,* at the concentration corresponding to the measured refractive index and a temperature representative of the fluid at the point of interest.

C6 *Apparatus.*

C6.1 *Configuration*. The test apparatus shall be comprised, as a minimum, of all the equipment shown on Figure C1 with the position of the Thermal Storage Device relative to the balance of the testing apparatus as shown. The apparatus may be of open or closed loop design.

C6.2 *Piping for Heat Transfer Fluid*. The piping to which the differential pressure measuring device (ΔPS-1) is connected shall be of the same diameter on both the inlet and the outlet of the Thermal Storage Device.

C6.3 *Insulation*. The piping between temperature measuring points TS-2 and TS-3, TS-4 and TS-1, and the full length of the by-pass loop shall be sufficiently insulated to minimize the heat losses that would otherwise affect the validity of the primary and confirming capacity measurements.

C7 *Test Procedure.*

C7.1 *Preparation for Test.*

C7.1.1 The storage device shall be installed in the test loop as shown in Figure C1 in accordance with the manufacturer's installation instructions. If located outdoors, the storage device shall be shielded from direct sunlight and protected from winds.

C7.1.2 After installation and before testing, the unit shall be cycled (charged and discharged) as recommended by the manufacturer.

C7.2 *Test Requirements and Operational Limits.*

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C7.2.1 The duration of the charge cycle test and the load profile of the discharge cycle test shall be determined prior to the start of the test.

C7.2.2 Steady state flow of the heat transfer fluid, as measured at FM-1 (Figure C1), shall be maintained over the duration of each test cycle. It shall be considered achieved if the measured flow rate varies less than ±10% over the duration of any given initial charge, charge or discharge cycle test.

C7.2.3 The initial charge test and the charge cycle test shall employ the same average heat removal rate (Charge Rate) over the duration of the test, the value of which shall be within 10% of the rate specified prior to the test. The capacity of the compression equipment shall not be mechanically altered during either test or between tests. For the tests to be valid, the average heat removal rate of the initial charge cycle test shall be within 10% of the average heat removal rate of the charge cycle test.

C7.2.4 The duration of the discharge cycle test and the profile of the load imposed on the Thermal Storage Device shall be determined prior to the start of the test. The duration of the discharge cycle test shall be within 10% of the time specified.

C7.2.5 The total heat removed from the Thermal Storage Device during the initial charge cycle test (Q_{IC}) or the charge cycle test (Q_{Ch}), and added to the device during the discharge cycle test (Q_D) shall be determined using the flow rate of the heat transfer fluid as measured at FM-2 and the temperatures of the heat transfer fluid as measured at sensors TS-3 and TS-4. After correcting the calculated values for ambient and parasitic heat gains (Q_{amb} and Q_{paras}), the total heat input during the discharge cycle test shall be within 5% of the total heat removed during the charge cycle test.

C7.2.6 The confirming test of the discharge cycle test shall consist of measuring and recording the flow rate and temperatures of the heat transfer fluid at flow meter FM-1 and temperature sensors TS-1 and TS-2 and using these values to calculate the total heat added to the storage device over the duration of the discharge cycle test, as specified in Section C7.2.5. For the discharge cycle test to be valid, the result of this confirming test shall agree within 3% of the primary test value.

C7.2.7 The confirming test of the charge cycle test shall consist of measuring and recording the flow rate and temperatures of the heat transfer fluid at flow meter FM-1 and temperature sensors TS-1 and TS-2 and using these values to calculate the total heat removed from the storage device over the duration of the charge cycle test, as specified in Section C7.2.5. For the charge cycle test to be valid, the result of the confirming test shall agree within 3% of the primary test value.

C7.3 *Test Sequence.* A full test shall consist of an initial charge cycle test, a discharge cycle test, and a charge cycle test, conducted in the following sequence:

C7.3.1 *Initial Steady State Condition.* With the Thermal Storage Device in the fully discharged condition and valve SV-2 fully closed, the heat transfer fluid shall be circulated through the test apparatus loop and the Thermal Storage Device until the initial steady state conditions are established. Initial steady state shall be considered achieved when the temperatures measured at TS-1, TS-2, TS-3, and TS-4 are equal to or greater than 7.2°C above the phase change temperature of the storage media for a period of 15 minutes.

C7.3.2 *Changeover Period I.* During this and all subsequent Changeover Periods, secondary sources of heat (such as auxiliary heaters, agitation systems in the Thermal Storage Device, etc.) shall be turned off. During this first changeover Period, the flow rates and valves shall be adjusted for the initial charge cycle test. When all components are set, the chiller shall be turned on.

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