ANSI/ASHRAE Standard 94.2-2010 (W)

Intent to Withdraw

Method of Testing Thermal Storage Devices with Electrical Input and Thermal Output Based on Thermal Performance

First Withdrawal Review (October 2018)

This standard will be submitted to the American National Standards Institute Board of Standards Review (BSR) with a notice of Intent-to-Withdraw.

This intent-to-withdraw draft has been recommended for public review by the cognizant technical committee and approved by a subcommittee of the Standards Committee. To submit a comment on this proposed withdrawal, go to the ASHRAE website at http://www.ashrae.org/technology/page/331 and access the online comment database. The draft is subject to modification until it is approved for publication by the ASHRAE Board of Directors and ANSI. Until this time, the current edition of the standard (as modified by any published addenda on the ASHRAE Web site) remains in effect. The current edition of any standard may be purchased from the ASHRAE Bookstore at www.ashrae.org or by calling 404-636-8400 or 1-800-527-4723 (for orders in the U.S. or Canada).

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NOTE

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FOREWORD

This is a revision of Standard 94.2-1981 (RA 2006). This standard was prepared under the auspices of the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). It may be used, in whole or in part, by an association or government agency with due credit to ASHRAE. Adherence is strictly on a voluntary basis and merely in the interests of obtaining uniform standards throughout the industry.

The changes made or the 2009 revision were:

- *References were updated*
- *Adding an Informative Annex*
- *Standards referenced in the body of the standard were updated to be consistent with the references section.*

1. PURPOSE

The purpose of this standard is to provide a standard procedure for determining the energy performance of electrically charged thermal energy storage devices used in heating systems.

2. SCOPE

2.1 This standard applies to thermal storage devices that are charged electrically and discharged thermally. The energy may be stored as latent heat or as sensible heat or as a combination of the two.

2.2 The device is charged by electric-resistance heating, and the electric-resistance mechanism is an integral part of, or is located inside, the storage device.

2.3 The device is discharged by a heat transfer fluid that enters the device through a single inlet and leaves the device through a single outlet. Storage devices having more than one inlet and/or outlet may be tested according to this standard, but each flow configuration involving a single inlet and single outlet must be tested separately. This standard is not applicable to those configurations in which there is simultaneous flow into the storage device through more than one inlet and/or simultaneous flow out of the storage device through more than one outlet. The transfer fluid may be either a gas or a liquid or a mixture of the two.

2.4 This standard does not include factors relating to cost, life, reliability, or the consideration of requirements for interfacing with specific heating and cooling systems.

2.5 The test procedure and equipment outlined in this standard are most easily adaptable to devices used to store thermal energy on the order of 10^{11} J (10^8 Btu) or less.

3. DEFINITIONS

The following definitions are stipulated for this document:

ambient air: the air in the space surrounding the central thermal energy storage device or calorimeter.

cycling (latent heat-type storage device): a process in which heat is supplied to and removed from the storage device in a cyclic manner, and the phase of the storage medium is changed twice in each cycle.

discharge capacity: the amount of heat that can be removed from the storage device during a period of time and for a specific set of charging conditions.

standard air: air weighing 1.2 kg/m^3 (0.075 lb/ft^3), which approximates dry air at a temperature of 21.1°C (70°F) and a barometric pressure of 101.3 kPa (29.92 in. of Hg).

standard barometric pressure: the barometric pressure of 101.3 kPa (29.92 in. of Hg) at 0°C (32°F).

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

storage medium: the material in the storage device, independent of the containing structure, in which the major portion of the energy is stored.

transfer fluid: the fluid that carries energy out of the storage device.

4. CLASSIFICATIONS

In this standard, thermal energy storage devices are classified according to the method they use to store energy, the type of transfer fluid they employ, and the usage of the unit.

4.1 Sensible heat-type storage devices are those in which the heat absorbed by or removed from the system results in an increase or decrease in the temperature of the storage medium, and there is no change of phase of any portion of the storage medium. Typical sensible heat-type storage devices employ water, water glycol, natural or artificial stone, and other materials singly or in combination.

4.2 Latent heat-type storage devices are those involving a change of phase of the storage medium. In this type of storage device, most of the heat added to or removed from the system goes into changing the enthalpy of the storage medium during a change of phase process. Some heat is also stored as sensible heat, since charging and discharging of the storage involves a finite change in the temperature of the system.

4.3 Central thermal storage devices are those in which the output is ducted or piped from the device in a "central" location to the space or to heat transfer devices.

4.4 Room thermal storage devices are those in which the storage device is installed within a space or room. The output from the device may be by radiation from the cabinet, by natural convection through the device, by forced convection through the device, or by a combination of radiation and convection.

5. REQUIREMENTS

5.1 Latent heat-type storage devices evaluated under this standard shall have been completely cycled (see definition of cycling) through their change of phase at least 30 times prior to being tested.

5.2 The transfer fluid used in evaluating the performance of a thermal energy storage device shall have a known specific heat that varies by less than ±0.5% over the temperature range encountered during a test.

5.3 The room where the testing of the storage device is performed shall have its temperature controlled to the extent that the average ambient air temperature, t_a, determined by the average of the four temperatures measured as specified in Section 8.6, varies between extremes by less than ±2.0°C (±3.6°F) during a test.

6. INSTRUMENTATION

6.1 Temperature Measurements

6.1.1 Temperature measurements shall be made in accordance with *ANSI/ASHRAE Standard 41.1*.[1]

6.1.2 The temperature difference of the transfer fluid across the thermal storage device may be measured with:

a. thermopiles
b. calibrated resistance thermometers connected in two arms of a bridge circuit (recommended only when a liquid is the transfer fluid)
c. precision thermometers
d. thermistors

6.1.3 The accuracy and precision of the instruments and their associated readout devices shall be within the following limits.

	Instrument Accuracy*	Instrument Precision†
Temperature	± 0.5°C (± 0.9°F)	± 0.2°C (± 0.4°F)
Temperature Difference	± 0.1°C (± 0.2°F)	± 0.1°C (± 0.2°F)

* The ability of the instrument to indicate the true value of the measured quantity.
† Closeness of the agreement among repeated measurements of the same physical quantity.
For definitions of instrument errors see *ASHRAE Guideline 2*.[5]

6.1.4 In no case shall the smallest scale division of the instrument or instrument system exceed two times the specified precision. For example, if the specified precision is ±0.1°C (±0.2°F), the smallest scale division shall not exceed 0.2°C (0.4°F).

6.1.5 The instruments shall be configured and used in accordance with Section 7.

6.1.6 When thermopiles are used, they shall be constructed in accordance with ANSI Standard MC96.1.[2]

6.2 Liquid Flow Measurements. The accuracy of the flow-measuring and associated readout devices shall be equal to or better than ±1.0% of the measured value.

6.3 Airflow Measurements. When air is used as the transfer fluid, airflow rate shall be determined as described in Section 7 using instrumentation described in *ANSI/ASHRAE Standard 37*[3] and *ANSI/ASHRAE Standard 70*.[4]

6.4 Pressure Measurements

6.4.1 Nozzle Throat Pressure. The pressure measurement at the nozzle throat shall be made with instruments that shall permit measurements of pressure to within ±2.0% absolute and whose smallest scale division shall not exceed two times the specified accuracy, see *ANSI/ASHRAE Standard 37*.[3]

6.4.2 Airflow Measurements. The static pressure differences across the nozzle and the velocity pressure at the nozzle throat shall be measured with instruments that have been calibrated and are to within ±1.0% of the reading.

6.4.3 Pressure Drop Across the Thermal Storage Device. The static pressure drop across the thermal storage device shall be measured with a differential pressure-measuring device having an accuracy of ±25 Pa (±0.1 in. of water).

6.5 Time and Mass Measurements. Time measurements and mass measurements shall be made to an accuracy of +0.20% for calibration purposes, see *ANSI/ASHRAE Standard 37*.[3]

6.6 Electrical Measurements. Electrical measurements shall be made with indicating instruments whose accuracy is within ±1.0% of the value being observed.

7. APPARATUS AND METHOD OF TESTING

7.1 Air as the Transfer Fluid (Central Devices)

7.1.1 Test Configuration. The relative positions of the thermal energy storage device, the temperature-measuring instrumentation, the airflow-measuring apparatus, and the differential pressure-measuring apparatus are shown in Figure 1. The figure shows a representative testing configuration using rectangular inlet and outlet ducts of cross section $a \times b$, and $a' \times b'$, respectively. Circular cross sections are also acceptable. A closed-loop test configuration is recommended, although an open loop is acceptable. If a closed loop is used, an air-reconditioning apparatus must be included in the loop in order to maintain the required constant inlet temperature.

7.1.2 Test Ducts. The inlet duct between the airflow-measuring apparatus and the thermal energy storage device shall have the same cross-sectional dimensions as the inlet to the storage device. The outlet test duct between the thermal energy storage device and the temperature-sensing locations shall have the same cross-sectional dimensions as the outlet of the storage device.

7.1.3 Measurement of Temperature Difference Across the Storage Device. The difference between the inlet air temperature and the outlet air temperature of the thermal storage

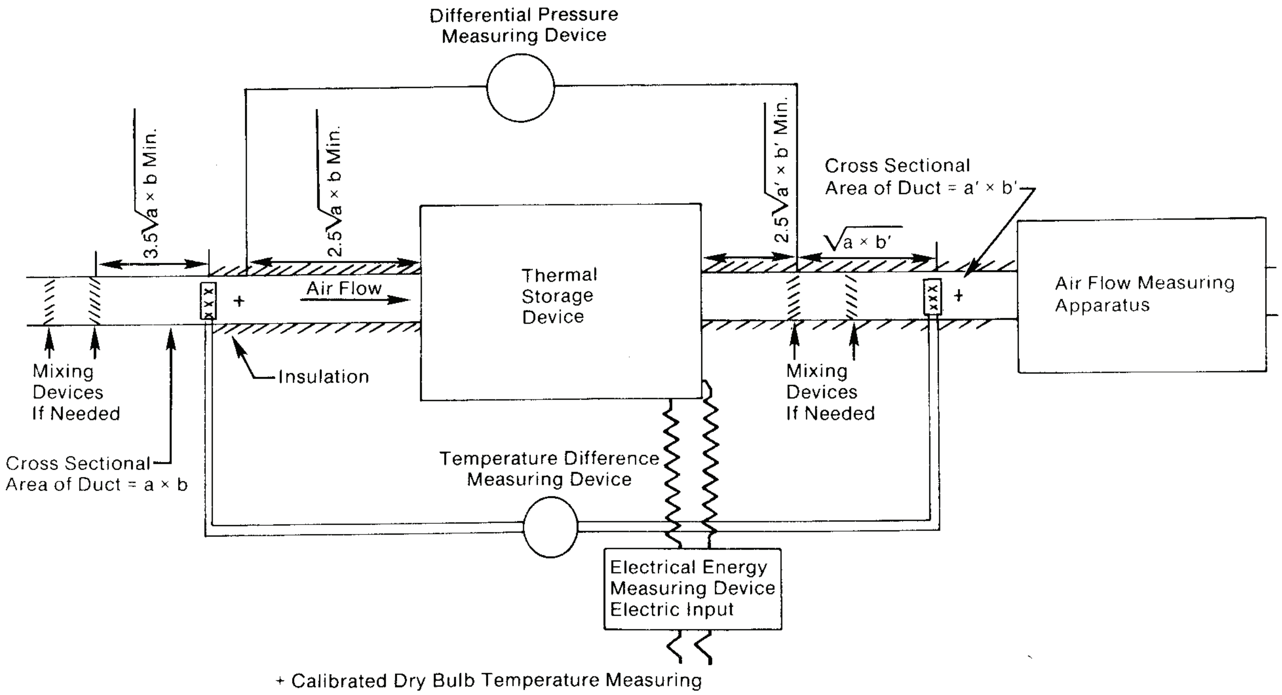

Figure 1 Representative test configuration for a central thermal storage device using air as the transfer fluid.

device shall be measured by means of the apparatus specified in Section 6.1.2. When thermopiles are used, they shall be constructed in their entirety from calibrated thermocouple wire taken from a single spool of wire. No extension wires are to be used in either their fabrication or installation. There shall be an even number of junctions in the air inlet test duct and the same number of junctions in the air outlet test duct as shown in Figure 2. These junctions shall be located at the center of equal cross-sectional areas.

When other methods are used to measure the temperature difference, the applicable procedures of *ANSI/ASHRAE Standard 41.1*[1] shall be followed.

During all tests, the variation in temperature across the air inlet and air outlet test ducts shall be less than ±0.8°C (±1.5°F). The variation shall be checked prior to testing utilizing instrumentation and procedures outlined in *ANSI/ASHRAE Standard 41.1*.[1] If the variation exceeds the limits above, mixing devices shall be installed to achieve this degree of temperature uniformity. Suitable mixing devices are described in *ANSI/ASHRAE Standard 41.1*.[1] Combination mixing and sampling devices specified in that reference are acceptable.

All temperature sensors shall be located as near as possible to the inlet and outlet of the thermal storage device. The air inlet and air outlet ducts shall be insulated in such a manner that the calculated heat loss from these ducts to the ambient air would not result in a temperature change for any test of more than 0.1°C (0.2°F) between the temperature-measuring locations and the storage device.

7.1.4 Dry-Bulb Temperature Measurements. Dry- bulb temperature measurements shall be made at the locations in the air inlet and the air outlet shown in Figure 1 in accordance with Section 4.1 of *ANSI/ASHRAE Standard 41.1*.[1]

7.1.5 Airflow-Measuring Apparatus. The airflow shall be measured with the nozzle apparatus described in Section 5.1 of *ANSI/ASHRAE Standard 70*[4] or in Section 7 of *ANSI/ASHRAE Standard 37*.[3] As shown in Figure 3, this apparatus consists basically of a receiving chamber, a discharge chamber, and an airflow-measuring nozzle. The distance from the center of the nozzle to the side walls shall be less than 1.5 times the nozzle throat diameter, and diffusers shall be installed in the receiving chamber at least 1.5 nozzle throat diameters upstream of the nozzle and 2.5 nozzle throat diameters downstream of the nozzle. The apparatus shall be designed so that the nozzle can be easily changed, and the nozzle used on each test shall be selected so that the throat velocity is between 15 m/s (2690 fpm) and 35 m/s (6900 fpm). Details on nozzle construction and discharge coefficients are described in Section 5.1.1 of *ANSI/ASHRAE Standard 70*.[4]

The dry-bulb and the wet-bulb temperatures of the air entering the nozzle shall be measured in accordance with *ANSI/ASHRAE Standard 41.1*.[1] The velocity of the air passing through the nozzle shall be determined by either measuring the velocity head with a commercially available pitot tube or by measuring the static drop across the nozzle with a differential pressure-measuring device. If the latter method is used, one end of the device shall be connected to a static pressure tap located flush with the inner wall of the receiving chamber and the other end to a static pressure tap located flush with the inner wall of the discharge chamber or, preferably, several taps in each chamber shall be connected through a manifold to a single differential pressure-measuring device. A means shall also be provided for measuring the absolute pressure of the air in the nozzle throat.

7.1.6 Air Leakage. Air leakage through the airflow-measuring apparatus, the air inlet test duct, the thermal storage

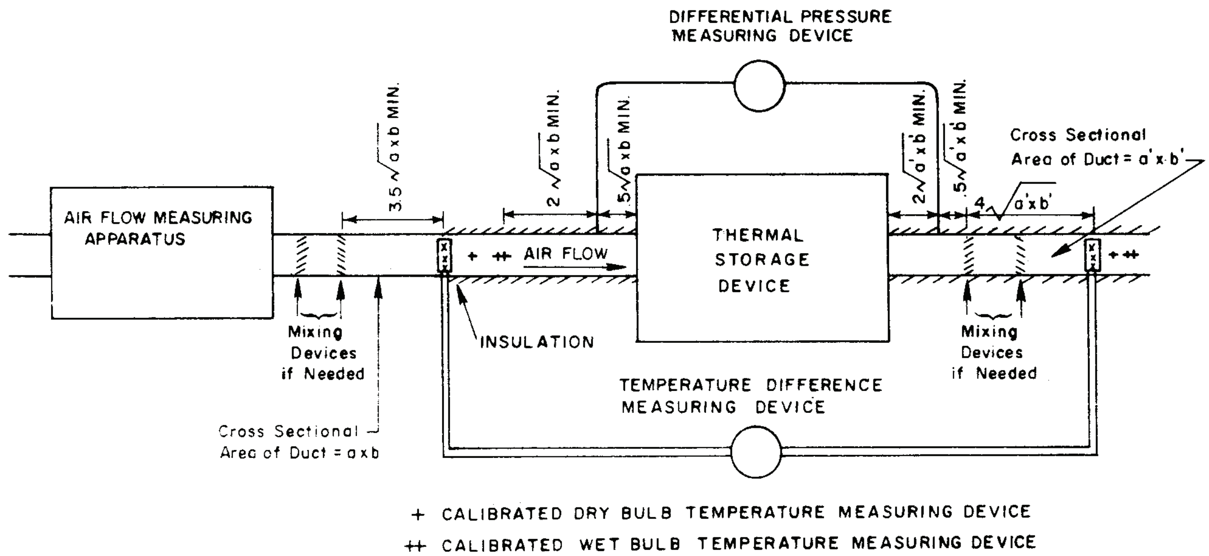

Figure 2 Nozzle apparatus for measuring airflow rate.

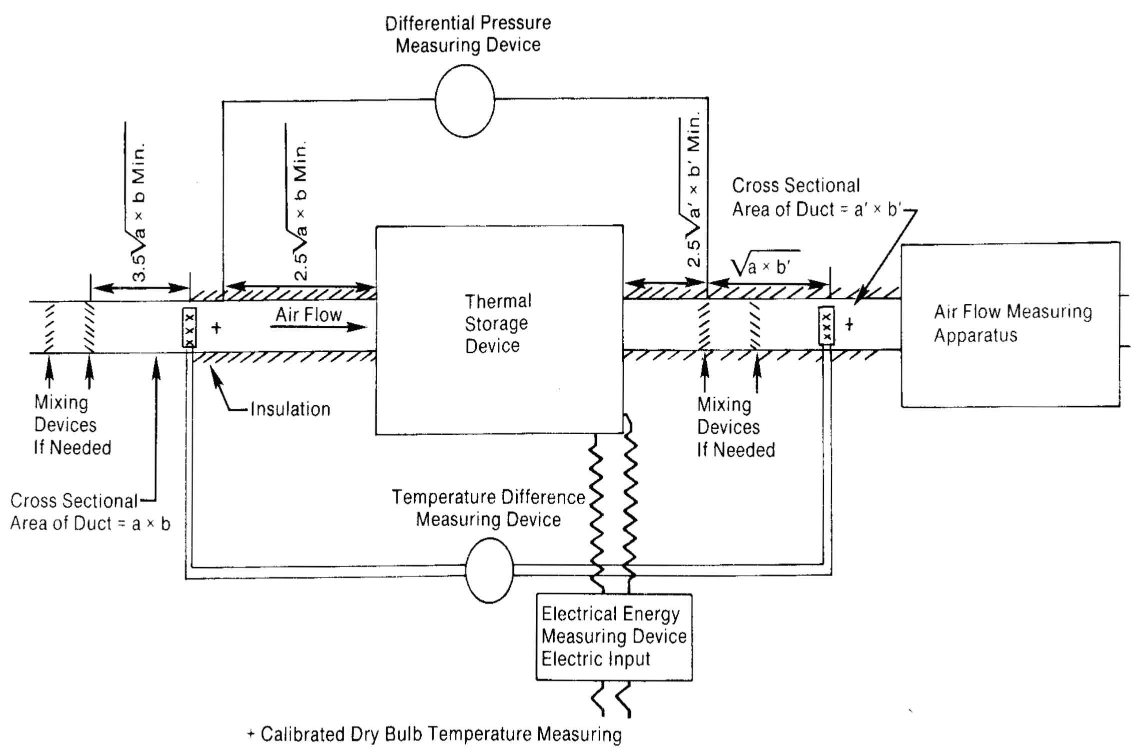

Figure 3 Schematic of the thermopile arrangement used to measure the temperature difference across the thermal storage device.

device, and the air outlet test duct shall be minimized by carefully sealing and taping all joints.

7.1.7 Air-Reconditioning Apparatus. The dry-bulb temperature of the air entering the storage device shall be maintained within ±1.0°C (±1.8°F) of the desired test values at all times during the tests. If necessary, an air-reconditioning apparatus shall be installed in an open-loop test configuration to achieve this. An air-reconditioning apparatus is required in a closed-loop test configuration.

7.2 Liquid as the Transfer Fluid (Central Type Devices)

7.2.1 Test Configuration. The relative positions of the thermal energy storage device, the temperature-measuring instrumentation, the liquid flow-measuring apparatus, and the differential pressure-measuring apparatus are shown in Figure 4. A closed-loop test configuration is recommended, although an open loop is acceptable. If a closed loop is used, a liquid-reconditioning apparatus must be included in the loop.

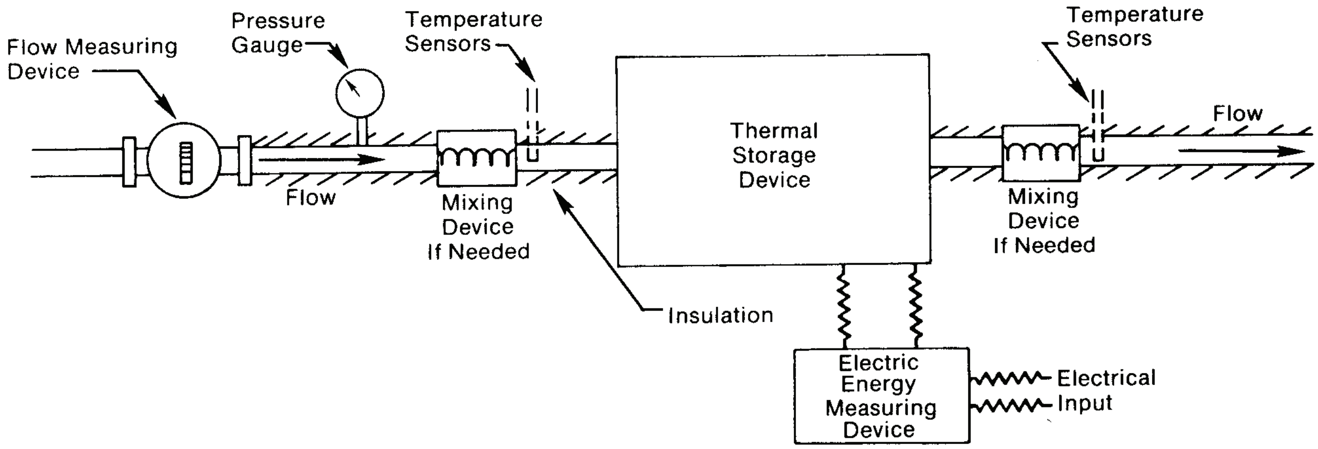

Figure 4 Representative test configuration for a thermal storage device using a liquid as the thermal transfer fluid.

7.2.2 Test Sections. The inlet test section between the liquid flow-measuring apparatus and the thermal energy storage device shall have the same cross-sectional dimensions as the inlet to the storage device. The outlet test section between the thermal energy storage device and the temperature-sensing locations shall have the same cross-sectional dimensions as the outlet of the storage device.

7.2.3 Measurement of Temperature Difference Across the Storage Device. The difference between the inlet liquid temperature and the outlet liquid temperature shall be measured by means of the apparatus specified in Section 6.1.2. When thermopiles are used, they shall be constructed as specified in Section 7.1.3. When other methods are used, the applicable procedures of *ANSI/ASHRAE Standard 41.1*[1] shall be followed.

To minimize temperature measurement error, the temperature-sensing stations shall be located as close as possible to the inlet or outlet of the storage device. In addition, the piping shall be insulated in such a manner that the calculated heat loss from this piping to the ambient air would not cause a temperature change for any test of more than 0.05°C (0.09°F) between each sensor and the storage system.

7.2.4 Measurement of Temperature Levels of the Transfer Fluid. The temperature of the transfer fluid at the two locations cited in 7.2.3 shall also be measured by appropriate sensors. *ANSI/ASHRAE Standard 41.1*[1] shall be followed in making these measurements.

7.2.5 Transfer Fluid-Reconditioning Apparatus. The temperature of the transfer fluid entering the storage system shall be maintained within ±1.0°C (±1.8°F) of the desired test values at all times during the tests. If necessary, a liquid-reconditioning apparatus shall be installed in an open-loop test configuration to achieve this. A liquid-reconditioning apparatus is required in a closed-loop test configuration. The heating and cooling capacity of this apparatus shall be selected so that the temperature of the liquid entering the reconditioning apparatus may be raised or lowered as required in accordance with Section 8.

7.3 Calorimeter (Room Type Devices)

7.3.1 The calorimeter chamber shall be constructed as shown in Figure 5.[6]

7.3.1.1 All surfaces of the calorimeter chamber shall be insulated to a conductance value of 0.4 W/m^2·°C (0.07 Btu/h·ft^2·°F).

7.3.1.2 All joints shall be sealed so that the calorimeter is essentially airtight except for inlet and outlet.

7.3.1.3 The bottom of the calorimeter shall be reinforced to withstand the weight of the device being tested. Thermal breaks shall be provided to minimize heat loss through the support section and the base of the calorimeter.

7.3.1.4 A safety device to prevent overheating shall be provided in the top of the calorimeter. A temperature sensor set at 70°C (160°F) shall cause the safety device to open and the power supply to the device under test to deactivate.

7.3.2 A variable-speed fan shall be provided in the outlet of the calorimeter to allow adjustment of the airflow rate. Variation of airflow over the range of approximately 0-1200 L/s (0-2500 ft^3/min) should be provided.

Fan speed measurements shall be made with instruments whose accuracy is within ±2.5% of the value being observed.

7.3.3 A thermopile shall be provided in the inlet and outlet consisting of at least 20 thermocouples at each location as shown in Figures 6 and 7. The thermocouples shall be interconnected as shown in Figure 8 to provide direct reading of the temperature difference from inlet to outlet. The supports for thermocouples shall not penetrate the insulation.

7.4 Calibration. The calorimeter shall be calibrated so that the capacity of room-type devices can be determined from temperature and fan speed measurements.[6]

7.4.1 A direct-type electrical heating element(s) with low thermal inertia and radiation shielding shall be placed within the calorimeter. The heating element(s) shall be capable of operating at various input ratings so that at least three different inputs may be selected for each calibration point.

7.4.2 The calibration heater shall be energized, and the calorimeter fan shall be operated at a constant speed. For each calibration point, the calorimeter shall be allowed to stabilize, and temperature and speed measurements shall be made every 5 minutes. When three consecutive readings are the same, indicating stable conditions, the calibration point is reached.

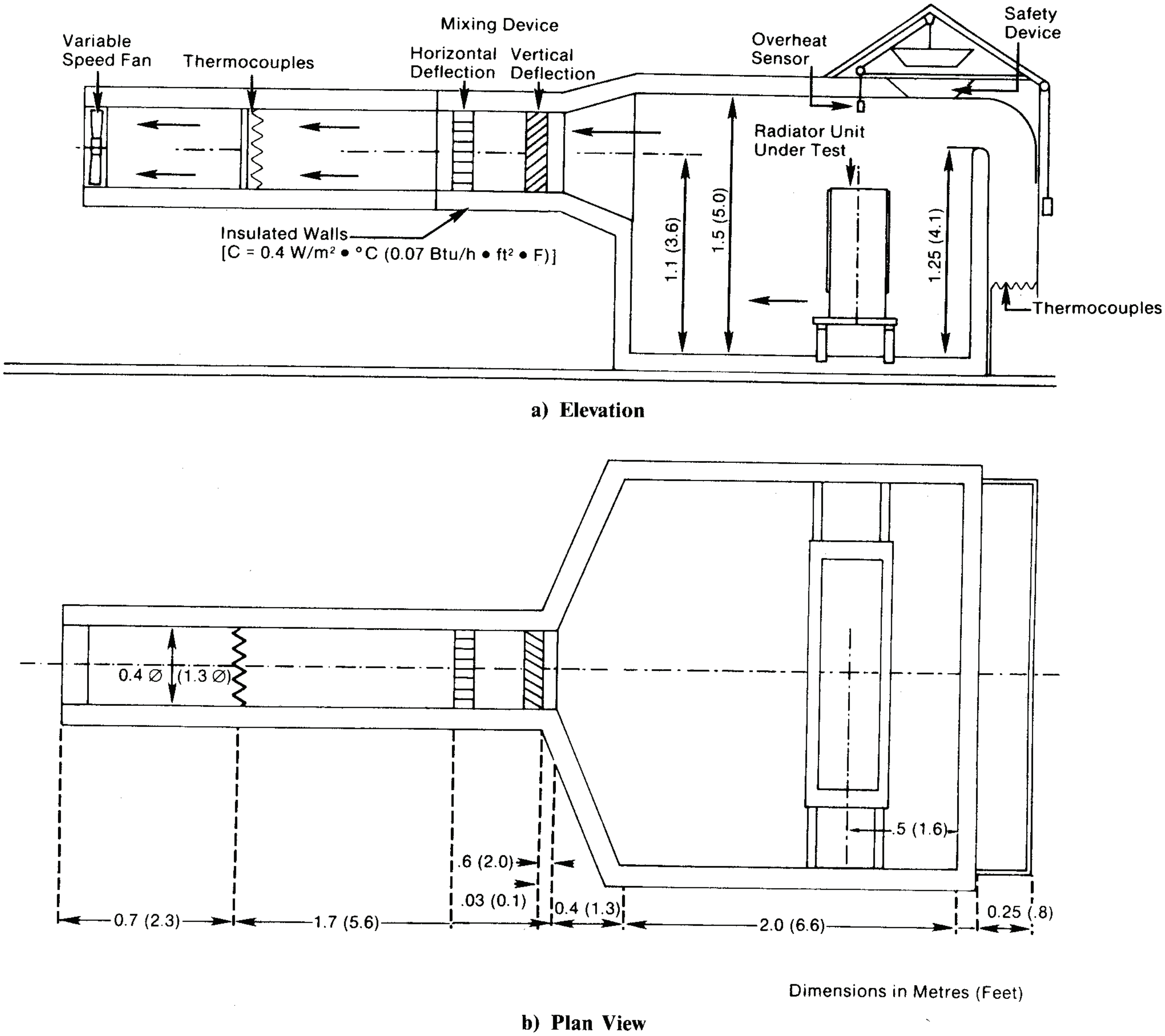

Figure 5 Calorimeter chamber.

7.4.3 A minimum of three calibration points for each fan speed shall be used to plot the calibration curve. A minimum of three fan speeds shall be selected for a minimum of nine calibration points. Fan speeds shall be selected so that the temperature difference is less than 15°C (27°F).

7.4.4 During the calibration test, the electrical power input to the calibration heater, *P*, and the temperature difference across the calorimeter, Δt_c, shall be recorded.

7.4.5 The temperature difference, the electrical power to the calibration heater, and the fan speed shall be plotted on a calibration curve (Figure 9).

8. CENTRAL THERMAL STORAGE DEVICE TESTING

The central thermal storage device shall be installed in accordance with the manufacturer's instructions in a test room as specified in Section 5.3. Prior to testing, any heating elements in the thermal storage device that are not used to charge the storage medium shall be disconnected. The tests to be performed are:

1. preconditioning (this test need not be performed in the test room; Section 8.1)
2. initial charge (Section 8.2)
3. maximum standby emission (Section 8.3)
4. discharge (Section 8.4)

8.1 Preconditioning Test

8.1.1 Purpose. The purpose of the preconditioning test is to stabilize the storage device for later tests and to verify control system performance.

8.1.2 Performance. The storage device control system shall be set to the maximum charge condition. If control system modifications are required to achieve the maximum charge condition, the manufacturer's instructions shall be followed. The device shall be brought to the maximum charge condition, and this condition shall be maintained for 24 hours by the built-in control system.

After the maximum charge condition has been reached and the 24-hour preconditioning period is completed, the

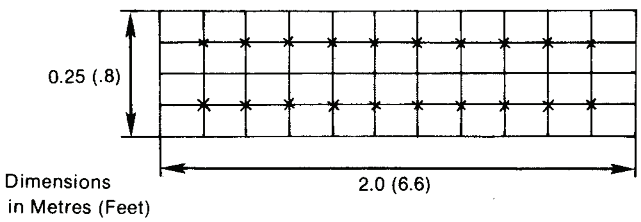

Figure 6 Thermopile in air inlet.

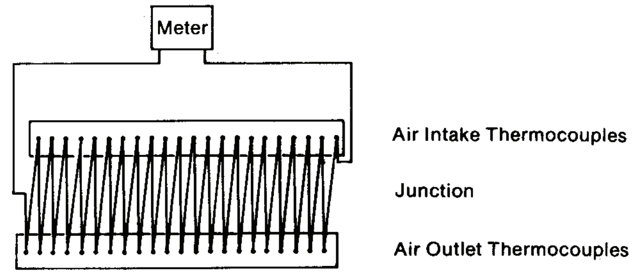

Figure 8 Thermopile interconnection.

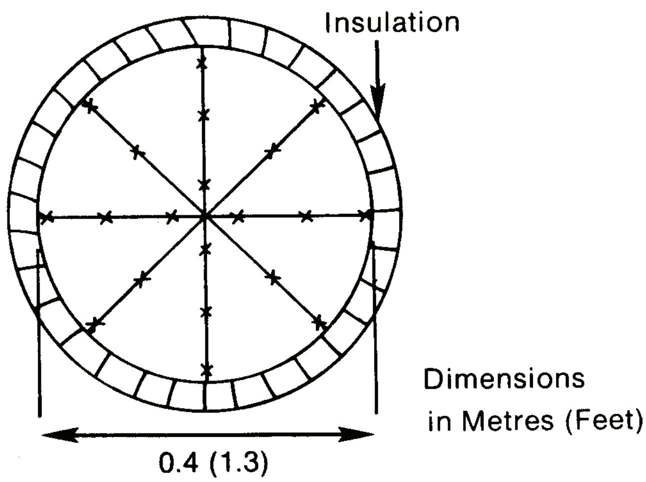

Figure 7 Thermopile in air outlet.

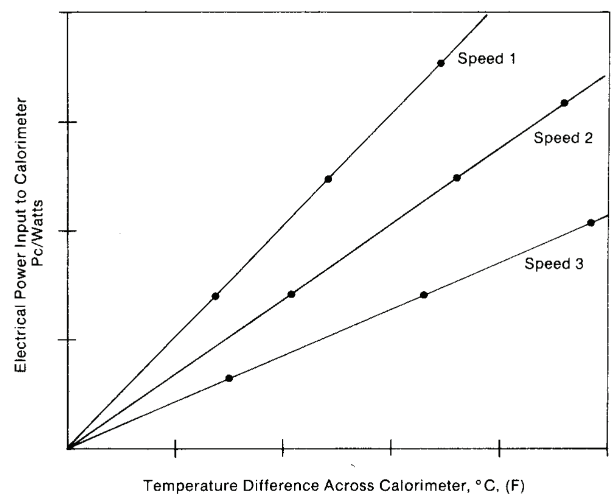

Figure 9 Calorimeter calibration curve.

device shall be discharged until all portions of the thermal storage device are at ambient temperature.

8.1.3 Measurements. No measurements need be made during the preconditioning test.

8.2 Initial Charge Test

8.2.1 Purpose. The purpose of this test is to determine the amount of energy required to bring the device to the maximum charge conditions.

8.2.2 Performance. Before the initial charge test is begun, the storage device shall be at the test room ambient temperature. The storage device control system shall be set to the maximum charge condition. If control system modifications are required to achieve the maximum charge condition, the manufacturer's instructions shall be followed.

8.2.3 Measurements. The total electrical input energy, E_1, required to reach the first controller cutoff shall be recorded.

8.3 Maximum Standby Emission Test

8.3.1 Purpose. The purpose of this test is to determine the standby emission (heat loss) from the storage device under maximum charge conditions.

8.3.2 Performance. Immediately after conclusion of the initial charge test (see Section 8.2), the maximum standby emission test shall be performed. During this test, the device shall remain in the non-discharge mode. The steady-state condition shall be maintained for not less than three cycles* of the charge controller, and the minimum test period shall be eight hours. If, toward the end of the eight-hour period, the charge controller has initiated another charge, the test shall be continued until that cycle is completed.

8.3.3 Measurements. The electrical input energy, E_2, required to maintain steady-state conditions and the total test period, τ_2, shall be measured.

8.4 Discharge Test (Device with Integral Fan or Pump)

8.4.1 Purpose. The purpose of this test is to determine the quantity of useful heat that can be extracted from the thermal storage device with integral fan or pump without recharging.

8.4.2 Performance. Immediately after the conclusion of the maximum standby emission test (see Section 8.3), the discharge test shall be performed in the following sequence.

8.4.2.1 Discharge. The device fan or pump shall be energized, and the device shall be discharged for a period of time, τ_3, until the outlet temperature drops by $\Delta t'/4$ below the outlet setpoint temperature, where $\Delta t'$ is the difference between outlet setpoint temperature and inlet temperature. The energy remaining in the storage device after this discharge period shall be defined as the residual energy.

8.4.2.2 Recharge. When the previously specified temperature difference has been reached, the device fan or pump

* A cycle is defined as the period of time from the shutoff to shutoff of the change controller.

shall be shut off, and immediately the device shall be recharged for the manufacturer's specified charge period, τ_4. If the manufacturer does not specify a charge period, the device shall be charged until the charge controller shuts off. The electrical input energy for this recharge is defined as E_4.

8.4.2.3 Measured Discharge. Immediately after the device has been recharged (Section 8.4.2.2), the device fan or pump shall be energized, and the device shall be discharged for a time, τ_5, until the outlet temperature drops by $\Delta t'/4$ below the outlet setpoint temperature, where $\Delta t'$ is the difference between outlet setpoint temperature and inlet temperature. During this discharge period, the initial average time interval for recording of measurements shall not be greater than 5% of the discharge period, τ_3, measured in Section 8.4.2.1. Toward the end of the measured discharge test, the time interval for recording of measurements shall be on the order of 2.5% of the discharge period, τ_3. The electrical energy required for the device fan or pump during the discharge period, τ_5, is defined as E_5. The heat transfer fluid mass flow rate is defined as *w*.

8.4.2.4 Recharge. After the measured discharge test (Section 8.4.2.3), is completed, the device fan or pump shall be shut off, and immediately the device shall be recharged as specified in Section 8.4.2.2. The electrical input energy for this recharge is defined as E_6.

8.4.3 Measurements. During the discharge test, the following measurements shall be made.

Test Section	Measured Quantities	Definitions	Units
8.4.2.1	τ_3	Initial discharge period	s (h)
8.4.2.2	τ_4	Charge period	s (h)
	E_4	Recharge electrical input energy	J (W·h)
8.4.2.3	E_5	Fan or pump energy	J (W·h)
	w	Heat transfer fluid mass flow rate	kg/s(lb/h)
	τ_5	Discharge period	
	Δt_1	Temperature difference between outlet and inlet	°C (°F)
8.4.2.4	E_6	Recharge electrical input energy	J (W·h)

8.5 Calculations. To evaluate the device performance, the following calculations shall be made.

8.5.1 Maximum Standby Emission. The maximum standby emission rate shall be computed as follows:

$$q_{e,max} = E_2/\tau_2 \quad = (3.413\ E_2/\tau_2) \tag{1}$$

8.5.2 Discharge Capacity. The heat delivered from the storage device shall be computed as follows:

$$Q_d = c_p \int_0^{\tau_5} \Delta t_1 d\tau \tag{2}$$

8.5.3 Residual Capacity. The residual capacity in the device after the test in Section 8.4 shall be computed as follows:

$$Q_r = \left(E_1 - \frac{E_4 + E_6}{2}\right) = \left(3.413\left[E_1 - \frac{E_4 + E_6}{2}\right]\right) \tag{3}$$

8.5.4 Effectiveness. The device effectiveness shall be computed as follows:

$$\eta = \frac{100 Q_d}{(E_4 + E_6)/2 + E_5} = \left(\frac{100 Q_d}{3.413[(E_4 + E_6)/2 + E_5]}\right) \tag{4}$$

8.6 Measurement of Ambient Air Temperature. The ambient air temperature, t_a, shall be the arithmetic average temperature of the test area, determined by four calibrated temperature sensors. *ANSI/ASHRAE Standard 41.1*[1] shall be followed in making these measurements. The sensors shall lie in a horizontal plane approximately at the vertical midpoint of the central storage device (calorimeter chamber for room storage devices) and shall be approximately 0.6 m (2 ft) from the sides of the central-type storage device (calorimeter chamber for room storage devices).

9. ROOM THERMAL STORAGE DEVICE TESTING

The room thermal storage device shall be installed in accordance with the manufacturer's instructions in a calorimeter chamber specified in Section 7.3. Prior to testing, any heating elements in the thermal storage device that are not used to charge the storage medium shall be disconnected. The tests to be performed are:

a. Preconditioning (this test need not be performed in the calorimeter chamber; Section 9.1)
b. Static discharge (Section 9.2)
c. Dynamic discharge (Section 9.3)

9.1 Preconditioning Test. The purpose, performance, and measurements for this test are specified in Section 8.1.

9.2 Static Discharge Test

9.2.1 Purpose. The purpose of this test is to determine the quantity of heat given off by the device under static conditions, i.e., when the built-in fan, if any, is not operating.

9.2.2 Performance. At the start of this test the device shall be at the calorimeter room ambient temperature. Because some room-type storage devices are designed to supply heat during the charging cycle, the calorimeter chamber shall be operating throughout this test.

The storage device control system shall be set to the maximum charge conditions. If control system modifications are required to achieve the maximum charge conditions, the manufacture's instructions shall be followed.

The device shall be brought to the maximum charge condition, and this condition shall be maintained for not less than three cycles* of the charge controller, and the minimum charging time shall be eight hours. If, toward the end of the eight-hour charging period, the charge controller has initiated another charge, the test shall continue until that cycle is completed.

After the charging is completed, all electrical inputs to the storage device shall be disconnected immediately, and the device shall discharge statically (built-in fan, if any, not operating) for 16 hours. Any manually adjustable discharge dampers within the unit shall be set for maximum discharge.

9.2.3 Measurements. The total electrical input energy, E_7, and the total charging period, τ_7, shall be measured.

The temperature differential across the calorimeter chamber and the calorimeter chamber fan speed shall be measured with a time interval between measurements of 15 minutes or less. The time intervals between all measurements shall be recorded. The device discharge period, τ_8, shall be measured.

9.3 Dynamic Discharge Test

9.3.1 Purpose. The purpose of this test is to determine the quantity of useful heat that can be extracted from the thermal storage device without recharging. This test applies only to those room thermal storage devices that have a built-in fan.

9.3.2 Performance. At the start of this test, the device shall be at the calorimeter room ambient temperature. Because some room storage devices are designed to supply heat during the charging cycle, the calorimeter chamber shall be operational throughout this test.

The storage device control system shall be set to the maximum charge condition. If control system modifications are required to achieve the maximum charge conditions, the manufacturer's instructions shall be followed.

The device shall be brought to the maximum charge condition, and this condition shall be maintained for not less than three cycles‡ of the charge controller, and the minimum charging time shall be eight hours. If, toward the end of the eight-hour charging period, the charge controller has initiated another charge, the test shall continue until that cycle is completed.

Immediately after the charging cycle is completed, the built-in fan shall be energized. The device shall be dynamically discharged for either 16 hours or until the temperature differential across the calorimeter has dropped to 5% of the temperature differential measured 30 minutes after the start of the discharge test, whichever occurs first.

9.3.3 Measurements. The total electrical input energy, E_9, and the total charging period, τ_9, shall be measured.

The temperature differential across the calorimeter chamber and the calorimeter fan speed shall be measured with a time interval between measurements of 15 minutes or less (during charging and discharging). The time intervals between all measurements shall be recorded. The device discharge period, τ_{10}, shall be measured. The electrical input to the storage device fan, E_{10}, shall be measured.

* A cycle is defined as the period of time from the shutoff to shutoff of the change controller.

9.4 Calculations.

The electrical power, P, shall be determined for each test condition from the calorimeter calibration curve developed in accordance with Section 7.4. By entering the curve with the measured temperature difference across the calorimeter and the measured fan speed, the electrical power, P, is determined.

To evaluate the device performance, the following calculations shall be made.

9.4.1 Case Emission (Static). The case emission during charging of room devices without fans (or with integral fans not operating) shall be computed as follows:

$$\begin{aligned} Q_c &= \Sigma P \cdot \Delta\tau \\ &= (\Sigma 3.413 \cdot \Delta\tau) \end{aligned} \tag{5}$$

9.4.2 Discharge Capacity (Static). The total heat emitted during static discharge shall be computed as follows:

$$\begin{aligned} Q_d &= \Sigma P \cdot \Delta\tau \\ &= (\Sigma 3.413 P \cdot \Delta\tau) \end{aligned} \tag{6}$$

9.4.3 Residual Capacity (Static). The residual capacity of room devices without fans (or with integral fans not operating) shall be computed as follows:

$$\begin{aligned} Q_r &= E_7 - Q_d - Q_e \\ &= (3.413 \times (E_7 - Q_d - Q_e)) \end{aligned} \tag{7}$$

9.4.4 Case Emission (Dynamic). The case emission during charging of room devices with integral fans operating shall be computed as follows:

$$\begin{aligned} Q_c &= \Sigma P \cdot \Delta\tau \\ &= \Sigma(3.413 P \cdot \Delta\tau) \end{aligned} \tag{8}$$

9.4.5 Discharge Capacity (Dynamic). The total stored heat emitted during dynamic discharge shall be computed as follows:

$$\begin{aligned} \mathrm{Q_c} &= \Sigma P \cdot \Delta\tau - \mathrm{E_{10}} \\ &= (3.413(\Sigma P \cdot \Delta\tau - \mathrm{E_{10}})) \end{aligned} \tag{9}$$

9.4.6 Residual Capacity (Dynamic). The residual capacity of room devices with integral fans operating shall be computed as follows:

$$\begin{aligned} Q_r &= E_9 - Q_d - Q_c \\ &= (3.413 \times (E_9 - Q_d - Q_e)) \end{aligned} \tag{10}$$

10. DATA TO BE RECORDED AND TEST REPORT

10.1 Central Thermal Storage Devices

10.1.1 Test Data. Table 1 1ists the measurements to be recorded during the various tests.

10.1.2 Test Report. Table 2 specifies the data to be reported in testing a central-type thermal storage device.

10.2 Room Thermal Storage Devices

10.2.1 Test Data. Table 3 lists the measurements to be made during the various tests.

10.2.2 Test Report. Table 4 specifies the data to be reported in testing a room thermal storage device.

11. NOMENCLATURE

c_p = specific heat of transfer fluid at test temperature, J/(kg·°C) (Btu/lb·°F)

E_1 = electrical input energy (initial charge test), J(W·h)

E_2 = electrical input energy (maximum standby emission test), J(W·h)

E_4 = recharge electrical input energy (discharge test), J(W·h)

E_5 = fan or pump electrical input energy, J(W·h)

E_6 = recharge electrical input energy (measured discharge test), J(W·h)

E_7 = electrical input energy (static discharge test), J(W·h)

E_9 = electrical input energy (dynamic discharge test), J(W·h)

E_{10} = fan electrical input energy (dynamic units), J(W·h)

P = power removed by calorimeter, W(W)

$q_{e,max}$ = maximum standby emission rate, W(Btu/h)

Q_d = discharge capacity, J(Btu)

Q_e = case emission, J(Btu)

Q_r = residual capacity, J(Btu)

w = mass flow rate, kg/s (lb/h)

Δt_c = temperature differential across calorimeter (calibration), °C (°F)

Δt_1 = temperature differential across thermal storage device, °C (°F)

$\Delta t'$ = difference between outlet setpoint temperature and inlet temperature,°C (°F)

η = device effectiveness, % (%)

τ = time, s (h)

τ_2 = standby emission test period, s (h)

τ_3 = initial discharge period, s (h)

τ_4 = charge period, s (h)

τ_5 = discharge period, s (h)

τ_7 = total static charge period, s (h)

τ_8 = static discharge period, s (h)

τ_9 = total dynamic charge period, s (h)

τ_{10} = dynamic discharge period, s (h)

$\Delta\tau$ = time interval between measurements, calorimeter, s (h)

12. REFERENCES

[1] ASHRAE. 1991. *ANSI/ASHRAE Standard 41.1-1986 (RA 2006)*, *Standard Method for Temperature Measurement*. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

[2] ANSI Standard MC96.1-82, Temperature Measurement Thermocouples. 1982. Reprinted in: *ISA Handbook of Standards*, Instrument Society of America, P.O. Box 12277, Research Triangle Park, NC 27709.

[3] ASHRAE. 1991. *ANSI/ASHRAE Standard 37-2009*, *Methods of Testing for Rating Unitary Air-Conditioning and Heat Pump Equipment*. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

[4] ASHRAE. 1991. *ANSI/ASHRAE Standard 70-2006*, *Method of Testing for Rating the Air Performance of Outlets and Inlets*. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

[5] ASHRAE. 1996. *Guideline 2-2005*, *Engineering Analysis of Experimental Data*. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

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INFORMATIVE ANNEX A

[1] Ray W. Herrick Laboratories. 1980. *Development of performance testing procedures for evaluation of room-size electrically heated thermal energy storage units (Task IV), HL 80-5*. Lafayette, Ind.: Purdue University.

[2] Deutsche Elektrotechnische Kommission. 1972. Elektrische raumheizgerate, speicherheizgerate mit steuerbarer warmeabgabe, DIN 44572, Blatt 5. (Electric heating appliances, storage heaters with controlled output; test method to determine the heat.) Berlin: Deutsche Elektrotechnische Kommission.

TABLE 1 Test Data to Be Recorded (Central-Type Devices)

Item (Specify All Units)	Tests Involving Air as the Transfer Medium	Tests Involving a Liquid as the Transfer Medium
Date	X	X
Observer	X	X
Equipment Name Plate Data	X	X
Temperature Difference Across Storage Device	X	X
Inlet Temperature, t_{in}	X	X
Outlet Temperature, t_{out}	X	X
Liquid Flow Rate		X
Barometric Pressure	X	X
Gauge Pressure at Inlet		X
Gauge Pressure at Nozzle Throat	X	
Nozzle Throat Diameter	X	
Velocity Pressure at Nozzle Throat or Static Pressure Difference Across Nozzle	X	
Dry-Bulb Temperature a Nozzle Throat	X	
Wet-Bulb Temperature at Nozzle Throat	X	
Ambient Air Temperature, t_a	X	X
Electrical Input Energy		
E_1 (8.2.3)	X	X
E_2 (8.3.3)	X	X
E_4 (8.4.2.2)	X	X
E_5 (8.4.2.3)	X	X
E_6 (8.4.2.4)	X	X
Times		
τ_2 (8.3.3)	X	X
τ_3 (8.4.2)	X	X
τ_4 (8.4.2.2)	X	X
τ_5 (8.4.2.3)	X	X

TABLE 2 Data to Be Reported (Central-Type Devices) (SI units recommended)

General Information

Manufacturer ____________________

Model Number ____________________

Serial Number ____________________

Storage Medium ____________________

Transfer Fluid ____________________

Container Material ____________________

Length ____________________

Width ____________________

Height ____________________

Weight of Storage Device ____________________

Volume of Storage Device ____________________

Rating of Electrical Elements
(Watts, Voltage, Phase) ____________________

Minimum Transfer Fluid Flow Rate ____________________

Maximum Transfer Fluid Flow Rate ____________________

Maximum Operating Pressure ____________________

Flow Configuration Tested ____________________ (picture or diagram)

INITIAL CHARGE TEST

Electrical Input Energy, E_1 ____________________

MAXIMUM STANDBY EMISSION TEST

Maximum Standby Emission Rate, Q_e ____________________

Electrical Input Energy, E_2 ____________________

Test Period, τ_2 ____________________

Discharge Test

Discharge Capacity, Q_d ____________________

Residual Capacity, Q_r ____________________

Effectiveness, η ____________________

Electrical Input Energy,

E_4 ____________________

E_5 ____________________

E_6 ____________________

Test Period

τ_3 ____________________

τ_4 ____________________

τ_5 ____________________

Mass Flow Rate, w ____________________

Ambient Temperature, t_2 ____________________

TABLE 3 Test Data to Be Recorded (Room-Type Devices)

Item (Specify All Units)	Without Fans	With Fans
Date	X	X
Observer	X	X
Equipment Name Plate Data	X	X
Temperature Difference Across		
Calorimeter, Δt_2	X	X
Inlet Temperature, t_{in}	X	X
Outlet Temperature, t_{out}	X	X
Dry-Bulb Temperature at Nozzle Throat	X	
Wet-Bulb Temperature at Nozzle Throat	X	
Ambient Air Temperature, t_a	X	X
Electrical Input Energy		
E_7	X	X
E_9		X
E_{10}		X
Times		
τ_7	X	X
τ_8	X	X
τ_9		X
τ_{10}		X
$\Delta\tau$	X	X
Calorimeter		

TABLE 4 Data to Be Reported (Room-Type Devices) (SI units recommended)

General Information
Manufacturer__________
Model Number__________
Serial Number__________
Storage Medium__________
Transfer Fluid__________
Container Material__________
Length__________
Width__________
Height__________
Weight of Storage Device__________
Volume of Storage Device__________
Rating of Electrical Elements (Watts, Voltage, Phase)__________
Flow Configuration Tested__________ (picture or diagram)
STATIC DISCHARGE
Discharge Capacity (Static), Q_d __________
Case Emission (Static), Q_e __________
Residual Capacity (Static), Q_r __________
Electrical Input Energy, E_7 __________
Charging Period, τ_7 __________
Discharge Period, τ_8 __________
DYNAMIC DISCHARGE (Room-Type Devices with Integral Fans Only)
Discharge Capacity (Dynamic), Q_d __________
Case Emission (Dynamic), Q_e __________
Residual Capacity (Dynamic), Q_r __________
Electrical Input Energy, E_9 __________
Charging Period, τ_9 __________
Discharge Period, τ_{10} __________
Fan Electrical Input Energy, E_{10} __________.

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ASHRAE's short-range goal is to ensure that the systems and components within its scope do not impact the indoor and outdoor environment to a greater extent than specified by the standards and guidelines as established by itself and other responsible bodies.

As an ongoing goal, ASHRAE will, through its Standards Committee and extensive technical committee structure, continue to generate up-to-date standards and guidelines where appropriate and adopt, recommend, and promote those new and revised standards developed by other responsible organizations.

Through its *Handbook*, appropriate chapters will contain up-to-date standards and design considerations as the material is systematically revised.

ASHRAE will take the lead with respect to dissemination of environmental information of its primary interest and will seek out and disseminate information from other responsible organizations that is pertinent, as guides to updating standards and guidelines.

The effects of the design and selection of equipment and systems will be considered within the scope of the system's intended use and expected misuse. The disposal of hazardous materials, if any, will also be considered.

ASHRAE's primary concern for environmental impact will be at the site where equipment within ASHRAE's scope operates. However, energy source selection and the possible environmental impact due to the energy source and energy transportation will be considered where possible. Recommendations concerning energy source selection should be made by its members.

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