BSR/ASHRAE Standard 150-2019R

Public Review Draft

Methods of Testing the Performance of Installed Cool-Storage Systems

First Public Review (June 2024)
(Complete Draft for Full Review)

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FOREWORD

ASHRAE Standard 150 was developed to provide a uniform method for evaluating the performance of cool-storage systems installed in buildings or central plants. Its intended users are Owners, operators, consultants, commissioning providers, and others. The test methods provided in this standard will eliminate the need to develop a specific test procedure for each individual project by the design team. There will continue to be specific additions or modifications for some projects. The standard can be used for newly installed projects or verification testing of the performance and capacity of existing systems. This Standard may be used for both new and existing systems.

Hereinafter in this foreword, "system" means "cool-storage system" unless noted otherwise.

Standard 150 is used to determine the performance of a new or existing system at the time of the test. This information may be desired to optimize the system or to determine the system's current capability prior to an increase in load or other changes. The standard includes options for testing a system at times when less than the peak load is available.

It is recognized that field testing is costly, and this standard may not provide sufficient benefit to warrant its use at every cool-storage installation. Some packaged or modular systems can be provided with sufficient data to establish their expected or design performance without detailed field testing. This has been addressed with the development of three methods of system performance and capacity testing or verification.

This standard provides three levels of performance testing and verification:

- *Test Method 1 is for Latent Cool Storage Systems. This is the base acceptable testing method primarily for ice storage systems.*
- *Test Method 2 is for Sensible Cool Storage Systems. This is the base acceptable testing method primarily for stratified chilled water and enhanced chilled water systems using low-temperature fluids (LTFs).*
- *Test Method 3 is an Enhanced Testing procedure for a more advanced testing method of Cool Storage systems. It is also recommended for systems that are not defined in test methods 1 and 2.*

Most cool-storage installations are completely or partially dependent on field assembly of components that cannot be prerated or tested prior to assembly of the total systems. For these systems, field testing is the only way to verify that the installed system meets the specified performance or capacity requirements.

It is usually in the best interest of Owners, contractors, manufacturers, and designers to establish the system's level of performance and capacity to a level of certainty at the time of installation. This may prevent costly disagreements or litigation after the system has been accepted and operated for a period of time, possibly even under different load conditions than the original design.

The test methods provided in this standard are intended to establish system performance, but not to diagnose system operation. These test methods specifically enable the user to determine the available capacity of the storage device, the capacity available to meet a load, and the efficiency of the system in *meeting the load. Users are encouraged to use additional instruments and take additional measurements beyond those required by the standard to aid in system diagnosis and optimization.*

This standard does not specify how test results will be used. Interpretation of the data obtained from the test is the responsibility of the user.

Test methods 1 and 2 were developed to provide the base acceptable test of performance and capacity for new and existing systems. Test Method 3 can be used for all cool storage systems and provides a more accurate evaluation of system performance and capacity. The differences among cool-storage technologies are addressed in Test Method 3 in the definitions of the test conditions.

This standard may be referenced in project specifications requiring performance testing or capacity verification of newly installed systems.

This standard covers the performance of the system and not the performance of the individual components such as chillers, pumps, heat exchangers, valves, or other major equipment related to the cool-storage systems. Users may want to concurrently test refrigeration system performance while performing the tests specified in this standard, since much of the required instrumentation may already be in place.

In keeping with common practice, the standard uses the units of ton-hour and kWh to measure cooling energy stored or delivered capacity. The standard uses the subscripted units kWhT and kWhE to differentiate thermal and electrical energy.

Designers desiring to utilize Standard 150 test methods should specify in their design documents the appropriate instrumentation and system configuration as defined in this standard for the applicable test method. The specification should include sufficient detail for the selected sensor or sensors to perform as required.

The instrument accuracy requirements in this standard for Test Method 3 were selected to provide 10% or better uncertainty in the overall calculation of capacity for most systems. The standard recommends that users who have stricter requirements conduct an uncertainty analysis prior to testing to aid in the selection of instrument types and the measurement method.

The uncertainty analysis helps confirm that the selected instruments will provide the desired accuracy in the test results. A similar uncertainty analysis should also be completed after testing, using measured data to determine the uncertainty interval in the test results. ASHRAE Guideline 22 discusses the issues addressed in an uncertainty analysis.

In general, the installed instrumentation will be used for all test methods. However, if the instrumentation installed does not meet the requirements of Test Method 3, then field instrumentation will be required.

1. PURPOSE

This standard prescribes a uniform set of testing procedures for determining the performance of installed cool storage systems, including cooling capacities, efficiencies, flows, peak and key charging and discharging, and other performance requirements.

2. SCOPE

2.1 This standard covers cool-storage systems composed of chillers, storage medium, storage device or vessel, heat sink equipment or heat sink systems, and other auxiliary equipment required to provide a complete and working system, The standard is limited to daily loads, weekly loads, and short-term industrial or food industry loads.

2.2 This standard includes:
(a). three uniform methods of testing,
1). Method 1: Base Acceptable Testing of Latent Ice Storage Systems.
2). Method 2: Base Acceptable Testing of Sensible Stratified Chilled Water or Low-Temperature Fluids Systems
3). Method 3: Enhanced Performance Test

(b). identification of test equipment for performing such tests,
(c). identification of data required and calculations to be used, and
(d). definitions and terminology.

2.3 This standard does not cover:
(a) testing of the air-side distribution,
(b) seasonal storage systems, or
(c) warm storage systems.

3. DEFINITIONS

accuracy: the ability of an instrument to indicate the true value of a measured quantity 1.

capacity: see *thermal storage capacity*, *cool-storage system capacity*.

charge: operational mode that replenishes the TES tank thermal capacity.

chilled water return (CHWR): chilled water that is returned to the tank after cooling has been provided during discharge mode or leaving the tank during charge mode.

chilled water supply (CHWS): chilled water that is supplied from the tank to provide cooling during charge mode or leaving the tank during discharge mode.

cool-storage system: a system that uses a thermal storage device to meet all or part of a cooling or refrigeration load. A cool-storage system is composed of chillers, thermal storage medium, thermal storage device or vessel, heat sink equipment or heat sink systems, and other auxiliary equipment and may be a part or subset of a larger cooling system.

cool-storage system capacity: the maximum amount of cooling energy that can be supplied by a cool-storage system in response to a particular load profile, as determined by the cool-storage system capacity test.

critical discharge point: the point in the load profile at which the combination of the required discharge rate and the current storage inventory causes the discharge temperature from the thermal storage device to rise to its highest value.

cycle: see *storage cycle*.

discharge: operational mode that withdraws the TES tank thermal capacity.

discharge capacity: the capacity of the thermal storage device as determined by the discharge test. This capacity is equivalent to the usable storage capacity if the fully discharged condition is defined by the criterion given in Section 11.3(k)(1)(i).

efficiency:

> ***cycle-specific energy use:*** ratio of the total energy input in kWh*E* or kWh*T* (kWh*E* or Btu) to the total energy in kWh*T* (ton-hour) removed from the load over one or more complete storage cycles. Total energy input includes the energy input to all waterside components that are part of the system under test.
>
> ***storage efficiency:*** discharge capacity divided by charge capacity 1.

fully charged condition: the state of a thermal storage device at which, according to the design, no more heat is to be removed from the thermal storage device. This state is generally reached when the control system stops the charge cycle as part of its normal control sequence.

fully discharged condition: the state of a thermal storage device at which no more usable cooling energy can be recovered from the storage device.

load profile: summary of thermal loads over a period of time. For the purposes of this standard, the load profile specifies thermal loads for each hour of the period, encompassing at least one complete storage cycle. The load profile indicates each hour's total load, the cooling output of the chiller(s) and the thermal storage device, and the state of charge of the thermal storage device. Tables 1 and 2 illustrate complete data, for two example load profiles.

maximum allowable charging period: the period of time within which charging of the thermal storage device must be completed. This period is typically determined by the utility rate structure, the building operating schedule, and the design operating strategy.

maximum usable cooling supply temperature: the maximum fluid supply temperature at which the cooling load can be met.

maximum usable discharge temperature: the maximum fluid temperature at which usable cooling can be obtained from the thermal storage device. This temperature may be selected to suit the specific needs of the test.

a. For systems configured with the chiller upstream of storage, it is generally equal to the maximum usable cooling supply temperature.
b. For systems configured with the chiller downstream of storage, it is generally determined as the highest temperature that the chiller can cool to the maximum usable cooling supply temperature.
c. From an operating standpoint, it may be possible that the actual maximum usable discharge temperature may be set higher than the temperatures noted above if the user desires to gain some limited usable cooling capacity beyond that considered usable under normal operating conditions. However, this is not considered or used in this standard.

nominal storage capacity: a theoretical capacity of the thermal storage device, which in many cases is greater than the usable storage capacity. This measure should not be used to compare usable capacities of alternative storage systems.

peak discharge rate: the maximum rate at which cooling is discharged from storage (heat is added to storage).

precision: closeness of agreement among repeated measurements of the same physical quantity.

pulldown load: the unmet cooling load that accumulates during a period when cooling is not provided to the load and that must be met on system start up. Maximum pulldown load generally occurs on a Monday morning.

refrigeration rate: instantaneous refrigeration delivered by the TES tank (tons), as determined by the mass flow rate and the temperature difference between the CHWS and CHWR.

resolution: the smallest incremental value of a measured quantity that can be reported by an instrument, typically half the smallest-scale division of an analog instrument or the least significant bit (LSB) of an analog to digital system. (LSB = full scale range/2*n*, where *n* = the number of bits of the analog to digital converter.)

shall: where "shall" or "shall not" is used for a provision, that provision is mandatory if compliance with this standard is claimed.

should: where "should" or "should not" is used for a provision, that provision is not mandatory for compliance with this standard but is desirable as good practice.

spatial variation: the uncertainty arising from the variation of a measured parameter due to its variation in space, with the data normalized to eliminate variation in the parameter over time.

specified load profile: the load profile that the cool storage system is expected to meet. This may be the load profile used to design the cool-storage system and size the equipment, or it may be based on actual or expected loads.

storage cycle: complete charge and discharge of a thermal storage device, beginning and ending at the same state of charge 1.

storage inventory: the amount of usable cooling energy remaining in a thermal storage device at any given time.

system**:** see *cool-storage system*.

test authority: the designated person, company, or agent who specifies the test requirements.

thermal storage capacity: the maximum amount of cooling that can be retained by a thermal storage device and be available for future use.

thermal storage device: container plus all the contents of the container used for storing thermal energy. The transfer fluid and accessories, such as heat exchangers, agitators, circulating pumps, flow-switching devices, valves, and baffles that are integral with the container, are considered a part of the thermal storage device.

thermal storage medium: substance in which cooling or heating energy is stored.

transfer fluid: fluid that carries energy from one location to another.

thermocline: temperature & density transition boundary region within a sensible thermal storage device between bulk cold-water region below and bulk warm water region above.

usable storage capacity: total amount of cooling discharged from a thermal storage device, at or below the maximum usable discharge temperature, for a particular storage cycle.

4. TYPES OF TESTS

Tests performed under this standard are classified as follows. The requirements vary based on which of the three Methods is used.

4.1 *Discharge test* measures the amount of cooling energy that can be delivered from the thermal storage device to meet the specified load profile.

4.2 *Charge test* measures the amount of cooling that can be stored in the thermal storage device within the time period available for charging.

4.3 *Cool-storage system capacity test* measures the amount of cooling energy that can be delivered by the system to meet the specified load profile. This test is identical to the discharge test if the thermal storage device is designed to provide full load shift.

4.4 *Cool-storage system efficiency test* measures the cycle specific energy use of the system.

5. TEST METHOD 1 – MINIMUM TESTING OF LATENT STORAGE SYSTEMS

5.1 Purpose. This procedure outlines the steps required for providing a performance test of a Latent Thermal Storage Device System, including devices that use different liquid solutions for charging and discharging (e.g., External Melt Ice-on Coil) and devices that use the same liquid solution for charging or discharging (e.g., which include, but are not limited to, Internal Melt-Ice-on-Coil and Encapsulated designs). If this test method is selected during the design, then the design engineer shall specify the characteristics of all instrumentation to be used in the test. The test procedure includes calculations that approximate the performance of the tank.

5.2 Apparatus

5.2.1 Cool-storage systems that will be tested under Test Method 1 of this standard shall be provided with instrumentation to measure the following properties. Typical fluid flow and temperature measurement locations are illustrated in Figures 1 , 2a, and 2b.

5.2.1.1 For Thermal Storage Devices using different liquid solutions for charging and discharging (e.g., External Melt):

5.2.1.1.1 F1—Fluid flow rate through the cool-storage system.

5.2.1.1.2 T1 —Fluid temperature leaving the cool-storage system (to Load).

5.2.1.1.3 T2—Fluid temperature entering the cool-storage system (from Load).

5.2.1.1.4 F2—Fluid flow rate through chiller and the thermal storage device.

5.2.1.1.5 T3—Fluid temperature entering the thermal storage device.

5.2.1.1.6 T4—Fluid temperature leaving the thermal storage device.

5.2.1.2 For Thermal Storage Devices using the same liquid solutions for charging and discharging (e.g., Internal Melt):

5.2.1.2.1 F2—Fluid flow rate through chiller, thermal storage device, and the cool-storage system.

5.2.1.2.2 T1 —Fluid temperature leaving the cool-storage system (to Load).

5.2.1.2.3 T2—Fluid temperature entering the cool-storage system (from Load).

5.2.1.2.4 T3—Fluid temperature entering the thermal storage device.

5.2.1.2.5 T4—Fluid temperature leaving the thermal storage device.

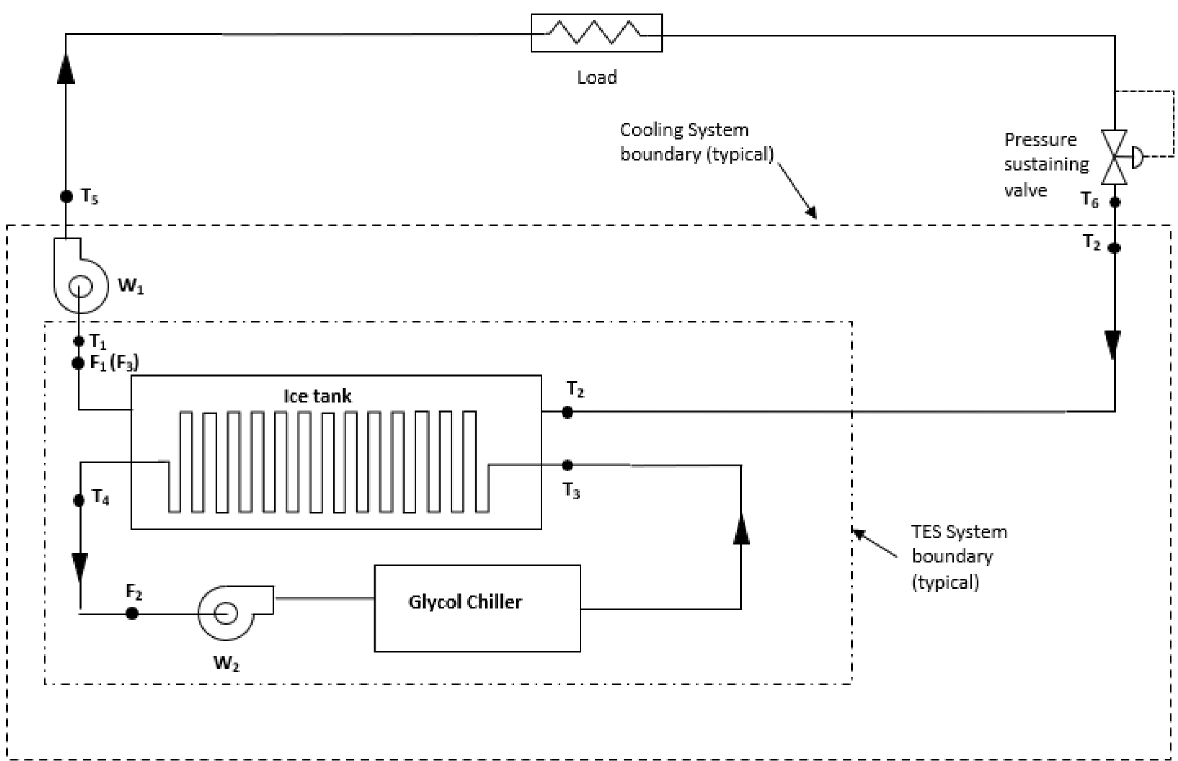


Figure 1 Secondary coolant external melt ice-on-coil configuration.

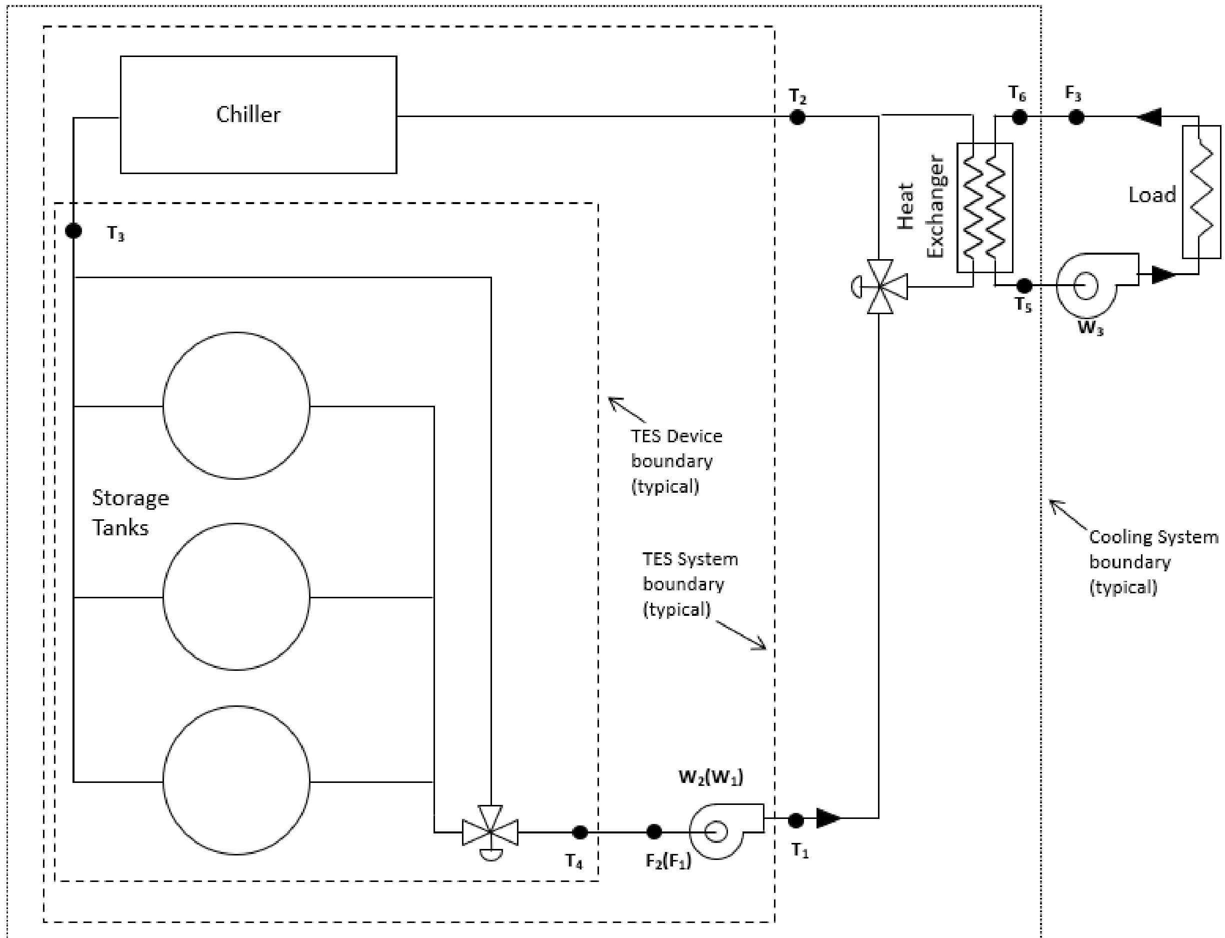


Figure 2a Typical Internal Melt or Encapsulated storage configuration.

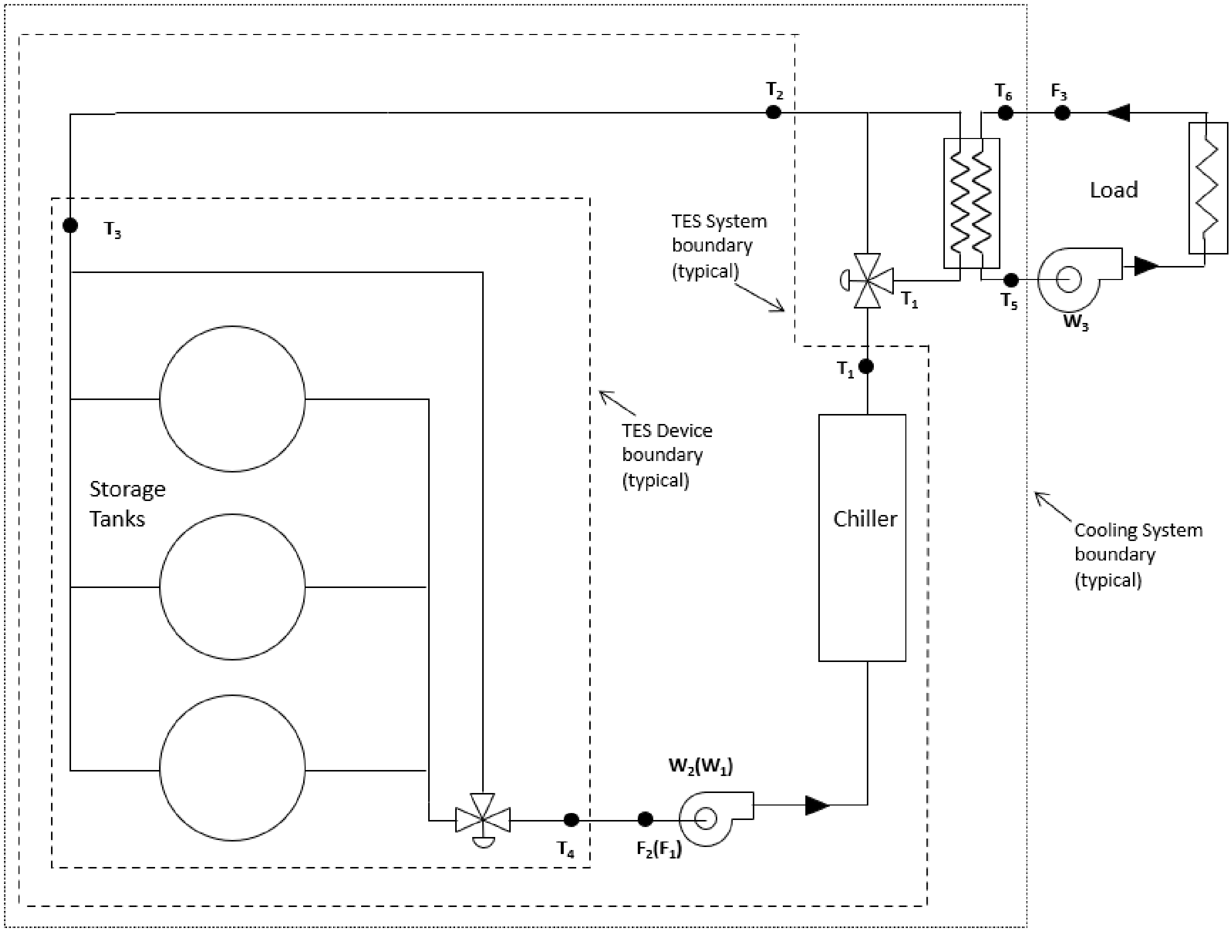


Figure 2b Typical Internal Melt or Encapsulated storage configuration.

5.3 Test Method. The complete test shall include two individual test runs: an initial charge cycle of the Thermal Storage Device and the discharge cycle test to verify the temperatures at which the Net Usable Storage Capacity of the device can be delivered. 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.

5.3.1 The initial charge cycle test shall determine the elapsed time required to bring the storage device to its fully charged condition, the amount of heat removed from the tank and the minimum temperature of the heat transfer fluid attained during the cycle. It shall also determine the time weighted average inlet temperature T3, the time weighted average outlet temperature T4, the average charging rate q_i, and the total heat removal required (Q_i) as calculated from F2, T3, and T4, to bring the storage device to its fully charged condition (Figures 1, 2a, and 2b).

5.3.1.1 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 6.4.1.

5.3.1.2 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.

5.3.2 The discharge cycle test shall verify that the coolant temperatures and capacities delivered by the Thermal Storage Device, Period by Period, meet the agreed upon requirements.

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

5.3.2.2 Since design loads are difficult to achieve in the field, up to 50% of the Thermal Storage Devices' capacity can be valved off at this time for this test. If part of the storage is removed from the discharge cycle test, a second discharge cycle test will need to be performed to remove the balance of the stored energy.

5.3.2.3 The discharge cycle test shall be conducted with the mixed temperature, as measured at sensor T4, held essentially constant ±1.0°C (±1.8ºF) by the temperature mixing valve at a preset value as determined by the parties to the test, prior to the test. (If no mixing valve is present in the system, temperatures in and out of the device can be use.)

5.3.2.4 The discharge cycle test shall be complete when the temperature mixing valve temperature, T4, is above the maximum usable cooling temperature for 15 continuous minutes or greater. (NOTE: Some residual cooling may 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).

6. TEST METHOD 1 – PROCEDURE FOR PERFORMANCE TEST

6.1 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, and discharge cycle tests.

6.1.1 The flow rate of the heat transfer fluid (Secondary Coolant) flowing through storage device, F2.

6.1.2 The temperatures of the heat transfer fluid (Secondary Coolant) T3 and T4.

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

6.1.4 The pressure loss of the heat transfer fluid across the Thermal Storage Device (Figure B-6)

6.1.5 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.

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

6.2 Preparation for Test.

6.2.1 The storage device shall be installed in accordance with the manufacturer's installation instructions.

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

6.2.3 The peak design flow rate for pumps shall be verified during charge and discharge operations. If not part of this storage performance test, it shall be a requirement of the Testing, Adjusting, and Balancing

(TAB) project specifications. The TAB results shall be reviewed and confirmed prior to performing this storage capacity and performance test.

6.3 Test Requirements and Operational Limits.

6.3.1 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. The discharge profile shall be an equal proportion of the design profile. Each hour of discharge shall be within 80-100% of the developed profile. The total discharge shall be within 95% of the test profile.

6.3.2 The duration of the discharge cycle test and the approximate profile of the load imposed on the Thermal Storage Device shall be approximated prior to the start of the test.

6.3.3 The total heat removed from the Thermal Storage Device during the initial charge cycle test (Q_{IC}) 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 F2 and the temperatures of the heat transfer fluid as measured at sensors T3 and T4.

6.4 Test Sequence. A full test shall consist of an initial charge cycle test and a discharge cycle test conducted within 48 hours of charge test completion, in the following sequence:

6.4.1 Initial Steady State Condition. With the Thermal Storage Device in the fully discharged state, the heat transfer fluid shall be circulated through the Thermal Storage Device and charging equipment until the initial steady state conditions are established. Initial steady state shall be considered achieved when the temperatures measured at T3 and T4 are equal to or greater than 13°F (7ºC)above the phase change temperature of the storage media for a period of 15 minutes.

6.4.2 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.

6.4.3 Initial Charge Cycle Test. During the initial charge cycle test, any agitation devices or other auxiliary equipment furnished with the device shall be operated in accordance with the manufacturer's published instructions. The initial charge cycle test shall end when the storage device is fully charged in accordance with the manufacturer's published instructions.

6.4.4 Changeover Period II. Immediately after the initial charge cycle test, with the Thermal Storage Device fully charged, the valve settings shall be adjusted to fully by-pass the Thermal Storage Device and to set the flow rate of the heat transfer fluid for the discharge cycle test.

6.4.5 Discharge Cycle Test. The discharge cycle test begins when the building load and the temperature modulating valve, T4, are activated. During this discharge cycle test, any agitation devices normally furnished with the Thermal Storage Device shall be operated in accordance with the manufacturer's published instructions. The discharge cycle test ends when the temperature mixing valve set point temperature, T4, is above the system supply temperature T1, at which point the heat source is deactivated.

6.4.6 Peak Discharge. For the discharge test to be valid, at the equivalent test storage discharge inventory as the occurrence of peak discharge load (see Table 1, hour 14 as an example of the specified peak design load and related storage inventory at the peak hour occurrence), an equivalent peak load shall be demonstrated for a period of at least 15 minutes.

6.4.7 Critical Load. For the discharge test to be valid, if the design discharge profile has defined a critical latent storage discharge period, an equivalent critical discharge test for at least 15 minutes shall be performed at the equivalent inventory level. (See Table 1, hour 16 as an example of critical discharge requirement).

7. TEST METHOD 1 – PERFORMANCE TEST CALCULATIONS

7.1 Charge Test Calculations

7.1.1 Once the Charge Test data has been collected, confirm that the data appears to fall within the design parameters and test parameters (listed above). If there are any spurious readings, these shall be removed from the data set prior to calculation.

7.1.2 Refrigeration delivered during each 10-minute interval can be determined by:

$$q_i = V_i \rho \cdot c_p \left(T_{w,i} - T_{c,i}\right) F_1 \quad (1)$$

Where:

i	=	Specific 10-minute interval
q_i	=	Refrigeration rate kW (tons)
V_i	=	Averaged flow rate L/s (gpm)
ρ	=	Mass density kg/m^3 (lb/ft^3) – of Secondary Coolant
c_p	=	Specific heat of Secondary Coolant kJ/kg·K (Btu/lb·°F)
$T_{w,i}$	=	Averaged CHWR Secondary Coolant temperature °C (°F)
$T_{c,i}$	=	Averaged CHWS Secondary Coolant temperature °C (°F)
F_1	=	Conversion factor
SI :	F_1 =	0.001 kJ/kg·K-L/m^3-s/hr
IP :	F_1 =	0.0006684 min-ft^3-ton-gallon-Btu

7.1.3 Total integrated refrigeration delivered during the charge period is:

$$Q_{total} = \sum_{i=1}^{n} q_i \cdot \frac{t_i}{60 \frac{\text{min}}{hr}} \quad (2)$$

Where:

Q_{total}	=	Total refrigeration delivered kWh$_T$ (ton-hours)
n	=	Total number of intervals
q_i	=	Increment refrigeration rate kW (tons)
t_i	=	Time increment duration (minutes)

7.2 Discharge Test Calculations

7.2.1 Once the Discharge Test data has been collected, confirm that the data appears to fall within the design parameters and test parameters (listed above). If there are any spurious readings, these shall be removed from the data set prior to calculation.

7.2.2 Refrigeration delivered during each 10-minute interval can be determined by:

$$q_i = V_i \rho \cdot c_p \left(T_{w,i} - T_{c,i}\right) F_1 \quad (3)$$

Where:

i	=	Specific 10-minute interval
q_i	=	Refrigeration rate kW (tons)

V_i	=	Averaged flow rate L/s (gpm)
ρ	=	Mass density kg/m^3 (lb/ft^3) – of water or Secondary Coolant
c_p	=	Specific heat of water or Secondary Coolant kJ/kg·K (Btu/lb·°F)
$T_{w,i}$	=	Averaged CHWR water or of Secondary Coolant temperature °C (°F)
$T_{c,i}$	=	Averaged CHWS water of Secondary Coolant temperature °C (°F)
F_1	=	Conversion factor
SI :	F_1 =	0.001 kJ/kg·K-L/m^3-s/hr
IP :	F_1 =	0.0006684 min-ft^3-ton-gallon-Btu

7.2.3 Total integrated refrigeration delivered during the charge period is:

$$Q_{total} = \sum_{i=1}^{n} q_i \cdot \frac{t_i}{60\,\frac{min}{hr}} \quad (4)$$

Where:

Q_{total}	=	Total refrigeration delivered kWh$_T$ (ton-hours)
n	=	Total number of intervals
q_i	=	Increment refrigeration rate kW (tons)
t_i	=	Time increment duration (minutes)

8. TEST METHOD 2 – MINIMUM TESTING OF SENSIBLE THERMAL STORAGE SYSTEMS

8.1 Purpose

8.1.1 This procedure outlines the steps required for providing a performance test of a chilled water Thermal Energy Storage (TES) tank system utilizing standard instrumentation typically included in a chilled water (CHW) TES tank system. If this test method is selected during the design, then the design engineer shall specify the characteristics of all instrumentation to be used in the test. The test procedure includes calculations that approximate the performance of the tank.

8.1.2 The performance test is comprised of four individual tests. The Charge Test and/or Discharge Test are required tests, and the Heat Gain (Hold Test) and Chilled Water Pressure Drop are optional tests.

8.2 Apparatus

8.2.1 Cool-storage systems that will be tested under Test Method 2 of this standard shall be provided with instrumentation to measure the following properties. Typical fluid flow and temperature measurement locations are illustrated in Figures 3 and 4.

8.2.1.1 CHWS Temperature (Tc) – sensor located in the piping from the thermal storage tank's bottom diffuser.

8.2.1.2 CHWR Temperature (Tw) – sensor located in the piping from the thermal storage tank's upper diffuser.

8.2.1.3 CHW Flow Rate (F2) – flow meter measuring flow through the thermal storage tank.

8.2.1.4 Tank Temperature (T) – sensors spaced evenly and mounted vertically within the tank.

8.2.1.5 Tank Water Level (not shown) – sensor measuring water level of the tank.

8.2.1.6 CHW Pressure Inlet /Outlet (Pc, Pw) – optional sensors in the inlet/outlet piping just outside of the tank.

8.2.1.7 Ambient Outdoor Air Dry-Bulb Temperature (not shown) – optional sensor located outdoors.

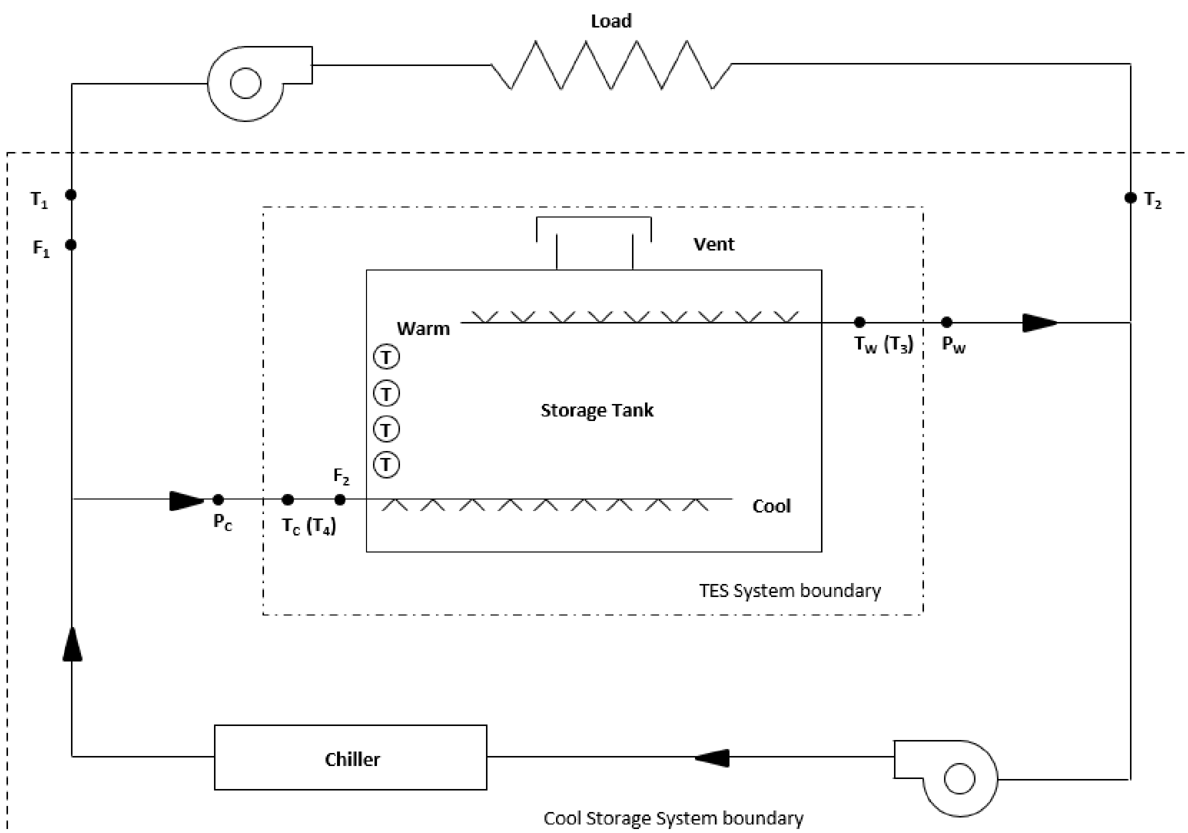


Figure 3. Stratified Chilled Water Charge Test.

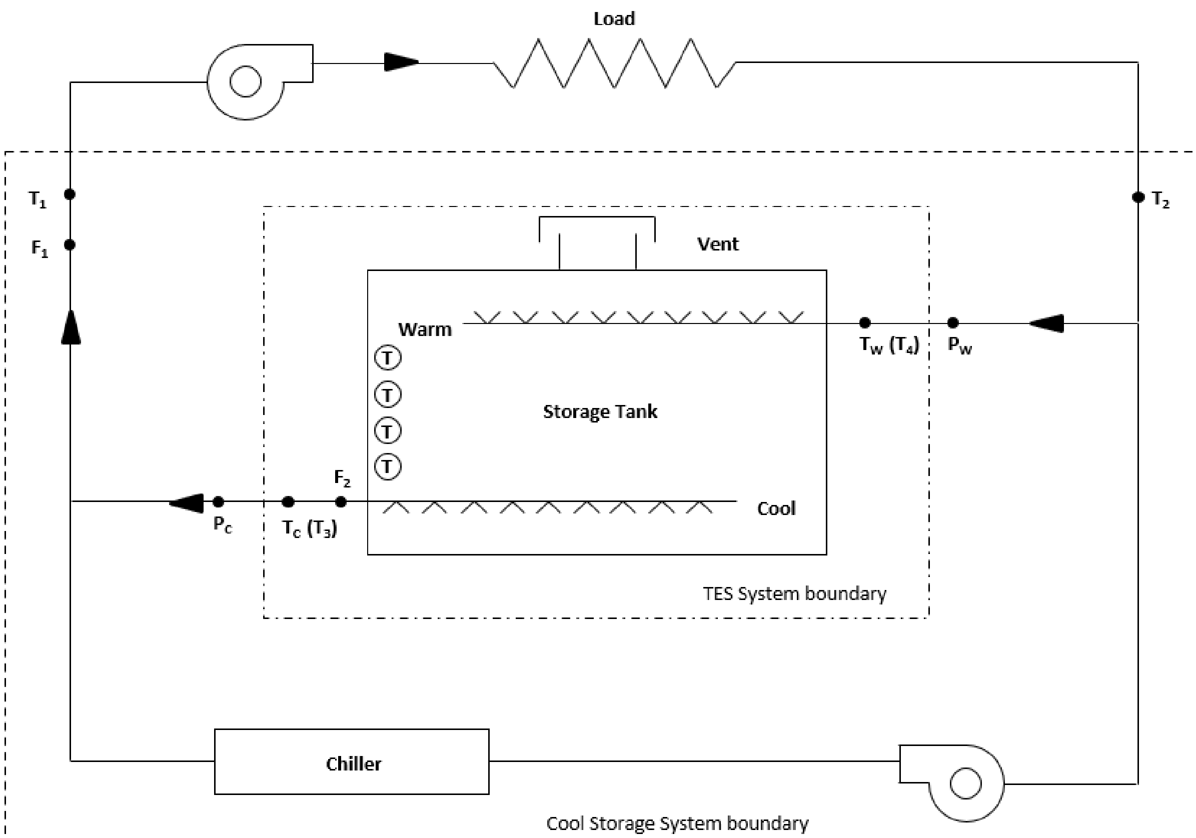


Figure 4. Stratified Chilled Water Discharge Test.

8.3 Prior to Collecting Performance Test Data:

8.3.1 Follow the manufacturer's recommendations for filling the tank, water quality requirements, initial charging of the tank, and start-up.

8.3.2 Provide all the necessary mechanical equipment, instrumentation, and recording devices to perform the tests.

8.3.3 Confirm that the instrumentation is calibrated, and the chilled water system is operational.

8.3.4 Fill the TES tank system to design operating water level.

8.3.5 To minimize the transient effects due to the first-time cool-down of the tank, its foundation, and the soil, the TES tank system shall be chilled to within the design operating temperature range (CHWS temperature to CHWR temperature), and the bottom eight feet (minimum) maintained at the CHWS temperature for a minimum of three days (72 hours). This must be completed prior to the performance test. Please note that if the TES tank has been operational for at least 72 hours, this hold period is not required.

8.3.6 Immediately prior to execution of the performance test, the TES tank system shall be brought to a fully discharged condition. This will be accomplished by withdrawing cold water from the tank and returning warm water to the tank at no less than the CHWR temperature until the average temperature of water stored in the tank is no less than the CHWR temperature.

9. TEST METHOD 2 – PROCEDURE FOR THE PERFORMANCE TEST

9.1 The following data shall be collected for an analysis of the performance of the TES tank:

9.2 TES Tank Charge Test

9.2.1 Starting with the TES tank fully discharged (the internal tank temperature sensors reading at or near CHWR design temperature), start to charge the TES tank by ramping up the flow using slow-opening valves and/or variable frequency drives on the pumps. Flow rate starts at zero gpm and is increased gradually up to the maximum design flow rate within 15 minutes.

9.2.2 Once full flow is established, charge the tank at the design flowrate (tolerance of +1 / -10 %)

Please note the following - Significant variations in the temperature of the charge water (especially when the thermocline is at or below the elevation of the lower diffuser) may impair the ability of the tank to stratify the water and invalidate the test. Adhere to the tank manufacturer's requirement for the minimum water level and maintain that minimum level or higher throughout the performance test. If the water level falls below the tank manufacturer's minimum requirement, it will invalidate the performance test.

9.2.3 Record the following data at the start and in intervals of at least every 10 minutes for the duration of the test until the tank is fully charged:

9.2.3.1 T_C (T_3) - CHWS temperature entering the tank.

9.2.3.2 T_W (T_4) - CHWR temperature leaving the tank.

9.2.3.3 F_2 - Flow rate entering/leaving the tank.

9.2.3.4 All internal tank temperatures

9.2.3.5 Tank water level

9.2.3.6 P_C, P_W - CHW Pressure at the inlet/outlet nozzles (if sensors are provided)

9.2.4 The test is completed when the tank is fully charged. This is indicated when the CHWR temperature leaving the tank (T_W) is within 2°F (1.1°F) of the CHWS design temperature.

9.3 TES Tank Discharge Test

9.3.1 Starting with the TES tank fully charged (the internal tank temperature sensors reading at the CHWS design temperature) start to discharge the TES tank by ramping up the flow using slow-opening valves and/or variable frequency drives on the pumps. Flow rate starts at zero gpm and is increased gradually up to the maximum design flow rate within 15 minutes.

Once full flow is established, discharge the tank at the design flowrate (tolerance of +1/-30%). Please note the following - if the water depth is below the upper diffuser, then this will invalidate the performance test.

9.3.2 Record the following data at the start and in intervals of at least every 10 minutes for the duration of the test:

9.3.2.1 T_W (T_3) - CHWR temperature entering the tank.

9.3.2.2 T_C (T_4) - CHWS temperature leaving the tank.

9.3.2.3 F_2 - Flow rate entering/leaving the tank.

9.3.2.4 All internal tank temperatures.

9.3.2.5 Tank water level.

9.3.3 The test is completed when the tank is fully discharged. This is indicated when CHWS temperature leaving the tank rises 2°F (1.1°F) above the design CHWS temperature.

9.4 TES Tank Pressure Drop Test (Optional Test)

During the data collection of the Charge and/or Discharge Performance Tests, record the following data at a minimum of four separate times during periods when the flow rate through the tank is near the design flowrate (tolerance of +1/-10%):

9.4.1 P_C - CHW pressure entering the tank.

9.4.2 P_W - CHW pressure leaving the tank.

9.4.3 F_2 - Flow rate entering and/or leaving the tank.

Please note the following – the pressures and flow rate data must be collected at precisely the same time. This is an optional test that requires pressure sensors at the inlet/outlet nozzles of the tank wall.

9.5 TES Tank – Heat Gain Test

Typically, there are no temperature sensors located in the optimum place to measure the heat gain in chilled water TES tank. Therefore, there is no recommended test procedure. See Heat Gain calculations section.

10. TEST METHOD 2 – PERFORMANCE TEST CALCULATIONS

10.1 Charge Test Calculations.

10.1.1 Once the Charge Test data has been collected, confirm that the data appears to fall within the design parameters and test parameters (listed above). If there are any spurious readings, these shall be removed from the data set prior to calculation.

10.1.2 Refrigeration delivered during each 10-minute interval can be determined by:

$$q_i = V_i \rho \cdot c_p \left(T_{w,i} - T_{c,i}\right) F_1 \quad (5)$$

Where:

i	=	Specific 10-minute interval
q_i	=	Refrigeration rate kW (tons)
V_i	=	Averaged flow rate measured at F_2 L/s (gpm)
ρ	=	Mass density kg/m³ (lb/ft³) – typically 1000 kg/m3 @ 4.44°C (62.43 lb/ft³ @ 40°F)
c_p	=	Specific heat -typically 4.186 kJ/kg·K (1.0 Btu/lb-°F)
$T_{w,i}$	=	Averaged CHWR (warm) water temperature °C (°F)
$T_{c,i}$	=	Averaged CHWS (cold) water temperature °C (°F)
F_1	=	Conversion factor
SI :	F_1 =	0.001 kJ/kg·K-L/m³-s/hr
IP :	F_1 =	0.0006684 min-ft³-ton-gallon-Btu

10.1.3 Total integrated refrigeration delivered during the charge period is:

$$Q_{total} = \sum_{i=1}^{n} q_i \cdot \frac{t_i}{60\,\frac{min}{hr}} \quad (6)$$

Where:

Q_{total}	=	Total refrigeration delivered kWh_T (ton-hours)
n	=	Total number of intervals
q_i	=	Increment refrigeration rate kW (tons)
t_i	=	Time increment duration (minutes)

10.1.4 Delta T Adjustment - The quantity of refrigeration storage (that can be provided by a tank) must be adjusted based on the temperature difference (Delta T) that is present during the test and the design conditions. The adjustment from test conditions to design conditions is performed as follows:

$$Q_{adjusted} = Q_{total}\,(Tw,d - Tc,d)\ /\ (\textstyle\sum_{t=1}^{n} Tw,i - \sum_{t=1}^{n} Tc,i) \quad (7)$$

Where:

$Q_{adjusted}$	=	Amount of refrigeration stored at the design Delta T kWh_T (ton-hours)
Q_{total}	=	Total refrigeration stored during the test kWh_T (ton-hours)
$T_{w,i}$	=	Averaged CHWR (warm) water temperature °C (°F)
$T_{c,i}$	=	Averaged CHWS (cold) water temperature °C (°F)
$T_{w,d}$	=	Design CHWR (warm) water temperature °C (°F)
$T_{c,d}$	=	Design CHWS (cold) water temperature °C (°F)

10.2 Discharge Test Calculations

10.2.1 Once the Discharge Test data has been collected, confirm that the data appears to fall within the design parameters and test parameters (listed above). If there are any spurious readings, these shall be removed from the data set prior to calculation.

10.2.2 Refrigeration delivered during each 10-minute interval can be determined by:

$$q_i = V_i \rho \cdot c_p \left(T_{w,i} - T_{c,i}\right) F_1 \quad (8)$$

Where:

i	=	Specific 10-minute interval
q_i	=	Refrigeration rate kW (tons)
V_i	=	Averaged flow rate measured at F_2 L/s (gpm)
ρ	=	Mass density kg/m^3 (lb/ft^3) – typically 1000 kg/m3 @ 4.44°C (62.43 lb/ft^3 @ 40°F) for water
c_p	=	Specific heat, typically 4.186 kJ/kg·K (1.0 Btu/lb-°F) for water
$T_{w,i}$	=	Averaged CHWR (warm) water temperature °C (°F)
$T_{c,i}$	=	Averaged CHWS (cold) water temperature °C (°F)
F_1	=	Conversion factor
SI :	F_1 =	0.001 kJ/kg·K-L/m^3-s/hr
IP :	F_1 =	0.0006684 min-ft^3-ton-gallon-Btu

10.2.3 Total integrated refrigeration delivered during the charge period is:

$$Q_{total} = \sum_{i=1}^{n} q_i \cdot \frac{t_i}{60 \frac{min}{hr}} \quad (9)$$

Where:

Q_{total}	=	Total refrigeration delivered kWh$_T$ (ton-hours)
n	=	Total number of intervals
q_i	=	Increment refrigeration rate kW (tons)
t_i	=	Time increment duration (minutes)

10.2.3.1 Delta T Adjustment -The quantity of refrigeration storage (that can be provided by a tank) must be adjusted based on the temperature difference (Delta T) that is present during the test and the design conditions. The adjustment from test conditions to design conditions is performed as follows:

$Q_{adjusted} = Q_{total}\ (Tw,d - Tc,d)\ /\ (\sum_{t=1}^{n} Tw,i - \sum_{t=1}^{n} Tc,i)$ (10)

Where:

i	=	Specific 10-minute interval
$Q_{adjusted}$	=	Amount of refrigeration stored at the design Delta T kWh$_T$ (ton-hours)

Q_{total} = Total refrigeration stored during the test kWh_T (ton-hours)

$T_{w,i}$ = Averaged CHWR (warm) water temperature °C (°F)

$T_{c,i}$ = Averaged CHWS (cold) water temperature °C (°F)

$T_{w,d}$ = Design CHWR (warm) water temperature °C (°F)

$T_{c,d}$ = Design CHWS (cold) water temperature °C (°F)

10.3 Pressure Drop Test Calculation

10.3.1 The TES tank system Pressure Drop Test shall be conducted concurrently with the Charge or Discharge Test, whichever provided the chilled water flow rate closest to the maximum design chilled water flow rate (tolerance of +1/-10%). Maximum tank system pressure drop will be the maximum recorded value at stable flow, disregarding pressure spikes caused by equipment external to the TES tank system (e.g., pumps, valves).

10.3.2 The Pressure Drop Test is intended to measure frictional pressure drop, only, within the TES tank. Gravity head shall be subtracted from the inlet and outlet pressure readings as required (e.g., for dissimilar nozzle elevations).

10.3.3 The maximum tank system pressure drop value shall be adjusted to account for any significant pipe length between the tank nozzles and the pressure sensors.

10.3.4 Once the Pressure Drop Test data has been collected, confirm that the data appears to fall within the design parameters and test parameters (listed above). If there are any spurious readings, these shall be removed from the data set prior to calculation.

$$\Delta P = \sum_{t=1}^{n} \frac{|(Pc-Pw)|}{n} \quad (11)$$

i = Specific 10-minute interval

Pc = Pressure of the cold water kPa (psi)

Pw = Pressure at the warm water kPa (psi)

10.4 Heat Gain (Holding Test) Calculations

Based on the project specifications, the tank manufacturer shall submit calculations for review and approval by the owner's engineer.

11. TEST METHOD 3 – REQUIREMENTS

11.1 Initialization

11.1.1 Cool-storage systems tested under this standard shall be fully operational with all components, including all control components and control sequences installed and working.

11.1.2 Prior to starting tests under Test Method 3 of this standard, cool-storage systems shall be operated through at least five cycles from fully charged to at least 70% discharged, but not fewer than the number of cycles recommended by the thermal storage device manufacturer, whenever this is more than five. This cycling is required to ensure that the thermal storage device is at an initial condition representative of normal operation,

11.2 Apparatus

11.2.1 Cool-storage systems tested under Test Method 3 of this standard shall be provided with instrumentation to measure the following properties. Fluid flow and temperature measurement locations are illustrated in Figure 5.

a. For the cool-storage system capacity test and the system efficiency test:
1. F1—Fluid flow rate through the cool-storage system under test.
2. T1—Fluid temperature leaving the cool-storage system under test.
3. T2—Fluid temperature entering the cool-storage system under test.
b. For the discharge test and the charge test:
1. F2—Fluid flow rate through the thermal storage device.
2. T3—Fluid temperature entering the thermal storage device.
3. T4—Fluid temperature leaving the thermal storage device.

c. For the cool-storage system efficiency test:
1. Electric energy use of all water-side equipment located inside the boundaries of the system under test. For equipment powered by input energy other than electricity, provide appropriate instrumentation to measure the input energy use.

d. Optional measurements applying to some cool-storage systems:
1. Liquid level in the thermal storage device, used for measuring latent inventory in some ice storage systems.
2. Vertical temperature profile in the thermal storage device, used for measuring sensible inventory in some chilled-water storage systems.

11.2.2 The locations of the measurement points T1 through T6 and F1 through F3 for a given system under test shall be specified by the test authority, as described in Section 11.3(c), in accordance with Sections 12.3.6 and 13.1.

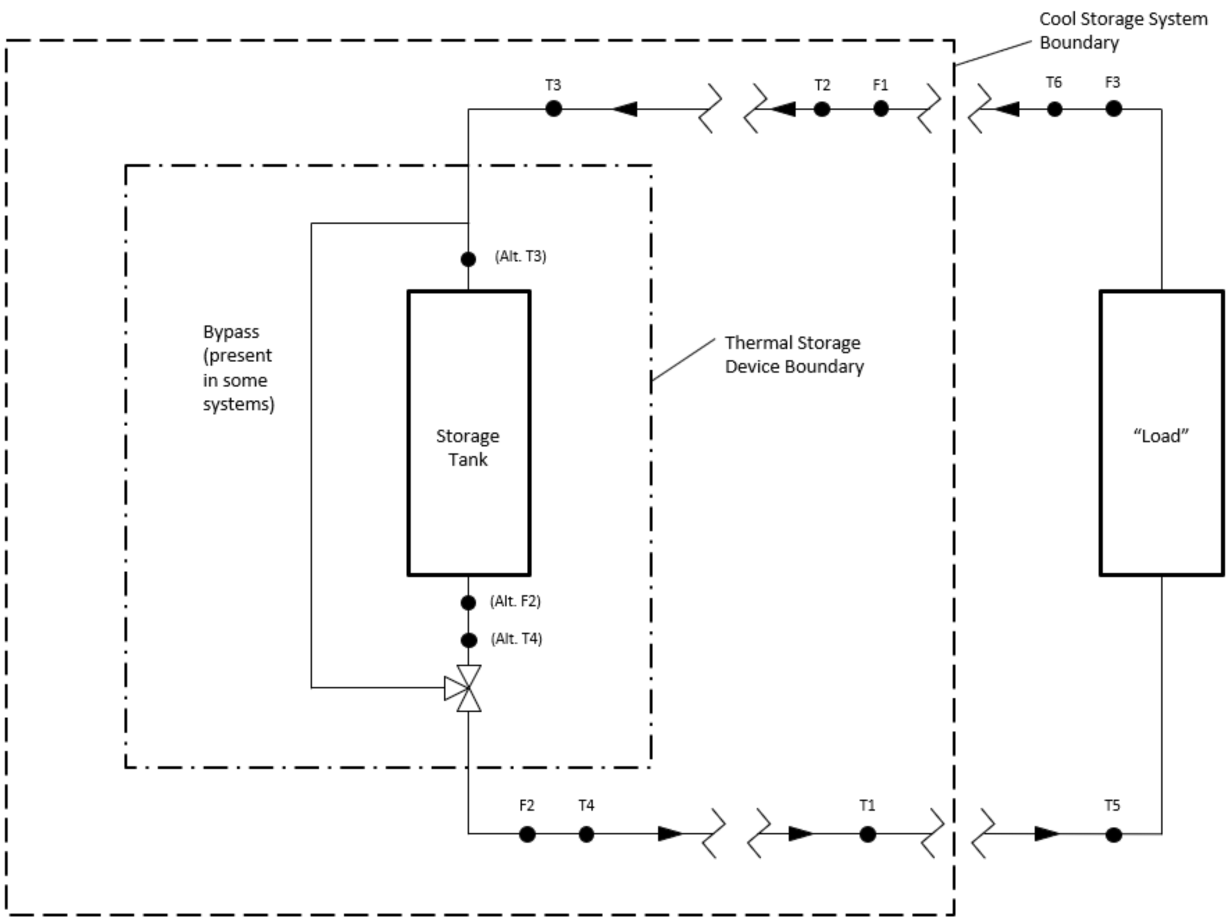
11.2.3 Instruments shall meet the requirements of Section 12.

11.3 Required Information. The following information shall be specified by the test authority prior to performing tests under this standard's Test Method 3:

a. The tests to be performed.

b. A specified load profile against which the system is to be tested. The load profile shall be determined by design flow rates and supply and return water temperatures for each portion of the system under test, as well as the corresponding design storage system capacity, for each hour of the storage cycle. See Tables 1 and 2 for examples of load profiles.

c. A schematic diagram illustrating the entire cool-storage system, including the following:
1. All major components and interconnecting piping.
2. The locations of the fluid flow and temperature measurement points. Point locations are discussed in Section 13.1.
3. The boundary of the system under test for the cool storage system capacity test and the cool-storage system efficiency test, as described in Section 13.1.2.



T1 – Fluid temperature leaving the cool storage system
T2 – Fluid temperature entering the cool storage system
T3 – Fluid temperature entering the thermal storage device
T4 – Fluid temperature leaving the thermal storage device
T5 – Fluid temperature entering the load
T6 – Fluid temperature leaving the load
F1 – Fluid flow rate through the system
(may be located on entering of leaving side)
F2 – Fluid flow rate through the thermal storage device
(may be located up- or downstream)
F3 – Fluid flow rate through the load
(may be located up- or downstream)
— — — — Boundary of cool storage system
— · — · — Boundary of thermal storage device

Figure 5 General cool-storage system test schematic.

Table 1 Example-Specified Load Profile Ice Storage, Constant Flow, Chiller Upstream (SI)

Hour	System, kW_T	Chiller, kW_T	Storage, kW_T	Notes	Storage Inventory, kWh_T	T1 Leaving System, °C	T2 Entering System, °C	T3 Entering Storage, °C	T4 Leaving Storage, °C	Entering Chiller, °C	Leaving Chiller, °C	F1 Through System, L/s	F2 Through Storage, L/s
1	0	756	756		4064	—	—	–4.1	–0.2	–0.2	–4.1	—	50
2	0	753	753		4817	—	—	–4.2	–0.4	–0.4	–4.2	—	50
3	0	747	747		5563	—	—	–4.4	–0.6	–0.6	–4.4	—	50
4	0	738	738		6301	—	—	–4.7	–0.9	–0.9	–4.7	—	50
5	0	738	738		7039	—	—	–4.7	–0.9	–0.9	–4.7	—	50
6	0	0	0		7039	—	—	—	—	—	—	—	—
7	0	0	0		7039	—	—	—	—	—	—	—	—
8	1407	1092	–315	Pulldown	6725	3.3	10.4	4.9	3.3	10.4	4.9	50	50
9	1231	1075	–156		6569	3.3	9.5	4.1	3.3	9.5	4.1	50	50
10	1407	1092	–315		6254	3.3	10.4	4.9	3.3	10.4	4.9	50	50
11	1759	1128	–631		5623	3.3	12.2	6.5	3.3	12.2	6.5	50	50
12	1934	1145	–789		4835	3.3	13.1	7.3	3.3	13.1	7.3	50	50
13	2110	1163	–947		3888	3.3	14.0	8.1	3.3	14.0	8.1	50	50
14	2198	1172	–1026	Maximum	2861	3.3	14.4	8.5	3.3	14.4	8.5	50	50
15	2110	1163	–947		1915	3.3	14.0	8.1	3.3	14.0	8.1	50	50
16	1934	1145	–789	Critical	1126	3.3	13.1	7.3	3.3	13.1	7.3	50	50
17	1671	1119	–552		574	3.3	11.7	6.1	3.3	11.7	6.1	50	50
18	1319	1083	–235	Final	339	3.3	10.0	4.5	3.3	10.0	4.5	50	50
19	1055	1055	0		339	3.3	8.6	3.3	3.3	8.6	3.3	50	50
20	352	821	470		821	0.6	2.3	–1.8	0.6	2.3	–1.8	11	50
21	317	800	483		1305	–0.1	1.5	–2.5	–0.1	1.5	–2.5	9	50

22	317	800	483		1788	–0.1	1.5	–2.6	–0.1	1.5	–2.6	9	50
23	0	761	761		2549	—	—	–3.9	–0.1	–0.1	–3.9	—	50
24	0	759	759		3308	—	—	–3.9	–0.1	–0.1	–3.9	—	50

Table 1 Example Specified Load Profile Ice Storage, Constant Flow, Chiller Upstream (I-P)

Hour	System, tons	Chiller, tons	Storage, tons	Notes	Storage Inventory, ton-hour	T1 Leaving System, °F	T2 Entering System, °F	T3 Entering Storage, °F	T4 Leaving Storage, °F	Entering Chiller, °F	Leaving Chiller, °F	F1 Through System, gpm	F2 Through Storage, gpm
1	0	215	215		1156	—	—	24.7	31.6	31.6	24.7	—	800
2	0	214	214		1370	—	—	24.5	31.3	31.3	24.5	—	800
3	0	212	212		1582	—	—	24.1	30.9	30.9	24.1	—	800
4	0	210	210		1792	—	—	23.6	30.3	30.3	23.6	—	800
5	0	210	210		2002	—	—	23.6	30.3	30.3	23.6	—	800
6	0	0	0		2002	—	—	—	—	—	—	—	—
7	0	0	0		2002	—	—	—	—	—	—	—	—
8	400	311	–89	Pulldown	1913	38.0	50.8	40.9	38.0	50.8	40.9	800	800
9	350	306	–44		1868	38.0	49.2	39.4	38.0	49.2	39.4	800	800
10	400	311	–89		1779	38.0	50.8	40.9	38.0	50.8	40.9	800	800
11	500	321	–179		1599	38.0	53.9	43.7	38.0	53.9	43.7	800	800
12	550	326	–224		1375	38.0	55.5	45.2	38.0	55.5	45.2	800	800
13	600	331	–269		1106	38.0	57.1	46.6	38.0	57.1	46.6	800	800
14	625	333	–292	Maximum	814	38.0	57.9	47.3	38.0	57.9	47.3	800	800
15	600	331	–269		545	38.0	57.1	46.6	38.0	57.1	46.6	800	800
16	550	326	–224	Critical	320	38.0	55.5	45.2	38.0	55.5	45.2	800	800
17	475	318	–157		163	38.0	53.1	43.0	38.0	53.1	43.0	800	800

18	375	308	–67	Final	96	38.0	50.0	40.1	38.0	50.0	40.1	800	800
19	300	300	0		96	38.0	47.6	38.0	38.0	47.6	38.0	800	800
20	100	234	134		234	33.0	36.2	28.7	33.0	36.2	28.7	170	800
21	90	227	137		371	31.8	34.7	27.4	31.8	34.7	27.4	142	800
22	90	227	137		508	31.8	34.7	27.4	31.8	34.7	27.4	142	800
23	0	216	216		725	—	—	25.0	31.9	31.9	25.0	—	800
24	0	216	216		941	—	—	24.9	31.8	31.8	24.9	—	800

Table 2 Example Specified Load Profile Chilled-Water Storage, Variable Flow (SI)

Hour	System, kW_T	Chiller, kW_T	Storage, kW_T	Notes	Storage Inventory, kWh_T	T1 Leaving System, °C	T2 Entering System, °C	T3 Entering Storage, °C	T4 Leaving Storage, °C	Entering Chiller, °C	Leaving Chiller, °C	F1 Through System, L/s	F2 Through Storage, L/s
1	0	1882	1882		14166	—	—	4.4	15.6	15.6	4.4	—	41
2	0	1882	1882		16048	—	—	4.4	15.6	15.6	4.4	—	41
3	0	1882	1882		17930	—	—	4.4	15.6	15.6	4.4	—	41
4	0	1882	1882		19811	—	—	4.4	15.6	15.6	4.4	—	41
5	0	1882	1882		21693	—	—	4.4	15.6	15.6	4.4	—	41
6	0	1882	1882		23574	—	—	4.4	15.6	15.6	4.4	—	41
7	0	1882	1882		25315	—	—	4.4	15.6	15.6	4.4	—	41
8	2110	0	–2110	Pulldown	23205	5.6	15.6	15.6	5.6	15.6	—	50	–50
9	1407	0	–1407		21798	5.6	15.6	15.6	5.6	15.6	—	34	–34
10	1759	0	–1759		20040	5.6	15.6	15.6	5.6	15.6	—	42	–42
11	2638	0	–2638		17402	5.6	15.6	15.6	5.6	15.6	—	63	–63
12	2638	0	–2638		14764	5.6	15.6	15.6	5.6	15.6	—	63	–63
13	3517	0	–3517		11247	5.6	15.6	15.6	5.6	15.6	—	84	–84

14	4045	0	–4045	Max, critical	7203	5.6	15.6	15.6	5.6	15.6	—	97	–97
15	2638	0	–2638		4565	5.6	15.6	15.6	5.6	15.6	—	63	–63
16	2638	0	–2638		1927	5.6	15.6	15.6	5.6	15.6	—	63	–63
17	1759	0	–1759	Final	169	5.6	15.6	15.6	5.6	15.6	—	42	–42
18	352	1882	1530		1699	4.4	15.6	4.4	15.6	15.6	4.4	8	33
19	352	1882	1530		3228	4.4	15.6	4.4	15.6	15.6	4.4	8	33
20	352	1882	1530		4758	4.4	15.6	4.4	15.6	15.6	4.4	8	33
21	0	1882	1882		6640	—	—	4.4	15.6	15.6	4.4	—	41
22	0	1882	1882		8522	—	—	4.4	15.6	15.6	4.4	—	41
23	0	1882	1882		10403	—	—	4.4	15.6	15.6	4.4	—	41
24	0	1882	1882		12285	—	—	4.4	15.6	15.6	4.4	—	41

Table 2 Example Specified Load Profile Chilled–Water Storage, Variable Flow (I–P)

Hour	System, tons	Chiller, tons	Storage, tons	Notes	Storage Inventory, ton-hour	T1 Leaving System, °F	T2 Entering System, °F	T3 Entering Storage, °F	T4 Leaving Storage, °F	Entering Chiller, °F	Leaving Chiller, °F	F1 Through System, gpm	F2 Through Storage, gpm
1	0	535	535		4030	—	—	40.0	60.0	60.0	40.0	—	642
2	0	535	535		4565	—	—	40.0	60.0	60.0	40.0	—	642
3	0	535	535		5100	—	—	40.0	60.0	60.0	40.0	—	642
4	0	535	535		5635	—	—	40.0	60.0	60.0	40.0	—	642
5	0	535	535		6170	—	—	40.0	60.0	60.0	40.0	—	642
6	0	535	535		6705	—	—	40.0	60.0	60.0	40.0	—	642
7	0	535	535		7200	—	—	40.0	60.0	60.0	40.0	—	642
8	600	0	–600	Pulldown	6600	42.0	60.0	60.0	42.0	60.0	—	800	–800
9	400	0	–400		6200	42.0	60.0	60.0	42.0	60.0	—	533	–533

10	500	0	–500		5700	42.0	60.0	60.0	42.0	60.0	—	667	–667
11	750	0	–750		4950	42.0	60.0	60.0	42.0	60.0	—	1000	–1000
12	750	0	–750		4200	42.0	60.0	60.0	42.0	60.0	—	1000	–1000
13	1000	0	–1000		3200	42.0	60.0	60.0	42.0	60.0	—	1333	–1333
14	1150	0	–1150	Max, critical	2050	42.0	60.0	60.0	42.0	60.0	—	1533	–1533
15	750	0	–750		1300	42.0	60.0	60.0	42.0	60.0	—	1000	–1000
16	750	0	–750		550	42.0	60.0	60.0	42.0	60.0	—	1000	–1000
17	500	0	–500	Final	50	42.0	60.0	60.0	42.0	60.0	—	667	–667
18	100	535	435		485	40.0	60.0	40.0	60.0	60.0	40.0	120	522
19	100	535	435		920	40.0	60.0	40.0	60.0	60.0	40.0	120	522
20	100	535	435		1355	40.0	60.0	40.0	60.0	60.0	40.0	120	522
21	0	535	535		1890	—	—	40.0	60.0	60.0	40.0	—	642
22	0	535	535		2425	—	—	40.0	60.0	60.0	40.0	—	642
23	0	535	535		2960	—	—	40.0	60.0	60.0	40.0	—	642
24	0	535	535		3495	—	—	40.0	60.0	60.0	40.0	—	642

4. The boundary of the system under test for the discharge test and the charge test, as described in Section 13.1.3.

d. A description of the intended cool-storage system operation for the cool-storage system capacity test. For example, there may be constraints on the chiller and storage loads during specific time periods.

e. A listing of the system components whose input energy is to be measured for the cool-storage system efficiency test.
1. At a minimum, the input energy measurement shall include the input energy for all components that are required to deliver cooling to the load, including thermal storage device auxiliaries, chiller compressors, chiller pumps, main distribution pumps, and heat rejection pumps and fans.
2. The input energy measurement may also include the input energy for tertiary or auxiliary distribution pumps or other components.

f. The magnitude of the load at the calculated critical discharge point, the hour of occurrence, and the calculated state of charge relative to the fully charged condition.

g. Maximum allowable duration of the charging period.

h. Maximum usable discharge temperature.

i. Maximum usable cooling supply temperature.

j. Criterion for determining the fully charged condition.
1. The test authority shall select the criterion for determining the fully charged condition. It may be one of the following:
i. With the flow rate as specified in Section 11.3(b), the temperature leaving the thermal storage device is less than a predefined value for a continuous 15-minute period.
ii. The height of fluid or ice in the thermal storage device is greater than a predefined value for a continuous 15-minute period.
iii. The calculated accumulated inventory is greater than a predefined value.
iv. The heat extraction rate reaches a predetermined benchmark heat extraction rate as measured by the test data recording instruments.
2. The value of temperature, height, or inventory that indicates the fully charged condition shall be specified by the test authority. It may be based on the value established in design or by current operating strategy.

k. Criterion for determining the fully discharged condition.
1. The test authority shall select the criterion for determining the fully discharged condition. It may be one of the following:
i. With the flow rate as specified in Section 11.3(b), the temperature leaving the thermal storage device is greater than the maximum usable discharge temperature for a continuous 15-minute period.
ii. The height of fluid, or of chilled fluid, in the thermal storage device is less than a predefined value for a continuous 15-minute period.
iii. The calculated accumulated inventory is less than a predefined value.
iv. The heat absorption rate reaches a predetermined benchmark heat absorption rate as measured by the test data recording instruments.
2. The value of temperature, height, or inventory that indicates the fully discharged condition shall be specified by the test authority. It may be based on the value established in design or by current operating strategy.

l. Maximum and minimum allowable ambient temperatures surrounding the thermal storage device as stipulated by the device manufacturer as the basis of design for their rating.

m. For cool-storage systems using a heat transfer fluid other than water, the relationship between the fluid concentration in percent by volume and the refractive index of the fluid shall be documented by data from the fluid manufacturer.

n. Documentation establishing that all instrumentation has been calibrated or verified to meet the requirements of Section 12.

11.4 Compliance with this standard shall not be claimed unless the required information specified in Section 11.3 has been provided. All required information shall be documented in the test report in accordance with Section 17.

12. TEST METHOD 3 – INSTRUMENTS

12.1 General

12.1.1 Instruments, whether existing or installed specifically for the purpose of testing, shall meet the requirements of Section 12.

12.1.2 The instrument accuracy requirements for Test Method 3 were selected to provide 10% or better uncertainty in the overall calculation of capacity for most systems. Users who have stricter requirements for uncertainty, or who for any reason wish to verify the actual uncertainty in the test results, should complete an uncertainty analysis prior to conducting testing to confirm that instrument specifications and potential field effects will not unduly affect test results. A post-test uncertainty analysis may also be completed to determine the actual uncertainty interval in the test results. ASHRAE Guideline 22, Table 5-2, and Informative Appendix C, provide an informative discussion of uncertainty analysis. An additional resource is ANSI/ASME PTC 19.1, *Test Uncertainty*[2].

12.1.3 Instruments noted as optional are exempted from the requirements of Section 12.

12.2 Temperature Measurement

12.2.1 Temperature shall be measured in accordance with ANSI/ASHRAE Standard 41.1[3].

12.2.2 The rated accuracy, precision, and resolution of the instruments and their associated readout devices shall be within the following limits for Test Method 3:

	Temperature	Temperature Difference
Accuracy	±0.15°C (±0.3°F)	±0.10°C (±0.2°F)
Precision	±0.10°C (±0.2°F)	±0.075°C (±0.15°F)
Resolution	±0.05°C (±0.1°F)	±0.05°C (±0.1°F)

12.2.3 The installed accuracy of temperature sensors shall be verified as specified in Sections 12.8.2 and 12.8.3.

12.2.4 Temperature sensors used for measuring the temperature difference across a component shall be calibrated as matched pairs by the manufacturer.

12.2.5 The use of surface temperature sensors is acceptable for the purposes of this standard if the following conditions are met:

a. The requirements of Sections 12.2.2 and 12.2.3 are met.

b. The installation is indoors.

c. Heat-conducting paste is utilized between the sensor and pipe.

d. Closed cell insulation with a minimum insulation value of 2 m2·K/J (12 ft2·°F/Btu) isolates the pipe from ambient conditions for a distance of at least 15 cm (6 in.) from the sensor.

e. The ambient temperature differs from the measured temperature by no more than 25°C (45°F).

f. When two surface temperature sensors are used to determine a temperature differential, the ambient temperatures at each sensor location differ by no more than 5°C (10°F).

12.3 Liquid Flow Measurement

12.3.1 Applicable Standards. Liquid flow shall be measured in accordance with the following standards:

a. Orifice flowmeters: ANSI/ASHRAE 41.8, *Standard Methods of Measurement of Flow of Liquids in Pipes Using Orifice Flowmeters*[4].

b. Turbine flowmeters.

c. ISA RP31.1, *Recommended Practice Specification, Installation, & Calibration of Turbine Flowmeters*[5].

d. For instruments without existing standards, such as velocity-dependent insertion flowmeters (axial turbine, tangential paddle-wheel, target), use manufacturers' recommendations as applicable.

e. Appendix A provides additional guidelines for liquid flow measurement.

12.3.2 Calibration. Liquid flowmeters shall have been laboratory-calibrated by the factory or an independent facility no more than one year prior to the date of the test. The calibration shall be by comparison with a NIST primary or secondary standard at a minimum of three (3) points representative of the minimum, typical, and maximum expected flow rates. Five (5) points are recommended for a proper curve fit.

12.3.3 The rated accuracy, precision, and resolution of the instruments and their associated readout devices shall be within the following limits:

a. Accuracy: ±1% of reading

b. Precision: ±2% of reading

c. Resolution: ±0.1% of reading

12.3.4 Dynamic Response. The instrument shall be capable of measuring the flow within the stated accuracy over the entire range of flow to be encountered.

12.3.5 Bidirectional Flow. For flow measurement locations where the direction of the flow changes with the operating mode, flow sensors shall be rated for bidirectional flow, or two (2) unidirectional sensors shall be provided.

12.3.6 Location. Flowmeters shall be installed according to the manufacturer's specifications, except as follows:

a. Flowmeters should be installed with a minimum length of straight run piping, clear of any flow disturbances, with both upstream and downstream straight pipe diameters in accordance with the flowmeter manufacturer's requirements.

b. Flowmeters shall not be located in vertical pipes where fluid is flowing down.

c. For insertion-type flowmeters, the insertion tap shall be oriented in the plane of the outside radius of the first upstream elbow.

d. If the required straight pipe runs are not available, or if dynamic flow conditions, severe rotational velocities, or high spatial variation in velocities are present such that spatial variation is greater than 5%, a flowmeter whose accuracy is not dependent on a uniform flow profile, or a flow straightening device, shall be employed. See Section 12.8.4.

12.3.7 The installed accuracy of liquid flowmeters shall be verified as specified in Section 12.8.4.

12.4 Electric Power Measurement

12.4.1 Electric power shall be measured using instruments that yield true rms power, based on measured current, voltage, and power factor.

12.4.2 The accuracy of the electric power measuring and associated readout devices shall be equal to or better than 1% of the measured value.

12.5 Density Measurement

12.5.1 Heat transfer fluid density, or specific gravity, shall be measured using a hydrometer that is designed for the appropriate temperature range expected to be encountered. Specific precautions are required for accurate density measurement, such as sampling technique, and the hydrometer manufacturer's directions should be followed in detail. Apply temperature effect calculations as necessary based on actual temperatures encountered versus the temperature range of the hydrometer used.

12.5.2 The accuracy of the hydrometer measurement shall be such that the percentage of heat transfer fluid in water is determined within ±2% of the actual value.

12.6 Refractive Index Measurement

12.6.1 For glycol heat transfer fluids, the percentage of glycol in water may be determined by a refractive index measurement with a refractometer. This measurement may be taken in lieu of a density measurement, so that the percentage of heat transfer fluid in water may be determined by a refractive index measurement with a refractometer. The use of automatic temperature compensation (ATC) shall be used as specified by the refractometer manufacturer.

12.6.2 The accuracy of the refractometer shall be such that the percentage of glycol, or other heat transfer fluid, in water is determined within ±1% of the actual value.

12.7 Data Recording Instruments. The data listed in Section 15 shall be recorded by data recording instruments meeting the following requirements:

a. Recording interval: Measurements shall be recorded at uniform intervals of no more than 15 minutes, with an integer number of intervals per hour. Each recorded value shall consist of the average of the values of at least 45 previous individual measurements observed at the scan rate.

b. Scan rate: Data recording instruments shall sample individual measurements at a rate of not less than five samples per second.

c. Scan interval: Separate scans of the complete set of measurements shall be initiated at least every 20 seconds.

d. Resolution: The minimum resolution of the recording instruments shall be 0.1% of the full-scale range and one second for time. This corresponds to the resolution of a 10-bit analog-to-digital converter.

e. Accuracy: The accuracy of the recording instruments shall be within 0.25% of full scale.

f. Precision: The precision of the recording instruments shall be within ±0.1% of full scale.

g. Time measurement: Resolution of time measurement shall be a minimum of one second. Accuracy and precision of time measurement shall be within one second per hour.

12.8 Field Calibration and Verification of Test Instruments

12.8.1 General

a. The installed accuracy of temperature and flow instruments shall be verified to be within the limits specified in Sections 12.2.2 and 12.3.3.

b. Field verification of installed accuracy shall be completed no more than three (3) months prior to the date of the test.

c. Instruments used to verify the accuracy of field-installed instruments shall have been calibrated no more than one year prior to the date of the test.

d. For further information, see ASHRAE Guideline 11, *Field Testing of HVAC Control Components*[6].

12.8.2 Temperature

12.8.2.1 Temperature sensors shall be calibrated by a two-point procedure, using an ice or water bath with a reference standard or a dry-well calibrator block constructed for that purpose.

a. The calibration reference instrument shall be a primary standard or a NIST-traceable calibrated secondary standard accurate to within ±0.05°C (±0.10°F).

b. One of the calibration points shall use an ice bath as the primary standard unless the sensor is not designed to transmit temperature measurements of 0°C (32°F). A sensor not designed to transmit temperature measurements of 0°C (32°F) shall be calibrated in a water bath or dry well at a known temperature near the low end of its operating range.

c. Each sensor shall also be calibrated in a water bath or dry well at a known temperature near the high end of its operating range.

12.8.2.2 Water Bath Calibration Procedure

a. The water bath shall consist of water in an insulated container having a volume of at least 0.5 L (0.13 gal).

b. Remove the sensor from its installed location and immerse it with the calibration instrument in the water bath. Allow the temperature reading to stabilize at the temperature of the bath. Record the sensor temperature reading at the data recording instrument and the calibration instrument reading at ten-second intervals for a period of at least five minutes.

12.8.2.3 Ice Bath Calibration Procedure

a. The ice bath shall consist of crushed or flake ice in water in an insulated container having a volume of at least 0.5 L (0.13 gal). The ice and liquid water should be distilled water. The ice shall occupy approximately 50% of the volume of the container so that the mass of ice is floating just above the bottom of the container.

b. Remove the sensor from its installed location and immerse it in the ice bath. Allow the temperature reading to stabilize at the temperature of the bath. Record the sensor temperature reading at the data recording instrument at ten-second intervals for a period of at least five minutes. The calibration reference reading for the ice bath is 0°C (32°F).

12.8.2.4 If temperature sensors are not constructed to allow immersion in water, use a dry-well calibrator.

12.8.2.5 If the difference between the sensor readings and the calibration instrument readings is greater than the allowable tolerance specified in Section 12.2.2, replace the sensor, or adjust the data acquisition system with an appropriate slope and offset. Record the adjustment on the instrument test report form. Repeat the verification procedure.

12.8.3 Temperature Difference. The measurement of temperature difference may be verified by the following method:

a. Configure the system so that the two sensors are subjected to fluid flow at the same temperature. For example, to verify temperature measurements entering and leaving a thermal storage device, set the bypass valve of the storage device to bypass the entire flow around storage.

b. Record both sensor temperature readings at the data recording instrument at ten-second intervals for a period of at least five (5) minutes.

c. Exchange the positions of the two sensors and again record the temperature readings as described in Section 12.8.3(b).

d. If the temperature sensors cannot be shown to be reading the actual temperature difference within the limits specified in Section 12.2.2, replace one or both of the sensors and then repeat this procedure.

12.8.4 Liquid Flow

12.8.4.1 To field-verify the installed accuracy of a flow sensor, the user shall confirm that the flow conditions in the field are consistent with the flow conditions that existed for the laboratory calibration. If the flow profile at the point of measurement is symmetrical and stable, the laboratory calibration can be considered to apply to the field installation.

12.8.4.2 For the purposes of this standard, the laboratory calibration will also be considered applicable if the spatial variation in flow is less than or equal to 5%. Spatial variation can be determined by sampling the flow profile at a number of points across the pipe cross section at the measurement location. Appendix A provides a suggested method for measuring spatial variation.

12.8.4.3 Spatial variation SV is calculated as follows:

$$\text{SV} = (t_{95} \times S_{corr}) / (\sqrt{N} \times \overline{F}_{corr}) \quad (12)$$

where
$t95$ = student's t static, with N degrees of freedom
$Scorr$ = standard deviation of measurements corrected
for variation due to time
N = number of measurements
= average of the corrected measurements
Further details are given in Appendix A.

12.8.4.4 If the spatial variation is greater than 5%, the following options are available:

a. Choose a suitable alternative measurement location.

b. Install a flow straightening device.

c. Replace the flow sensor with an instrument that is not vulnerable to spatial variation or swirl, such as a magnetic flowmeter.

d. Use a pitot tube to calibrate the installed flow sensor. For further information, see ASME Power Test Code (PTC) 19.5, Part 2 of *Fluid Meters: Interim Supplement on Instruments and Apparatus*[7], or see CTI 146, *Code Tower Specifications for Liquid Flow Measurement*[8].

12.8.4.5 The flow profile shall be verified at the minimum, typical, and maximum expected flow rates.

12.8.4.6 Magnetic flowmeters and Coriolis flowmeters do not require verification of flow profile in the field.

12.8.4.7 For further information, see ANSI/ASME MFC-10M, *Method for Establishing Installation Effects on Flowmeters*[9].

12.8.5 Alternative Verification Methods. Verification of sensor accuracy by methods other than those described in Section 12.8.2.1 shall be approved by the test authority prior to the test and shall be documented in the test report.

13. TEST METHOD 3 – TEST PROCEDURES

13.1 Test Configurations

13.1.1 The numbering of measurement points for the purposes of this standard is illustrated in Figure 5. The labeling of the points is as follows:

a. F1—Fluid flow rate through the system under test
b. T1—Fluid temperature leaving the system under test
c. T2—Fluid temperature entering the system under test
d. F2—Fluid flow rate through the thermal storage device
e. T3—Fluid temperature entering the thermal storage device
f. T4—Fluid temperature leaving the thermal storage device
g. T5—Fluid temperature entering the load
h. T6—Fluid temperature leaving the load
i. F3—Fluid flow rate through the load

13.1.2 Points F1, T1, and T2 define the boundary of the system that is to be tested by the cool-storage system capacity test and the system efficiency test. For the purpose of these tests, the selection of these points divides the entire cooling system into the system under test and the load.

13.1.3 Points F2, T3, and T4 define the boundary of the thermal storage device that is to be tested by the discharge test and the charge test. In some cases, such as a chilled-water storage system, the flow and temperature can be the same as shown in Table 2.

13.1.4 Figures in Appendix C illustrate locations of these points for a number of cool-storage system configurations.

13.1.5 Flowmeter locations shall conform to Section 12.3.6.

13.2 Determination of Test Conditions

13.2.1 General

13.2.1.1 For each test, the system shall be subjected to a sequence of loads, fluid flow rates, and temperatures as defined by the specified load profile for the chilled-water and cool-storage system configuration.

13.2.1.2 After the test is completed, compare the measured loads to the specified load profile. Compliance with the standard requires that the measured load profile be substantially equivalent to the appropriate portion of the specified load profile as enumerated in the test method options in Section 13.2.1.3.

13.2.1.3 Cool-storage systems differ in their normal temperature and flow characteristics and in the extent to which temperatures and flows can be manipulated for the purposes of testing. The test conditions are determined largely by the cooling loads present in the facility served by the system. Because of the difficulty in achieving specified loads for a field test, two methods are provided for determining whether the measured loads comply with the requirements of the standard.

13.2.1.3.1 Test Procedure 1. This procedure is required for the charge test, the cool-storage system capacity test, and the cool-storage system efficiency test. This procedure is also preferred for the discharge test if adequate loads are available. The measured loads comply with the requirements of the standard if the following conditions are true:

a. The average load in each hour of the test is at least 90% of the corresponding hour's load in the specified load profile.

b. The total cooling load, determined by summing the loads for each hour of the test in the test load profile, is at least 95% of the total cooling load in the specified load profile.

13.2.1.3.2 Test Procedure 2. This procedure shall be used for the discharge test if loads satisfying Procedure 1 are not available. The measured loads comply with the requirements of the standard if all of the following conditions are true:

a. The average load in the first hour is at least 90% of the first hour's load in the specified load profile.

b. The maximum hour's load is at least 90% of the maximum hour's load in the specified load profile.

c. The load at the critical discharge point is at least 90% of the critical discharge load in the specified load profile. The test critical discharge point occurs when the state of charge relative to the fully charged condition is within ±10% of that specified by the test authority for the design critical discharge point.

d. The average load in the last hour is at least 90% of the last hour's load in the specified load profile.

e. The total cooling load, determined by summing the loads for each hour in the test load profile, is at least 95% of the total cooling load in the specified load profile.

f. The average load in any hour is at least 25% of the load in the corresponding hour in the specified load profile. The corresponding hour is the first hour when the cumulative discharge in the specified load profile is equal to or greater than the current cumulative discharge.

13.2.1.4 If the available cooling loads are not high enough to allow a valid test, they may be increased by measures including, but not limited to, the following:

a. Not operating other sources of cooling

b. Overriding economizer-free cooling

c. Operating existing or temporary heating devices in the conditioned space

d. Operating existing or temporary heating devices in the cool-storage system or facility.

13.2.2 Test Conditions for Discharge Test. The measured loads for the discharge test shall be equivalent to the discharge portion of the specified load profile, as determined by Procedure 1 or Procedure 2 in Section 13.2.1.3.

13.2.2.1 If the entire specified load profile has been applied, and if the end of the test as specified in Section 8.3.4 has not been reached (i.e., the thermal storage device has not been fully discharged), continue applying the last hour's load until the end of the test is reached.

13.2.2.2 Figures 6, 7, and 8 illustrate an example specified load profile for a discharge test and two acceptable sequences of measured loads.

13.2.3 Test Conditions for Charge Test. In each hour of the test period, chilled fluid shall be introduced to the thermal storage device at a supply temperature (T2) within ±0.5°C (1.0°F) and a charge flow rate (F2) within ±10% of those specified in the charge portion of the specified load profile.

13.2.4 Test Conditions for Cool-Storage System Capacity Test

13.2.4.1 The measured loads for the cool-storage system capacity test shall be equivalent to the system loads in the specified load profile as determined by Procedure 1 in Section 13.2.1.3.

13.2.4.2 The system shall be operated in accordance with the intended system operation, as specified under Section 11.3(d).

13.2.5 Test Conditions for Cool-Storage System Efficiency Test. The requirements for the test conditions for the cool-storage system efficiency test are the same as those for the cool-storage system capacity test.

13.3 Determining Fluid Properties. Properties shall be determined for the heat transfer fluid at the average temperature entering the thermal storage device. The density, specific heat, and viscosity of a heat transfer fluid other than water shall be determined by one of the following methods.

13.3.1 The fluid properties of a glycol heat transfer fluid may be determined by a refractive index measurement.

a. Determine glycol concentration in percent by volume from the refractive index measurement using data provided by the manufacturer.

b. Determine density and specific heat from the glycol concentration in percent by volume using data provided by the manufacturer or data published in 2021 *ASHRAE Handbook—Fundamentals*[10], Chapter 31, “Physical Properties of Secondary Coolants (Brines).”

13.3.2 The fluid properties of a glycol or other heat transfer fluid may be determined by a density measurement.

a. Determine concentration in percent by volume from the density measurement using data provided by the heat transfer fluid manufacturer or data published in 2021 *ASHRAE Handbook—Fundamentals*[10], Chapter 31, “Physical Properties of Secondary Coolants (Brines).”

b. Determine specific heat from the concentration in percent by volume using data provided by the heat transfer fluid manufacturer or data published in 2021 *ASHRAE Handbook—Fundamentals*[10], Chapter 31, “Physical Properties of Secondary Coolants (Brines).”

13.3.3 Viscosity. If viscosity is a required parameter for flow measurement, use data provided by the heat transfer manufacturer or data published in 2021 *ASHRAE Handbook—Fundamentals*[10], Chapter 31, “Physical Properties of Secondary Coolants (Brines).”

14. TEST METHOD 3 – TEST EXECUTION

14.1 Initialization. Before any testing is performed, the thermal storage device shall have been initialized as specified in Section 11.1.

14.2 Concurrent Testing. At the option of the test authority, the discharge test, the cool-storage system capacity test, and the cool-storage system efficiency test may be conducted concurrently.

14.3 Discharge Test

14.3.1 This test is intended to measure the amount of cooling energy that can be delivered from the thermal storage device to meet the specified load profile. The boundary of the thermal storage device under test shall be defined by the test authority in accordance with Section 13.1.3.

14.3.2 The discharge test shall begin with the thermal storage device in the fully charged condition.

14.3.3 Return fluid shall be supplied to the thermal storage device at the rate and at the temperatures determined by the method given in Section 13.2.2. The intent of the test is to subject the system to a load profile as close as possible to the specified load profile. Acceptable deviations from specified conditions shall be determined by the method given in Section 13.2.2.

Hour	Load		Cumulative Discharge		Notes
	kW	Tons	kWh	Ton-hours	
1	314	89	314	89	Pulldown
2	156	44	471	134	
3	314	89	785	223	
4	631	179	1416	403	
5	789	224	2205	627	
6	947	269	3152	896	
7	1026	292	4178	1188	Maximum
8	947	269	5125	1458	
9	789	224	5914	1682	Critical
10	552	157	6465	1839	
11	235	67	6701	1906	Final

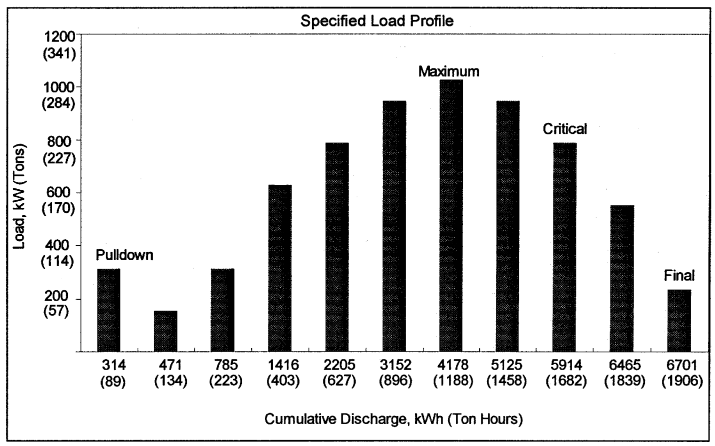


Figure 6 Example load profile for discharge test-specified load profile.

Hour	Load		Cumulative Discharge		Notes
	kW	Tons	kWh	Ton-hours	
1	285	81	285	81	Pulldown
2	176	50	461	131	
3	299	85	759	216	
4	598	170	1357	386	
5	791	225	2148	611	
6	932	265	3080	876	
7	932	265	4012	1141	Maximum
8	932	265	4943	1406	
9	721	205	5664	1611	Critical
10	510	145	6174	1756	
11	214	61	6389	1817	Final

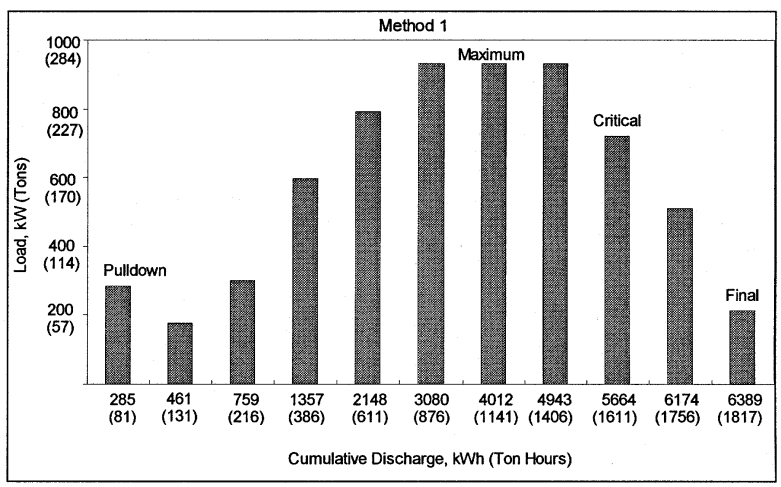


Figure 7 Example load profile for discharge test-equivalent by Method 1 (preferred).

Hour	Load		Cumulative Discharge		Corresponding Hour in Specified Load Profile	Notes
	kW	Tons	kWh	Ton-hrs		
1	285	81	285	81	1	Pulldown
2	211	60	496	141	3	
3	281	80	777	221	3	
4	422	120	1199	341	4	
5	527	150	1726	491	5	
6	615	175	2342	666	6	
7	703	200	3045	866	6	
8	932	265	3977	1131	7	Maximum
9	615	175	4592	1306	8	
10	615	175	5207	1481	9	
11	721	205	5928	1686	10	Critical
12	422	120	6350	1806	10	
13	214	61	6564	1867	11	Final

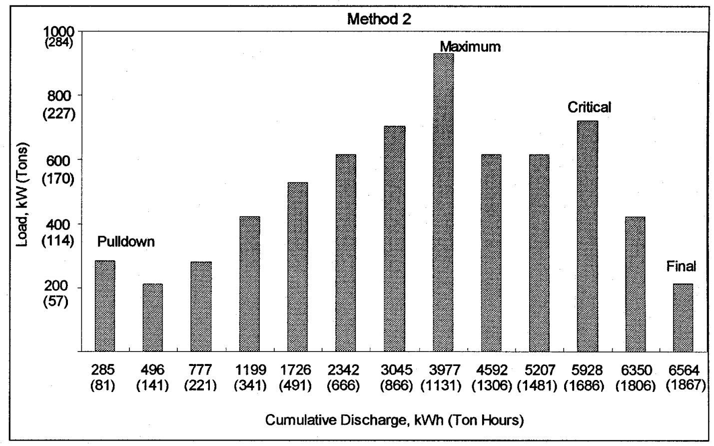


Figure 8 Example load profile for discharge test-equivalent by Method 2 (alternate).

14.3.4 The discharge test shall continue until the thermal storage device reaches the fully discharged condition, as specified under Section 11.3(k) or until the time available for discharging has elapsed.

14.3.5 Data shall be recorded as specified in Section 15.2.

14.3.6 The total discharge capacity shall be calculated as specified in Section 16.2.

14.4 Charge Test

14.4.1 This test is intended to measure the amount of cooling that can be stored in the thermal storage device within the time period available for charging. The boundaries of the thermal storage device under test shall be defined by the test authority in accordance with Section 13.1.3.

14.4.2 The charge test shall begin with the thermal storage device in the fully discharged condition.

14.4.3 Chilled fluid shall be supplied to the thermal storage device at the rate and at the temperatures determined by the method given in Section 13.2.3.

14.4.4 The charge test shall continue until the thermal storage device reaches the fully charged condition or until the maximum allowable charging period has elapsed.

14.4.5 Data shall be recorded as specified in Section 15.3.

14.4.6 The total charge capacity shall be calculated as specified in Section 16.3.

14.5 Cool-Storage System Capacity Test

14.5.1 This test is intended to measure the ability of the system to deliver cooling to the load. The boundary of the system under test shall be defined by the test authority in accordance with Section 13.1.2.

14.5.2 The cool-storage system capacity test shall begin with the thermal storage device in either the fully charged condition or the fully discharged condition.

14.5.3 Chilled fluid shall be supplied from the system at the rate and at the temperatures determined by the method given in Section 13.2.4.

14.5.4 Run the system through a complete cycle based on the specified load profile. This cycle shall include charging, discharging, chiller-only operations, and any non-cooling or idle periods. The condition of the storage device at the end of the cycle shall be the same as at the beginning of the cycle.

14.5.5 Data shall be recorded as specified in Section 15.4.

14.5.6 The system capacity shall be calculated as specified in Section 16.4.

14.6 Cool-Storage System Efficiency Test

14.6.1 This test is intended to measure the cycle-specific energy use of the system while meeting the specified load profile. The boundary of the system under test shall be defined by the test authority in accordance with Section 13.1.2.

14.6.2 Follow the steps given in Sections 14.5.2 through 14.5.4 for the cool-storage system capacity test.

14.6.3 Measure the input energy of the components specified under Section 11.3(e).

14.6.4 Data shall be recorded as specified in Section 15.5.

14.6.5 The cycle-specific energy use shall be calculated as specified in Section 16.5.

15. TEST METHOD 3 – DATA TO BE RECORDED

15.1 General. Record all measurements at the time intervals specified in Section 12.7. Record the time of each measurement to the nearest second. For each test, record the following quantities at the time intervals specified in Section 12.7:

a. Dry-bulb temperature surrounding the thermal storage device

b. Liquid level in thermal storage device (if applicable)

c. Vertical thermal storage device array temperatures (if applicable)

15.2 Discharge Test. Record average values of the following quantities at the time intervals specified in Section 12.7:

a. F2—Fluid flow rate through the thermal storage device

b. T3—Fluid temperature entering the thermal storage device

c. T4—Fluid temperature leaving the thermal storage device

15.3 Charge Test. Record average values of the following quantities at the time intervals specified in 12.7:
a. F2—Fluid flow rate through the thermal storage device

b. T3—Fluid temperature entering the thermal storage device

c. T4—Fluid temperature leaving the thermal storage device

If the specified load profile calls for loads to be met during charging, record average values of the following additional quantities at the time intervals specified in Section 12.7:

a. F3—Fluid flow rate to the load

b. T5—Fluid temperature entering the load

c. T6—Fluid temperature leaving the load

15.4 Cool-Storage System Capacity Test. Record average values of the following quantities at the time intervals specified in Section 12.7:

a. F1—Fluid flow rate through the system under test

b. T1—Fluid temperature leaving the system under test

c. T2—Fluid temperature entering the system under test

15.5 Cool-Storage System Efficiency Test. Record average values of the following quantities at the time intervals specified in Section 12.7:

a. F1—Fluid flow rate through the system under test

b. T1—Fluid temperature leaving the system under test

c. T2—Fluid temperature entering the system under test

d. *Ein*—Input energy for each component specified under Section 5.3(e)

16. TEST METHOD 3 – CALCULATION OF RESULTS

16.1 Nomenclature, Symbols, and Subscripts

ρ = density, kg/m3 (lb/ft3)
cp = specific heat, kJ/kg·K (Btu/lb·°F)
$F1,i$ = fluid flow rate through the cool storage system, L/s (gpm), average for recording interval *i*
$T1,i$ = fluid temperature leaving the cool storage system, °C (°F), average for recording interval *i*
$T2,i$ = fluid temperature entering the cool storage system, °C (°F), average for recording interval *i*
$F2,i$ = fluid flow rate through the thermal storage device, L/s (gpm), average for recording interval *i*
$T3,i$ = fluid temperature entering the thermal storage device, °C (°F), average for recording interval *i*
$T4,i$ = fluid temperature leaving the thermal storage device, °C (°F), average for recording interval *i*
Qdisch,i = cooling energy discharged from storage, kWh*T* (ton-hour), for recording interval *i*
Qdisch,j = cooling energy discharged from storage, kWh*T* (ton-hour), for hour *j*
Qdisch = total cooling energy discharged from storage, kWh*T* (ton-hour), for discharge test
Qcharge,i = cooling energy charged in storage, kWh*T* (ton-hour), for recording interval *i*
Qcharge,j = cooling energy charged in storage, kWh*T* (ton-hour), for hour *j*
Qcharge = total cooling energy charged in storage, kWh*T* (ton-hour), for charge test
Qsys,i = cooling energy supplied to the load, kWh*T* (ton-hour), for recording interval *i*
Qsys,j = cooling energy supplied to the load, kWh*T* (ton-hour), for hour *j*
Qsys = total cooling energy supplied to the load, kWh*T* (ton-hour), for cool-storage system capacity test

Espec = cycle-specific energy use, kWh*E*/kWh*T* (kWh*E*/ton-hour)
Ein = input energy of thermal storage system components, kWh*E* or kWh*T* (Btu)
η*stor* = storage efficiency
tD = number of hours in discharge test
tC = number of hours in charge test
tS = number of hours in cool-storage system capacity test or cool-storage system efficiency test
tri = recording interval, minutes
Nri = number of recording intervals per hour
Nri = 60/*tri* (*Nri* is an integer)
*C*1 = unit conversion constant
SI: *C*1 = (3600 kJ/kWh*T*)(1000 L/m3)/(60 s/min) = 60,000
IP: *C*1 = (12,000 Btu/ton·h)(7.48 gal/ft3) = 89,760

16.2 Calculation of Discharge Capacity from Temperature and Flow Measurements

$$Q_{dish,i} = \frac{\rho c_p t_{ri} F_{2,i}(T_{4,i} - T_{3,i})}{C_1} \qquad (13)$$

$$Q_{disch,j} = \sum_{i=1}^{N_{ri}} Q_{disch,i} \qquad (14)$$

$$Q_{disch} = \sum_{j=1}^{t_D} Q_{disch,j} \qquad (15)$$

16.3 Calculation of Charge Capacity from Temperature and Flow Measurements

$$Q_{charge,i} = \frac{\rho c_p t_{ri} F_{2,i}(T_{4,i} - T_{3,i})}{C_1} \qquad (16)$$

$$Q_{charge,j} = \sum_{i=1}^{N_{ri}} Q_{charge,i} \qquad (17)$$

$$Q_{charge} = \sum_{j=1}^{t_C} Q_{charge,j} \qquad (18)$$

16.4 Calculation of Cool-Storage System Capacity from Temperature and Flow Measurements

$$Q_{sys,i} = \frac{\rho c_p t_{ri} F_{1,i}(T_{2,i} - T_{1,i})}{C_1} \qquad (19)$$

$$Q_{sys,j} = \sum_{i=1}^{N_{ri}} Q_{sys,i} \qquad (20)$$

$$Q_{sys} = \sum_{j=1}^{t_S} Q_{sys,j} \tag{21}$$

16.5 Calculation of Cycle-Specific Energy Consumption

$$E_{spec} = \frac{\sum E_{in}}{Q_{sys}} \tag{22}$$

where

• Ein is expressed in units of kWhE or kWhT (kWhE or Btu);
• $\sum Ein$ is the total measured energy use of all equipment in the cool-storage system, as defined in Section 5.3(e);
• $Qsys$ is the total cooling energy delivered to the load, from Equation 21; and
• $\sum Ein$ and $Qsys$ are both measured over one or more complete storage cycles.

16.6 Calculation of Storage Efficiency

$$\eta_{stor} = \frac{Q_{disch}}{Q_{charge}} \tag{23}$$

where $Qdisch$ and $Qcharge$ are measured during consecutive discharge and charge periods, which together make up one or more complete storage cycles that begin and end with the storage device at the same condition.

17. TEST REPORT

The data obtained during the application of the standard shall be reported on a standard form. The layout of the form shall be as detailed in Appendix C or an equivalent format. Data in addition to that shown in Appendix C may be provided at the discretion of the owner, design engineer, or testing professional. These data shall be included separately and not as part of the standard form.

For Test Method 3, the party performing the test shall certify on each test report form that the test has been performed in accordance with Test Method 3 of this standard. If any part of the test, including instrument accuracy, test conditions, procedures, or other, has not satisfied some provision of the standard, the party performing the test shall provide an explanation of the discrepancy as part of the test report.

18. REFERENCES

1. ASHRAE Terminology On-Line. http://www.ashrae.org/ashraeterms

2. ASME. 2013. ANSI/ASME PTC 19.1, *Test Uncertainty*. New York: The American Society of Mechanical Engineers.

3. ASHRAE. 2020. ANSI/ASHRAE Standard 41.1, *Standard Method for Temperature Measurement*. Atlanta: ASHRAE.

4. ASHRAE. 2016(RA 2019) ANSI/ASHRAE Standard 41.8, *Standard Methods of Measurement of Flow of Liquids in Pipes Using Orifice Flowmeters*. Atlanta: ASHRAE.

5. ISA. 1977. RP31.1, *Recommended Practice Specification, Installation, and Calibration of Turbine Flowmeters*. Research Triangle Park, NC: International Society for Measurement and Control.

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11. ASHRAE. 2020. ANSI/ASHRAE Standard 125, *Method of Testing Thermal Energy Meters for Liquid Streams in HVAC Systems*. Atlanta: ASHRAE.

(This appendix is not part of this standard. It is merely informative and does not contain requirements necessary for conformance to the standard. It has not been processed according to the ANSI requirements for a standard and may contain material that has not been subject to public review or a consensus process.)

INFORMATIVE APPENDIX A FOR METHOD 3 AND REFERENCE FOR METHODS 1 AND 2 DISCUSSION OF FLUID FLOW MEASUREMENT METHODS

A1. INTRODUCTION

Choosing a flowmeter for a particular application requires knowledge of the following:

a. Accuracy required

b. Fluid type and its properties, including temperature, density, pressure, viscosity, cleanliness of the fluid (turbidity), and levels of aeration

c. Flow conditions the meter is to encounter, including the range of expected flow velocities and flow profile at the point of measurement

d. Budget available

In general, flow sensors can be grouped into four different meter types:

a. Differential pressure flowmeters (e.g., orifice plate meter, venturi meter, pitot tube meter)

b. Obstruction flowmeters (e.g., variable-area meter, positive displacement meter, turbine meter, tangential paddlewheel meter, target meter, vortex meter, insertion magnetic meter)

c. Noninterfering meters (e.g., ultrasonic meter, full-bore magnetic meter)

d. Mass flowmeters (e.g., Coriolis mass flowmeter, angular momentum mass flowmeter)

While there are specific applications for each of these metering technologies, this section discusses the most common liquid flow measurement devices that are used in conjunction with temperature measurements to determine the thermal energy in a fluid flow. Differential pressure flowmeters will not be discussed due to the extensive availability of literature on the subject.

A2. OBSTRUCTION SAMPLING-TYPE FLOWMETERS

Several types of obstruction sampling-type flowmeters have been developed that are capable of providing a linear output signal over a wide range of flow rates, often without the severe pressure-loss penalty that is incurred with orifice plate or venturi meters. These include the variable-area meter, positive displacement meter, axial turbine meter, tangential paddle-wheel meter, target meter, vortex meter, and insertion magnetic meter. In general, these meters place a much smaller target, weight, spinning wheel, or sensor in the flow stream that allows the velocity of the fluid to be determined. The information gathered is representative only of the sampled flow. Care in calibration and installation must be given to ensure that the sampled flow velocity can be accurately related to the average flow velocity.

A2.1 Axial Turbine Meters. Axial turbine meters measure fluid flow by counting the rotations of the rotor that is placed in a flow stream. Axial turbine meters can be full-bore type or insertion type. Full-bore turbine meters have an axial rotor and a housing that is sized for a specific installation.

Turbine insertion meters allow the axial turbine to be inserted into the fluid stream and use the existing pipe as the meter body. These types of meters can be hot-tapped into existing pipes through a valving system without having to shut down the system.

The insertion turbine meter may have one or two turbines. The single turbine only measures the fluid velocity at a small cross-sectional area of the flow. Therefore, total volumetric flow rate can only be accurately inferred if the meter location provides fully developed flow conditions with minimal rotational or skew components. The manufacturer's specifications rely on providing these conditions. This type of flow is typically found in long, straight sections of pipe with stable flow conditions.

A dual turbine insertion meter offers the advantage of counter-rotating turbines, thereby reducing the impacts of rotational flow while increasing the cross-sectional area observed.

Insertion meters can be used on pipes above 50 mm (2 in.) diameter with very low-pressure loss. The rate of rotation of the turbine, driven by the fluid, provides an output that is linear with flow rate over a wide range. This output can usually be obtained either as a signal pulse representing a quantity of fluid flow or as a frequency or analog signal proportional to flow rate. Though they are somewhat vulnerable to large debris in the flow stream, insertion turbine meters offer excellent accuracy at a reasonable price.

A2.2 Vortex Meters. Vortex meters utilize the same physical effect that makes telephone wires oscillate in the wind between telephone poles. This effect is due to oscillating instabilities in fluid flow after it splits into two streams around a blunt object. Vortex meters have no moving parts and are suitable for gas, steam, or liquid flow measurements. They require minimal maintenance and have good accuracy and long-term repeatability. Vortex meters provide a linear digital or analog output.

A2.3 Insertion Magnetic Meters. Insertion magnetic meters use Faraday's law of electromagnetic induction to facilitate the measurement of sampled flow. Insertion magnetic meters are available with single or multiple sensors per probe. Greater accuracy can be obtained if multiple probes are used at each measurement location. They offer excellent accuracy at a reasonable price and are typically provided with analog outputs.

A3. NONINTERFERING FLOWMETERS

In all of the previously mentioned meters, some interference with the flow stream was necessary to extract a measurement. A relatively new class of meters has been developed that are able to extract a measurement without placing an obstruction into the fluid stream.

A3.1 Ultrasonic Flowmeters. Two basic types of ultrasonic flowmeters available for general use are transit time and Doppler. Transit-time ultrasonic flowmeters measure fluid velocities by detecting small differences in the transit time of sound waves that are projected across a fluid stream. Various designs have been developed that use multiple pass and multiple path configurations. Clamp-on ultrasonic flowmeters have been developed that now facilitate rapid measurement of fluid velocities in pipes of varying sizes. Typical levels of manufacturers' stated flow uncertainty are 1% to 3% of actual flow, 5% of actual flow in pipe diameters less than 300 mm (12 in.), or 2% of full scale.

Doppler ultrasonic flowmeters measure fluid velocities by sensing the velocity of small particles or air bubbles entrained in the fluid with sound waves that are shot at an angle across a fluid stream. Such meters require a certain amount of particles and air in the fluid to reflect the signal for detection by the receiver.

Doppler-effect meters are available with stated flow uncertainties between 2% and 5% of full scale and are normally less expensive than transit-time ultrasonic meters.

It should be noted that ultrasonic flowmeters are difficult to field calibrate. These meters are velocity-dependent devices and are highly vulnerable to errors caused by poor pipe and flow conditions and by improper installation techniques, as are the obstruction types of flowmeters. The use of manufacturer's stated accuracy for field applications can be risky. The uncertainty in the flow measurement should be considered to be 5% at best for pipe diameters less than 300 mm (12 in.) when pipe and flow conditions are unknown. The larger the diameter of pipe, the less vulnerable the measurement is to unknown pipe or flow conditions. Greater confidence can be placed in the measured data when stable flow conditions are verified.

A3.2 Full-Bore Magnetic Flowmeters. Magnetic flowmeters use Faraday's law of electromagnetic induction to measure the average flow velocity in a pipe. Magnetic coils surround the flow, using a pulsed DC or AC generated field to produce a signal. The signal is proportional to the average velocity in the pipe and is nearly unaffected by flow profile. Manufacturers of pulsed DC excited magnetic flowmeters have a stated flow uncertainty of 1% within a 10:1 turndown if flow velocity is greater than 0.15 m/s (0.5 ft/s). AC excited magnetic flowmeters have a stated flow uncertainty of 1% to 2% full scale.

A4. THERMAL PRODUCT ENERGY USE MEASUREMENTS

An accurate thermal product energy use measurement requires a calibrated flowmeter, density and specific heat constants for the fluid being measured, and temperature measurements for the supply and return temperatures.

One method of recording the thermal product energy use (e.g., the cooling provided by the building chillers) is with an energy meter. An energy meter, either as a standalone device or as part of a larger recording system, performs an internal energy flow calculation in real time based on inputs from a flowmeter and supply and return temperature sensors. With stable specific heat and density constants and accurate sensors, electronic energy meters can offer accuracy better than 3%. These meters are most attractive on larger or more-critical installations where accuracy is a prime concern. A side benefit is the availability of real-time operating data, such as flow rate, supply and return temperatures, and thermal product rate. Many also offer totalization. When measuring the narrow differential temperature (°T) range typical of chilled water systems, the two temperature sensors should be matched or calibrated to the tightest tolerance possible. For the purpose of computing thermal loads in Btu per hour or tons of refrigeration, it is more important that the sensors be matched or calibrated with respect to one another than for their calibration to be traceable to a standard. Attention to this detail will maximize the accuracy of the thermal load computation. Suppliers of temperature sensors can provide sets of matched devices when ordered for this purpose. Typical purchasing specifications are for a matched set of RTD assemblies (each consisting of RTD probe, holder, connection head with terminal strip, and stainless steel thermowell) calibrated to indicate the same temperature within a tolerance of 0.1°C (0.15°F) over the range –5°C to 25°C (25°F to 75°F). A calibration data sheet should be provided with each set.

A5. REFERENCES

Houghton, D. 1996. *Tech Update: Know Your Flow*. Boulder, CO: E Source, Inc.

Liptak, B. (ed.). 2003. *Instrument Engineers' Handbook, Vol. 1: Process Measurement & Analysis, Instrument Engineer's Handbook*, 4th ed. Radnor, PA: Chilton Book Company.

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INFORMATIVE APPENDIX B FOR METHOD 3
EXAMPLE COOL-STORAGE SYSTEM INSTRUMENTATION SCHEMATICS

The figures provided in this appendix show suggested locations of sensors for some cool-storage system configurations. The figures also show the thermal storage device boundary as a shaded area and the cool-storage system boundary as a dotted line. For systems not shown in this appendix, use the general principles of instrumentation placement as applied in this appendix to develop a schematic for the system under test.

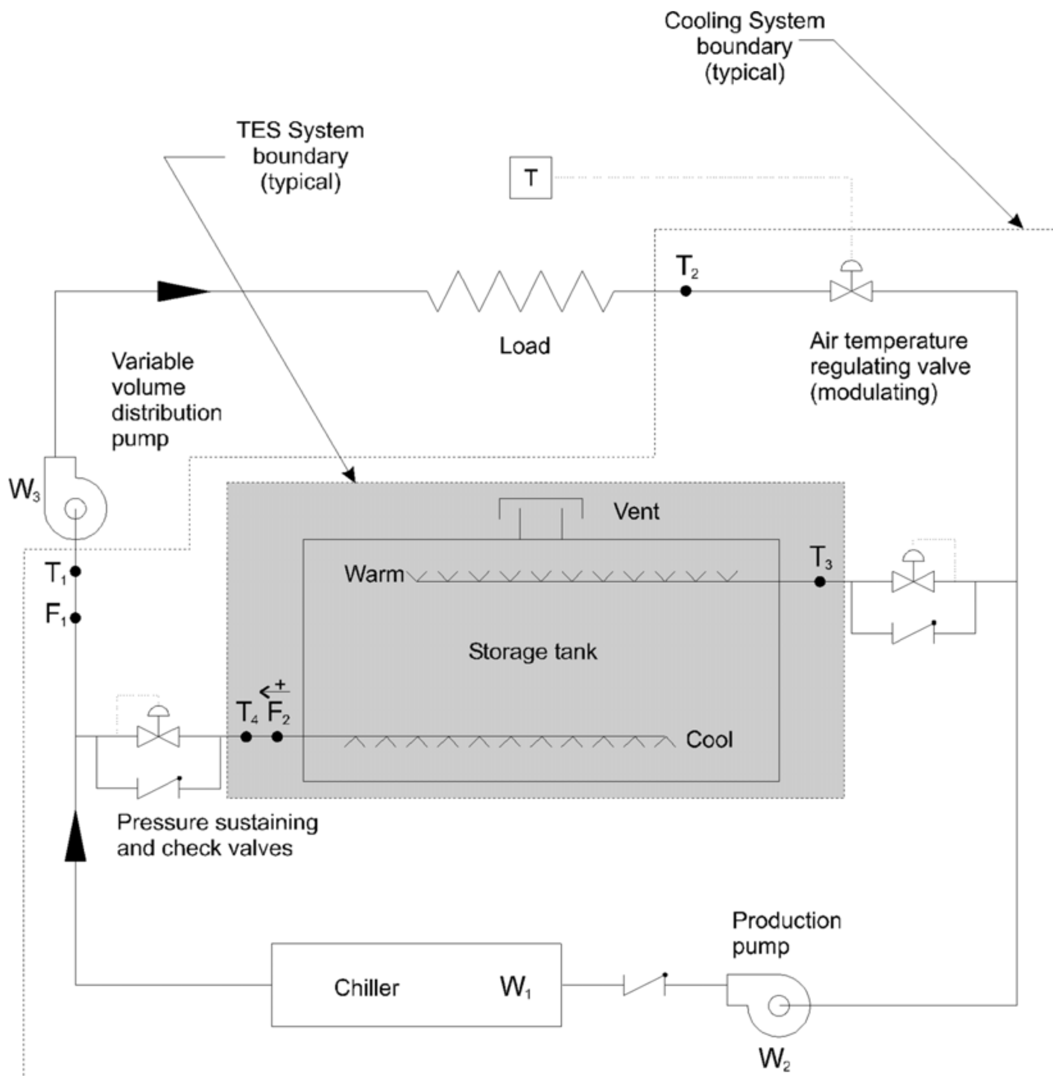


Figure B-1 Basic stratified chilled-water configuration.

Notes:
(1) F_1 may be located upstream of T_2.
(2) F_2 may be located upstream of T_3.
(3) F_2 must be a bidirectional flowmeter.

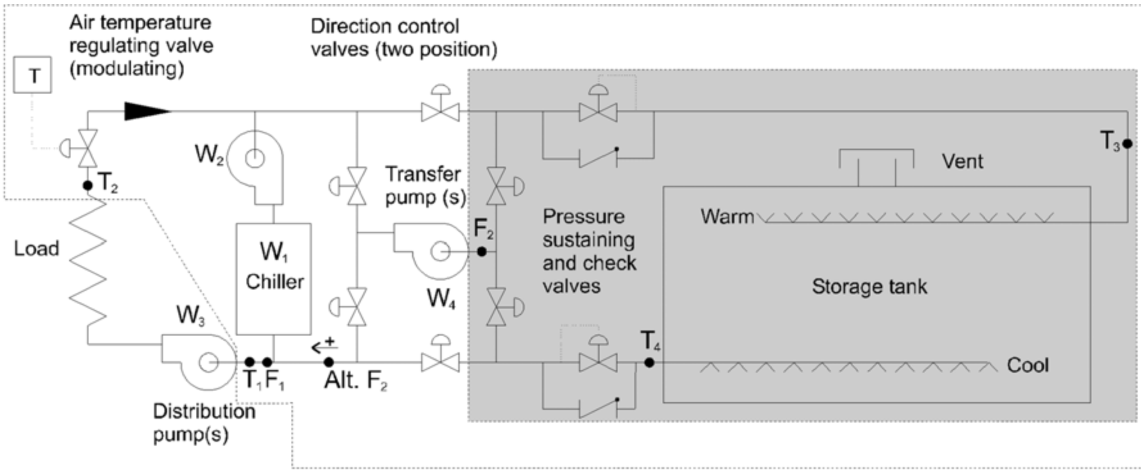


Figure B-2 Pressure control for stratified chilled-water storage.

Note: F_2 must be a bidirectional flowmeter.

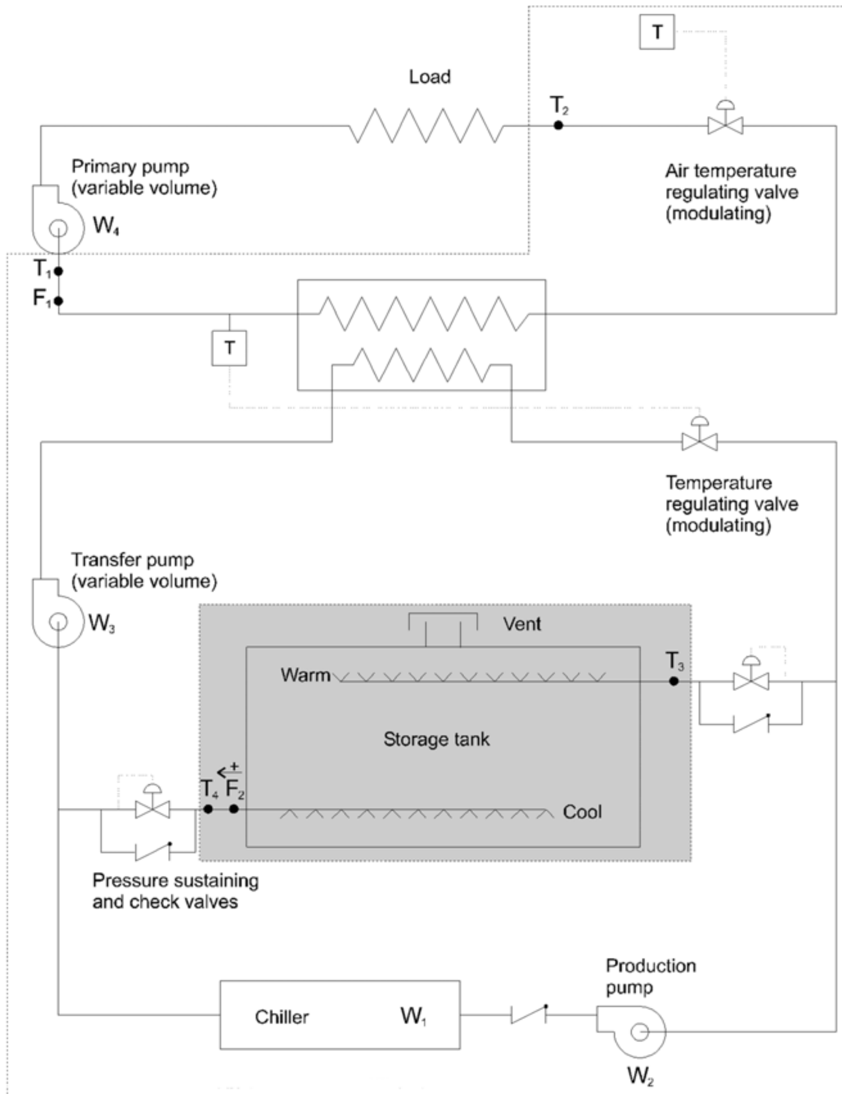


Figure B-3 Basic stratified chilled-water configuration with secondary loop.

Notes:

(1) F_1 may be located upstream of T_2.
(2) F_2 may be located upstream of T_3.
(3) F_2 must be a bidirectional flowmeter.

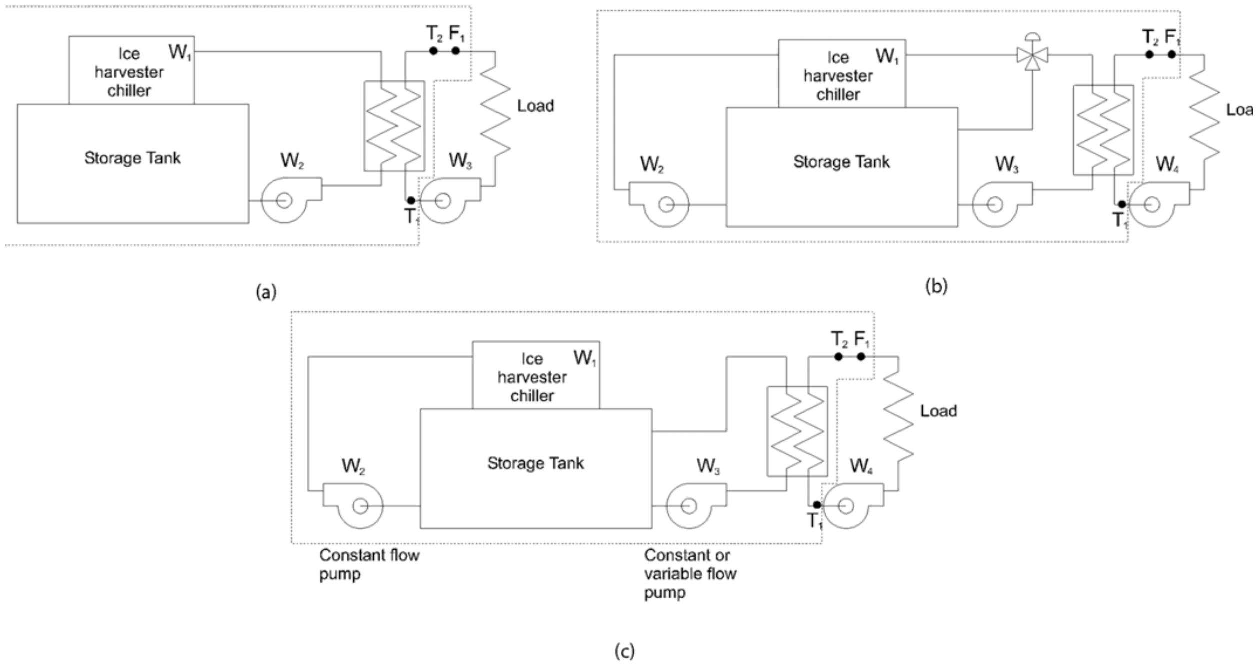


Figure B-4 Three ice harvester pumping configurations: (a) single, constant-flow pump with heat exchanger; (b) dual constant-flow pumps with heat exchanger and bypass to tank during discharge; and (c) dual pumps with heat exchanger and 100% return to tank during discharge cycle.

Notes:

(1) F_1 may be located upstream of T_1.

(2) T_1 and T_2 as is with or without heat exchanger

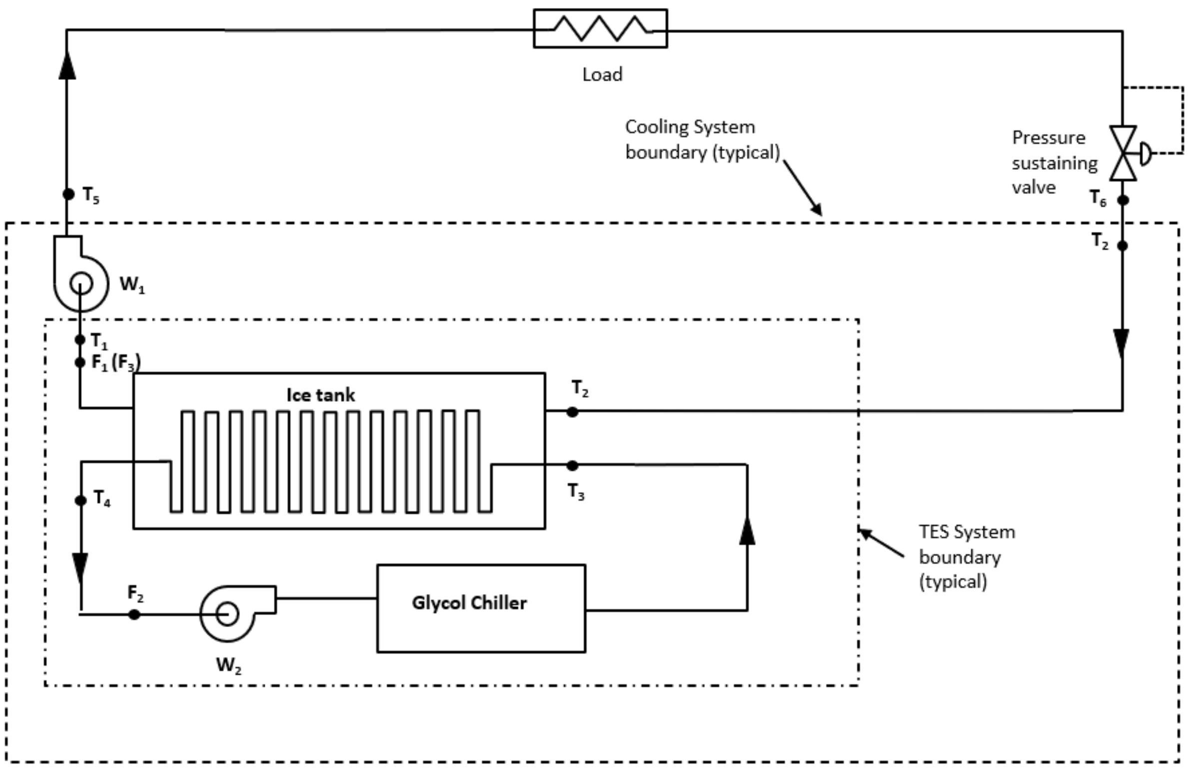
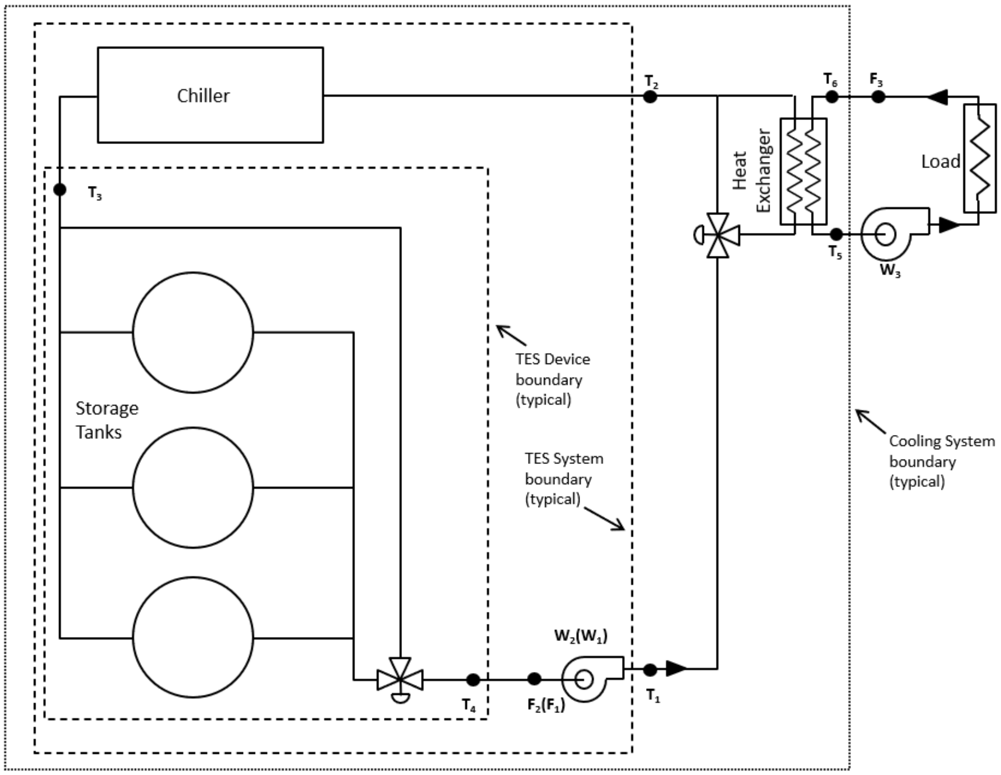
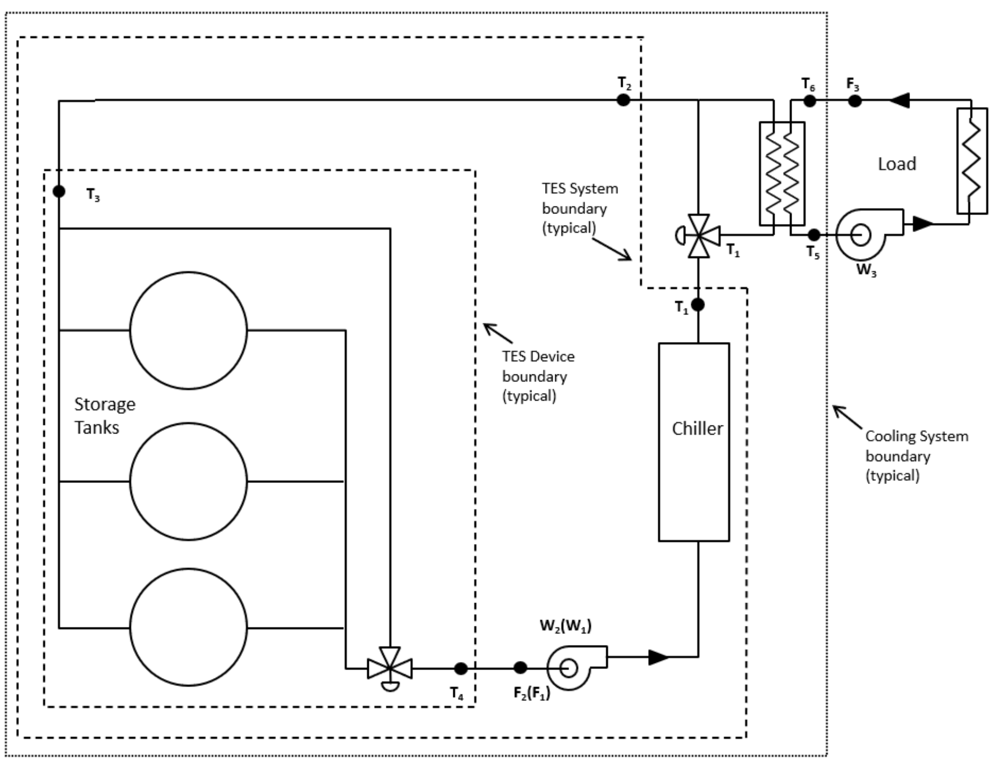


Figure B-5 Secondary coolant external melt ice-on-coil configuration.

Note: F_1 may be located upstream of T_2.



(a)



(b)

Figure B-6 Typical internal melt storage configuration: (a) chiller upstream and (b) chiller downstream.

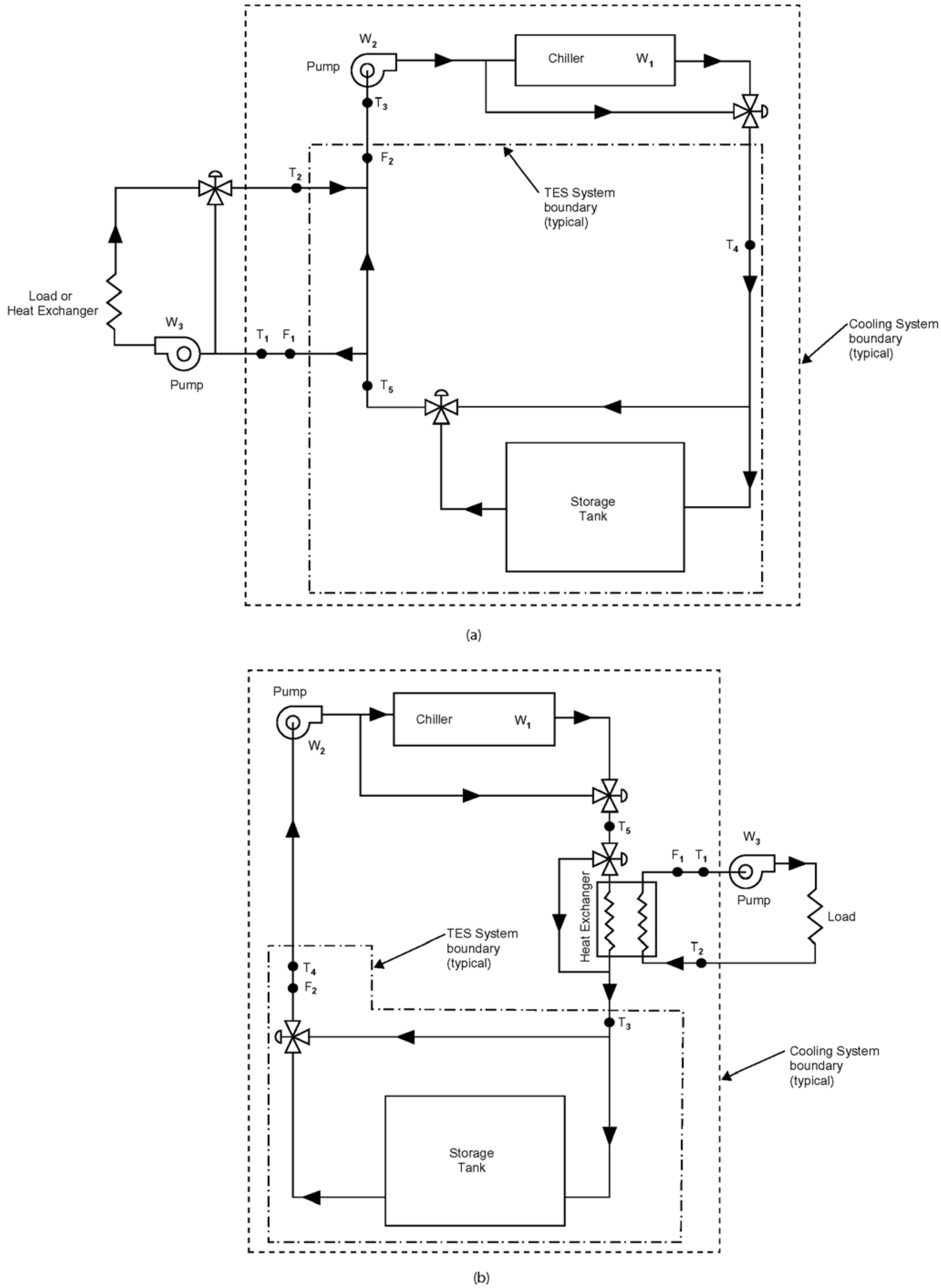


Figure B-7 Typical encapsulated ice configuration (a) chiller upstream and (b) chiller downstream.

(This is a normative appendix and is part of the standard.)

NORMATIVE APPENDIX C FOR METHOD 3 TEST REPORT FORMS

The forms provided in this appendix shall be used for reporting the data obtained in applying the standard.

General Information

Project: ____________________
Client: ____________________
Tester: ____________________ Date: __________
Testing Organization: ____________________

Required Information

□ Test(s) to be performed: ___ Discharge ___ Charge ___ System Capacity ___ System Efficiency [5.3 (a)]

□ Specified load profile (flow rates and supply and return temperature for each hour) [5.3 (b)]. See *Graphical Test Results.*

□ A schematic diagram illustrating system with major components and measuring points and the boundary of the system to be tested for the System Capacity and Efficiency Tests [5.3 (c)]. See *Schematic Drawing.*

□ A description of the intended system operation for the System Capacity Test [5.3 (d)]. See *Test Results.*

□ List of system components whose energy inputs are required for the System Efficiency Test [5.3(e)]. See *Test Results.*

□ Magnitude of the load at the critical discharge point, hour of occurrence and amount of stored cooling relative to the fully charged condition [5.3 (f)]. See *Test Results.*

□ Maximum allowable duration of the charging period [5.3 (g)]. See *Test Results.*

□ Maximum usable discharge temperature [5.3 (h)]. See *Test Results.*

□ Maximum usable cooling supply temperature [5.3 (i)]. See *Test Results.*

□ Criterion for determining the fully charged condition [5.3 (j)].

- □ The temperature leaving the storage tank is less than _____ °C (_____ °F) for a continuous 15-minute period
- □ The height of fluid or ice in the storage tank is greater than _____ cm (_____ inches) for a continuous 15-minute period
- □ An accumulated inventory calculation is greater than _____ kWh_T (_____ ton-hour)

□ Criterion for determining the fully discharged condition [5.3 (k)]

- □ The temperature leaving the storage tank is greater than _____ °C (_____ °F) for a continuous 15-minute period
- □ The height of fluid or ice in the storage tank is less than _____ cm (_____ inches) for a continuous 15-minute period
- □ An accumulated inventory calculation is less than _____ kWh_T (_____ ton-hour)

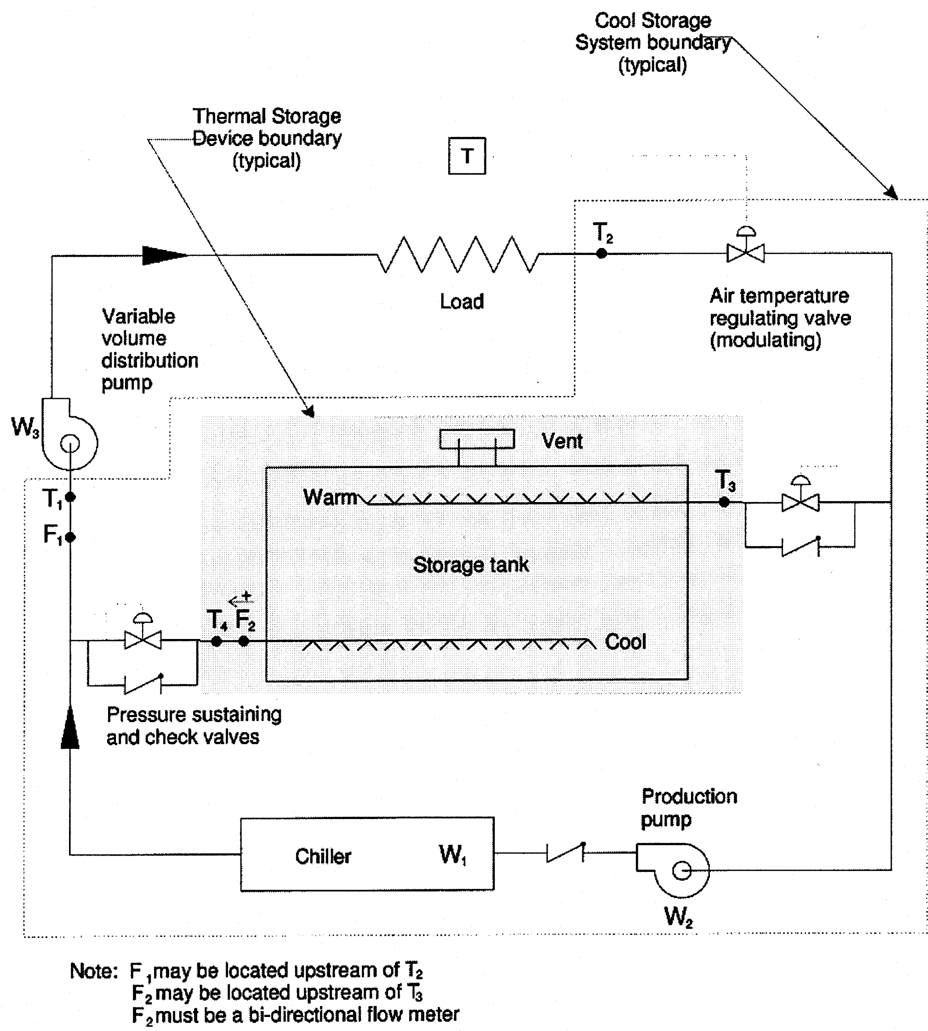
□ Maximum and minimum allowable ambient temperature surrounding the thermal storage device [5.3 (l)]. See Test Results.

For heat transfer fluid other than water, the relationship between the fluid concentration in percent by volume and the refractive index of the fluid as documented by the fluid manufacturer [5.3 (m)]

- ◻ Refractive Index: _______________
- ◻ Specific Gravity: ____________________
- ◻ Manufacturer: _______________________________
- ◻ Fluid: ____________________________

◻ All calibration information on any instruments used - See *Instruments* [5.3 (n)]

Schematic Drawing [5.3 (c)]



Example Schematic Diagram—Basic Stratified Chilled-Water Configuration

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Test Results

Description of the intended system operation for the System Capacity Test [5.3 (d)]

____

____

____

____

List of system components whose energy inputs are required for the System Efficiency Test [5.3 (e)]

____

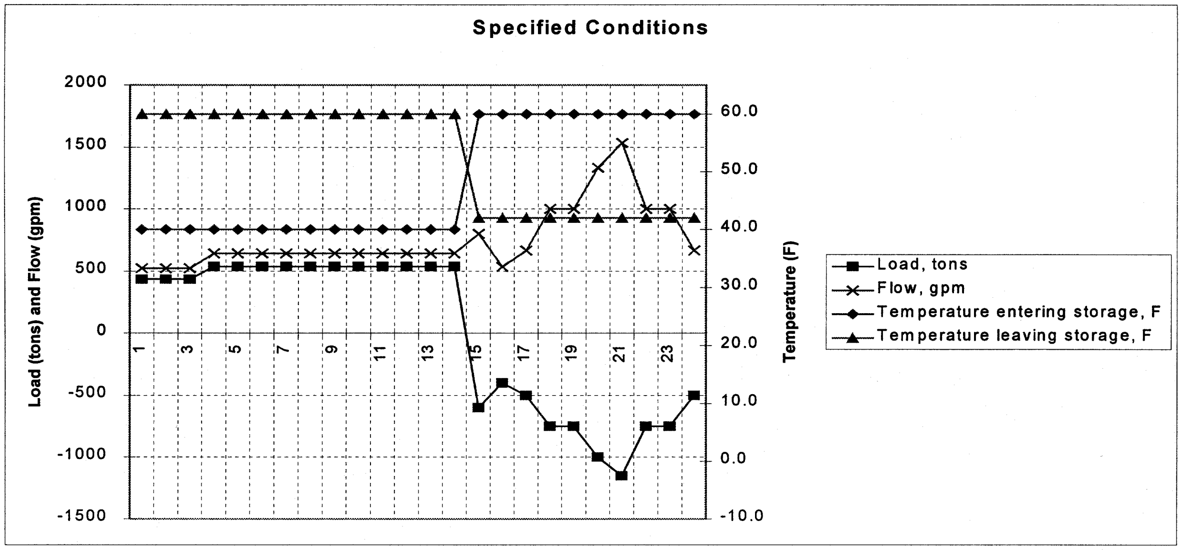
____

____

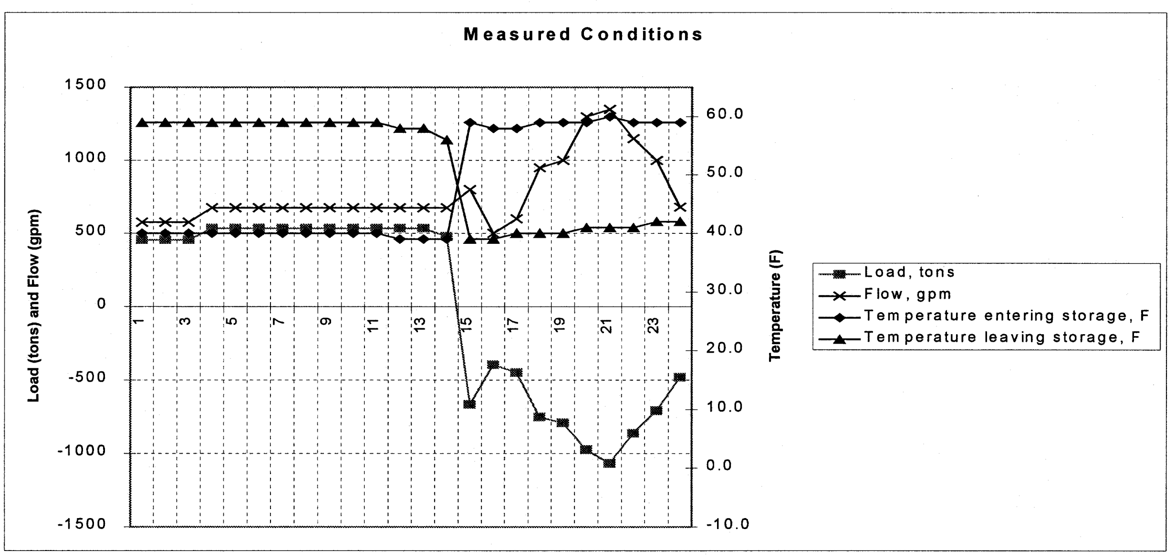
____

	Specified	Measured
Critical discharge point [5.3 (f)]		
Time, hour	________	________
Load, kW_T (ton)	________	________
Stored cooling (relative to fully charged), kWh_T (ton-hr)	________	________
Maximum allowable charging period, hours [5.3 (g)]	________	________
Maximum usable discharge temperature, °C (°F) [5.3 (h)]	________	________
Maximum usable cooling supply temperature, °C (°F) [5.3 (i)]	________	________
Maximum/minimum ambient temperature, °C (°F) [5.3 (l)]	________	________
Discharge capacity, kWh_T (ton-hour)	________	________
Charge capacity, kWh_T (ton-hour)	________	________
Storage efficiency, %	________	________
Charging period (start/finish), hour	________	________
Net usable storage capacity, kWh_T (ton-hour)	________	________
Peak discharge rate, kW_T (ton)	________	________
Pull down load, kW_T (ton)	________	________

Example Results



Hour of Day	18	19	20	21	22	23	24	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Load, Tons	435	435	435	535	535	535	535	535	535	535	535	535	535	535	-600	-400	-500	-750	-750	-1000	-1150	-750	-750	-500
Temperature entering Storage, F	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0
Temperature leaving storage, F	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0
Flow, gpm	522	522	522	642	642	642	642	642	642	642	642	642	642	642	800	533	667	1000	1000	1333	1533	1000	1000	667



Hour of Day	18	19	20	21	22	23	24	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Load, Tons	455	455	455	534	534	534	534	534	534	534	534	534	534	478	-667	-396	-450	-752	-792	-975	-1069	-863	-708	-482
Temperature entering Storage, F	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	39.0	39.0	39.0	59.0	58.0	58.0	59.0	59.0	59.0	60.0	59.0	59.0	59.0
Temperature leaving storage, F	59.0	59.0	59.0	59.0	59.0	59.0	59.0	59.0	59.0	59.0	59.0	58.0	58.0	56.0	39.0	39.0	40.0	40.0	40.0	41.0	41.0	41.0	42.0	42.0
Flow, gpm	575	575	575	675	675	675	675	675	675	675	675	675	675	675	800	500	600	950	1000	1300	1350	1150	1000	680

Instruments

The following instruments were used for this test and for validation (including those used for temperature, pressure, flow, and electric power).

Name	Tag	Instrument Type	Manufacturer	Model	Range	Accuracy	Precision	Resolution*	Calibration Date	Calibration Agency

* Includes data acquisition system conversions

Data acquisition system

Manufacturer ______________________ Model ______________________

\# channels ______________________ Scan rate ______________________

Resolution ______________________

Instruments - Field Calibration and Verification
The following instruments were field calibrated and verified prior to use.

Name	Tag	Instrument Type	Range Applied To	Point 1 Results	Point 2 Results	Point 3 Results	Point 4 Results	Point 5 Results	Calibration Date	Name of Calibrator

Certification

- ☐ This test has been performed in accordance with the requirements of ASHRAE Standard 150P.
- ☐ This test has been performed in accordance with the requirements of ASHRAE Standard 150P, with the following exceptions: (Attach additional pages as necessary)

____

____

____

Tester: ____________________ Signature:________________________ Date:________

NORMITIVE APPENDIX D- CLASSIFICATION OF TES EQUIPMENT

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 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