STANDARD

ANSI/ASHRAE Standard 94.1-2010
(Supersedes ANSI/ASHRAE 94.1-2002 [RA 2006])

Method of Testing Active Latent-Heat Storage Devices Based on Thermal Performance

Approved by the ASHRAE Standards Committee on June 26, 2010; by the ASHRAE Board of Directors on June 30, 2010; and by the American National Standards Institute on July 1, 2010.

ASHRAE Standards are scheduled to be updated on a five-year cycle; the date following the standard number is the year of ASHRAE Board of Directors approval. The latest edition of an ASHRAE Standard may be purchased on the ASHRAE website (www.ashrae.org) or from ASHRAE Customer Service, 1791 Tullie Circle, NE, Atlanta, GA 30329-2305. E-mail: orders@ashrae.org. Fax: 404-321-5478. Telephone: 404-636-8400 (worldwide) or toll free 1-800-527-4723 (for orders in US and

© 2010 ASHRAE ISSN 1041-2336

Approved American National Standard
ANSI
www.ansi.org

ASHRAE Standard Project Committee 94.1
Cognizant TC: TC 6.9, Thermal Storage

Calvin D. MacCrackern, *Chair*
Brian Brinkworth
Roger L. Cole
Harry Fischer
Dennis Jones
Paul Kando
George Kvajlk
James Martin
Paul J. Moses
Robert H. Stevenson
B. Thomas Tamblyn
Maurice W. Wildin

**Denotes members of voting status when the document was approved for publication*

ASHRAE STANDARDS COMMITTEE 2009–2010

Steven T. Bushby, Chair
H. Michael Newman, Vice-Chair
Douglass S. Abramson
Robert G. Baker
Michael F. Beda
Hoy R. Bohanon, Jr.
Kenneth W. Cooper
K. William Dean
Martin Dieryckx
Allan B. Fraser
Nadar R. Jayaraman
Byron W. Jones
Jay A. Kohler
Carol E. Marriott
Merle F. McBride
Frank Myers
Janice C. Peterson
Douglas T. Reindl
Lawrence J. Schoen
Boggarm S. Setty
Bodh R. Subherwal
James R. Tauby
James K. Vallort
William F. Walter
Michael W. Woodford
Craig P. Wray
Wayne R. Reedy, BOD ExO
Thomas E. Watson, CO

Stephanie Reiniche, Manager of Standards

SPECIAL NOTE

This American National Standard (ANS) is a national voluntary consensus standard developed under the auspices of ASHRAE. *Consensus* is defined by the American National Standards Institute (ANSI), of which ASHRAE is a member and which has approved this standard as an ANS, as "substantial agreement reached by directly and materially affected interest categories. This signifies the concurrence of more than a simple majority, but not necessarily unanimity. Consensus requires that all views and objections be considered, and that an effort be made toward their resolution." Compliance with this standard is voluntary until and unless a legal jurisdiction makes compliance mandatory through legislation.

ASHRAE obtains consensus through participation of its national and international members, associated societies, and public review.

ASHRAE Standards are prepared by a Project Committee appointed specifically for the purpose of writing the Standard. The Project Committee Chair and Vice-Chair must be members of ASHRAE; while other committee members may or may not be ASHRAE members, all must be technically qualified in the subject area of the Standard. Every effort is made to balance the concerned interests on all Project Committees.

The Manager of Standards of ASHRAE should be contacted for:

a. interpretation of the contents of this Standard,
b. participation in the next review of the Standard,
c. offering constructive criticism for improving the Standard, or
d. permission to reprint portions of the Standard.

DISCLAIMER

ASHRAE uses its best efforts to promulgate Standards and Guidelines for the benefit of the public in light of available information and accepted industry practices. However, ASHRAE does not guarantee, certify, or assure the safety or performance of any products, components, or systems tested, installed, or operated in accordance with ASHRAE's Standards or Guidelines or that any tests conducted under its Standards or Guidelines will be nonhazardous or free from risk.

ASHRAE INDUSTRIAL ADVERTISING POLICY ON STANDARDS

ASHRAE Standards and Guidelines are established to assist industry and the public by offering a uniform method of testing for rating purposes, by suggesting safe practices in designing and installing equipment, by providing proper definitions of this equipment, and by providing other information that may serve to guide the industry. The creation of ASHRAE Standards and Guidelines is determined by the need for them, and conformance to them is completely voluntary.

In referring to this Standard or Guideline and in marking of equipment and in advertising, no claim shall be made, either stated or implied, that the product has been approved by ASHRAE.

CONTENTS

ANSI/ASHRAE Standard 94.1-2010, Method of Testing Active Latent-Heat Storage Devices Based on Thermal Performance

SECTION	PAGE
Foreword	2
1 Purpose	2
2 Scope	2
3 Definitions	2
4 Classification	3
5 Requirements	3
6 Instrumentation	3
7 Apparatus and Method of Testing	3
8 Test Procedures	7
9 Test Report and Data to be Recorded	9
10 References	11
11 Nomenclature	11
Informative Annex A: Mathematical Derivations	12
Informative Annex B: Bibliography	16

NOTE

Approved addenda, errata, or interpretations for this standard can be downloaded free of charge from the ASHRAE Web site at www.ashrae.org/technology.

© 2010 ASHRAE

1791 Tullie Circle NE · Atlanta, GA 30329 · www.ashrae.org · All rights reserved.

ASHRAE is a registered trademark of the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.
ANSI is a registered trademark of the American National Standards Institute.

(This foreword 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. Unresolved objectors on informative material are not offered the right to appeal at ASHRAE or ANSI.)

FOREWORD

This is a revision of Standard 94.1-2002 (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 for the 2010 revision include the following:

- *The references were updated.*
- *The normative references were separated from the bibliography.*
- *Informative Annex B (Bibliography) was added.*
- *The Table of Contents was updated.*
- *The numbering of the standards referenced in the body were updated to be consistent with the references and bibliography sections.*
- *The figures were enlarged for easier reading.*
- *Other minor editorial corrections were made.*

1. PURPOSE

The purpose of this standard is to provide a standard procedure for determining the thermal performance of latent heat thermal energy storage devices used in heating, air-conditioning, and service hot water systems.

2. SCOPE

2.1 This standard applies to latent heat thermal energy storage devices in which a transfer fluid enters the device through a single inlet and leaves the device through a single outlet. This standard is not applicable to those configurations in which there is simultaneous flow into the storage device through more than one inlet or simultaneous flow out of the storage device through more than one outlet. The transfer fluid can be either a liquid or a noncondensing gas.

2.2 This standard does not include factors relating to cost, life, or reliability. It anticipates a variety of energy sources but does not consider the interfacing requirements of any specific heating or cooling system. In particular, the five cycles prior to testing specified in Section 5.1 are not intended as a measure of phase-change material degradation.

2.3 The test procedure and equipment outlined in this standard are most easily adaptable to devices used to store thermal energy on the order of 10^7 Btu (10^{10} J) or less.

2.4 This standard permits testing of a storage device containing a source of internal heating, such as a stirring pump or an electric immersion heater, provided that less than 10% of the charge capacity in a test is supplied by the internal heating. If such a source of internal heating is used, the internal heat input must be measured and Equations 2 and 5 must be appropriately modified.

3. DEFINITIONS

The following definitions are stipulated for this document:

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

charge capacity: the amount of heat that can be transferred into the storage device at a specified rate for a specific set of values for the initial temperature of the storage device, the temperature rise of the exiting fluid, and the mass flow rate of fluid through the storage system.

charge test time: the duration of a single transient test in which energy is added to the storage device.

cycling (latent-heat-type storage device): a process in which heat is applied 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 at a specified rate and for a specific set of values for the initial temperature of the storage device, the temperature decrease of the exiting fluid, and the mass flow rate of fluid through the storage system.

discharge test time: the duration of a single transient test in which energy is removed from the storage device.

heat loss coefficient: the rate at which heat is lost from the storage device per degree temperature difference between the average storage medium temperature and the average ambient air temperature (or ground temperature, if the storage device is buried).

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

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

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

storage efficiency: discharge capacity divided by charge capacity.

4. CLASSIFICATION

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 involve a finite change in the temperature of the system.

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 five times prior to being tested. This cycling is to ensure that the device is in an operational rather than a start-up condition.

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 6.1.7, varies between extremes by less than ±3.6°F (±2.0°C) 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, *Standard Method for Temperature Measurement*.[1]

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

a. thermopiles,
b. resistance thermometers,
c. precision thermometers, or
d. thermistors.

It is recommended that a Btu meter or real-time computer processing of data be used to combine flow rate and temperature difference measurement and provide a visual display of Btu rate and cumulative Btus.

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	±0.9°F (±0.5°C)	±0.4°F (0.2°C)
Temperature Difference	±0.2°F (±0.1°C)	±0.2°F (±0.1°C)

* The ability of the instrument to indicate the true value of the measured quantity.
† Closeness of agreement among repeated measurements of the same physical quantity.

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 ±0.2°F (±0.1°C), the smallest-scale division shall not exceed 0.4°F (0.2°C).

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

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

6.1.7 The ambient air temperature, t_a, shall be the arithmetic average temperature of the test area, determined by four calibrated temperature sensors. 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 storage device and shall be approximately 2 ft (0.6 m) from the sides of the storage device.

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 mass flow rate.

6.3 Airflow Measurements. When air is used as the transfer fluid, the airflow rate shall be determined as described in Section 7.1 using instrumentation described in ASHRAE Standard 37, *Methods of Testing for Rating Unitary Air Conditioning and Heat Pump Equipment*, and ASHRAE Standard 70,[3] *Methods of Testing for Rating the Performance of Air Outlets and Inlets*.[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.[3]

6.4.2 Airflow Measurements. The static pressure across the nozzle and the velocity pressure at the nozzle throat shall be measured with instruments that have been calibrated and are accurate 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 ±0.1 in. of water (±25 Pa).

6.5 Time and Mass Measurements. Time measurements and mass measurements shall be made to an accuracy of ±0.20% for calibration purposes.[3]

7. APPARATUS AND METHOD OF TESTING

7.1 Air as the Transfer Fluid

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 configuration is acceptable. An air-reconditioning apparatus must be included in the loop in order to maintain the required constant heat input and output specified in Section 8. An air-moving device (fan or blower) must be included in both open- and closed-test loops.

7.1.2 Test Ducts. The inlet test 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 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.

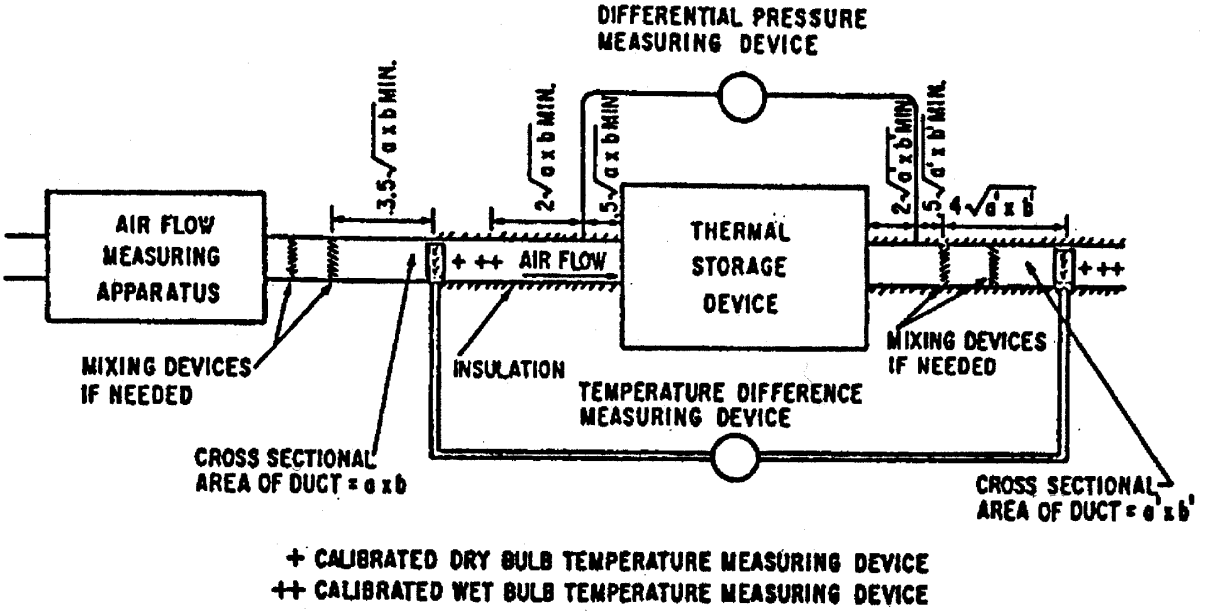


Figure 1 Positions of instrumentation relative to the thermal energy storage device for devices using air as the transfer fluid.

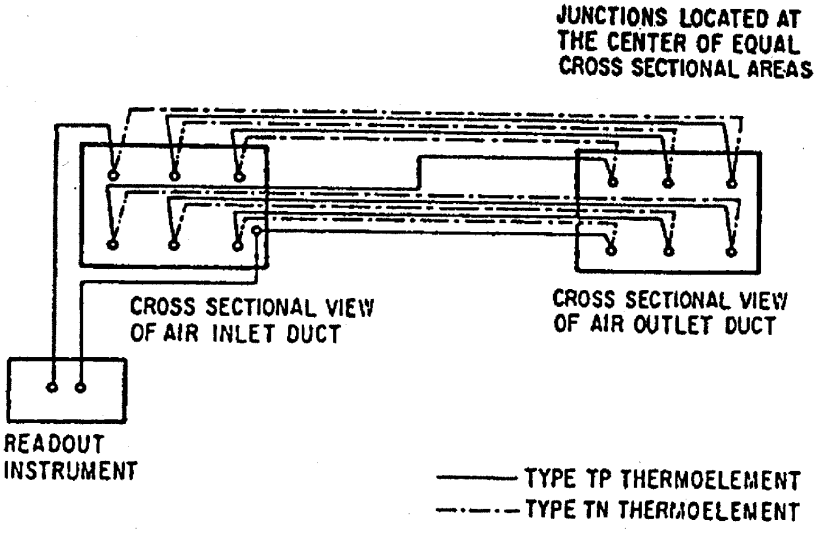


Figure 2 Typical locations of temperature-difference thermocouple junctions in rectangular air ducts.

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

A digital readout Btu meter or real-time computer processing of data is recommended to facilitate manual adjustment of constant heat input and output.

During all tests, the variation in temperature across the air inlet and air outlet test ducts shall be less than ±1.5°F (±0.8°C). The variation shall be checked prior to testing by utilizing the instrumentation and procedures outlined in 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 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 0.2°F (0.1°C) between the temperature-measuring locations and the storage device.

7.1.4 Dry-Bulb and Wet-Bulb Temperature Measurements. Dry-bulb and wet-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 ASHRAE Standard 41.1.[1]

7.1.5 Duct Pressure Measurements. The static pressure drop across the thermal storage device shall be measured using a differential pressure measuring device as shown in Figures 1 and 3. Each side of such a device shall be connected to four pressure taps that are connected to an external manifold on the air inlet and air outlet ducts. The pressure taps shall consist of 1/4 in. (6.4 mm) nipples fastened to the duct and centered over 0.040 in. (1 mm) diameter holes. The edges of these holes on the inside surfaces of the ducts shall be free of burrs and other irregularities.[B2]

If the cross-sectional areas at the two sensing locations of the differential pressure measuring device are unequal, a correction for the difference in velocity pressure at the two locations shall be made in accordance with Section 7.1 of ASHRAE Standard 70.[4]

7.1.6 Airflow-Measuring Apparatus. The airflow shall be measured with the nozzle apparatus described in Section 5.1 of ASHRAE Standard 70[4] or in Section 7 of ASHRAE Standard 37.[3] As shown in Figure 4, this apparatus consists basically of a receiving chamber, a discharge chamber, and an airflow-measuring nozzle. This distance from the center of the nozzle to the side walls shall not be less than 1 1/2 times the nozzle throat diameter, and diffusers shall be installed in the receiving chamber at least 1 1/2 nozzle throat diameters upstream of the nozzle and 2 1/2 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 2960 fpm (15 m/s) and 6900 fpm (35 m/s). Details on nozzle construction and discharge coefficients are contained in Section 5.1.1 of ASHRAE Standard 70.[4]

The dry-bulb and wet-bulb temperatures of the air entering the nozzle shall be measured in accordance with ASHRAE Standard 41.1.[1] The velocity of the air passing through the nozzle shall be determined either by measuring the velocity head with a pitot tube or by measuring the static pressure 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

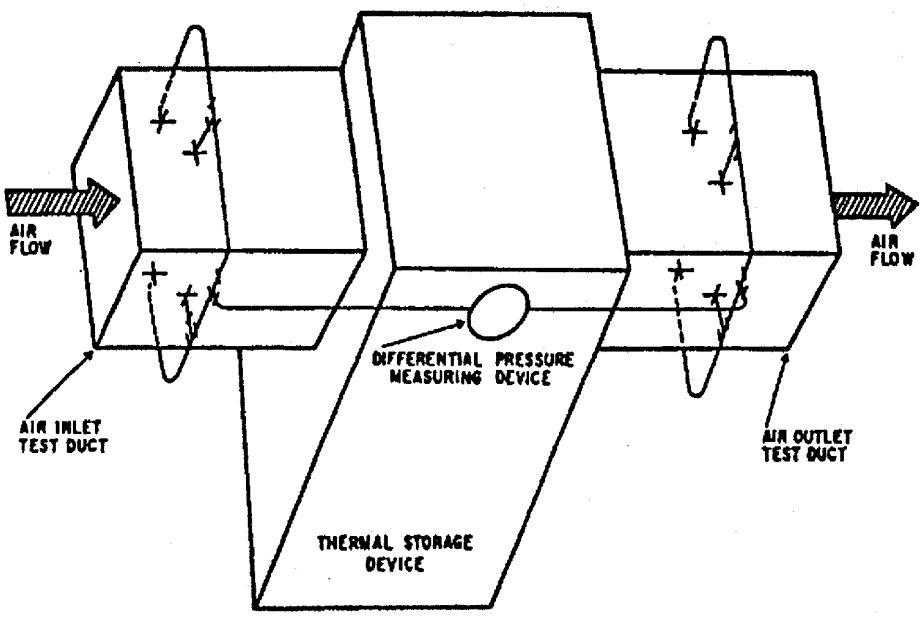


Figure 3 Measurement of static pressure drop across the thermal storage device.