STANDARD

ANSI/ASHRAE Standard 93-2010 (RA 2014)
(Reaffirmation of ANSI/ASHRAE Standard 93-2010)

Methods of Testing to Determine the Thermal Performance of Solar Collectors

Approved by the ASHRAE Standards Committee on January 18, 2014; by the ASHRAE Board of Directors on January 22, 2014; and by the American National Standards Institute on January 23, 2014.

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: 678-539-2129. Telephone: 404-636-8400 (worldwide) or toll free 1-800-527-4723 (for orders in US and Canada). For reprint permission, go to www.ashrae.org/permissions.

 ISSN 1041-2336

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 93-2010 (RA 2014), Methods of Testing to Determine the Thermal Performance of Solar Collectors

SECTION **PAGE**

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.

(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

ASHRAE Standard 93 provides a test procedure whereby solar energy collectors can be tested both indoors and outdoors to rate the collectors in accordance with their thermal performance and to determine their time constants and the variations in their efficiency with changes in the angle of incidence between the sun's direct rays and the normal to the collector aperture. The standard carefully defines its applicability to both liquid-cooled nonconcentrating and concentrating collectors and collectors that use air as the heat transfer fluid.

First published in 1986, the Standard 93 was reaffirmed in 1991 and again in 2003. This revision of the standard brings it into agreement with ISO Standard 9806-1. The test procedure for performance remains the same as in previous editions, but additional methods for calculating performance efficiency from the recorded data have been added. Whereas performance was previously calculated based on gross area and inlet fluid temperature, in this edition of the standard three new methods of calculation are provided. Now performance can be calculated based upon (1) gross area and average fluid temperature, (2) absorber area and inlet fluid temperature, and (3) absorber area and average fluid temperature. In addition, the way in which the heat-capacity time constant is determined has also been changed to align in with ISO 9806-1. In earlier editions this constant was determined by exposing the collector to thermal stabilization, then covering it. The heat capacity was found as function of how quickly the collector cooled. In this edition, however, the collector is covered to achieve thermal stabilization and then it is uncovered under exposure. The heat capacity is found as a function of how quickly the collector heats up. Finally, various editorial corrections have been made, and the standard's references have been updated to the most recent editions.

This is a reaffirmation of Standard 93-2010. This standard was prepared under the auspices of 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 guidelines throughout the industry.This version of the reaffirmation has no changes.

1. PURPOSE

The purpose of this standard is to provide test methods for determining the thermal performance of solar energy collectors that use single-phase fluids and have no significant internal energy storage.

2. SCOPE

2.1 This standard applies to nonconcentrating and concentrating solar collectors in which a fluid enters the collector through a single inlet and leaves the collector through a single outlet.

2.1.1 Collectors containing more than one inlet and more than one outlet may be tested according to this standard provided that the external piping or ducting can be connected so as to provide effectively a single inlet and a single outlet.

2.2 The heat transfer fluid may be either a liquid or a gas but not a mixture of the two phases.

2.3 This standard contains methods for conducting tests outdoors under natural solar irradiance and for conducting tests indoors under simulated solar irradiance.

2.4 This standard provides test methods and calculation procedures for determining steady-state and quasi-steady-state thermal performance, time, and angular response characteristics of solar collectors.

2.5 This standard is not applicable to those collectors in which the thermal storage unit is an integral part of the collector to such an extent that the collection process and the storage process cannot be separated for the purpose of making measurements of these two processes.

2.6 This standard does not apply to:

(a) those unglazed solar collectors that can be tested in accordance with ASHRAE Standard 96-1980 (RA 89)[1] and

(b) those collectors in which the heat transfer fluid changes phase and the leaving transfer fluid contains vapor. However, a suggested test procedure is given in Appendix I for those phase-change collectors with an integral heat exchanger that conform to the descriptions in Sections 2.1 and 2.2 of this standard.

3. DEFINITIONS AND NOMENCLATURE

3.1 Definitions

absorber: the absorber is that part of the solar collector that receives the incident radiation energy and transforms it into thermal energy. It may possess a surface through which energy is transmitted to the transfer fluid; however, the transfer fluid itself can be the absorber.

absorber area: the absorber area is the total heat transfer area from which the absorbed solar irradiance heats the transfer fluid or the area of the absorber medium if both transfer fluid and solid surfaces jointly perform the absorbing function.

air mass: the air mass is the ratio of the mass of atmosphere in the actual earth-sun path to the mass that would exist at sea level if the sun were directly overhead.

angle, acceptance: the angular zone within which radiation is accepted by the receiver of a concentrator. Radiation is said to be accepted because radiation incident within this angle reaches the absorber after passing through the aperture.

angle of incidence: the angle of incidence is the angle between the direct solar irradiance and the normal to the aperture plane.

apparent solar time: time based on the apparent angular motion of the sun across the sky, with solar noon the time the sun crosses the meridian of the observer.

area, aperture: the aperture area is the maximum projected area of a solar collector through which the unconcentrated solar radiant energy is admitted.

area, gross: the gross collector area is the maximum projected area of the complete collector module including integral mounting means. (*Note:* The "complete collector module" is the collector unit shipped by the manufacturer for installation on a structure or in an array. However, if the manufacturer requires that additional insulation be placed in any manner along all or any part of the perimeter (edge) of the collector module in order that the performance characteristics, determined with the test procedures herein, will be indicative of those that would occur when the collector is part of an installed system, the gross area will have to be adjusted. If the installed array is specified as a one-row array, then the dimensions are the centerline-to-centerline distance between two adjacent collectors installed in the array times the collector height. If the installed array is specified as a two-row or larger array, the gross area is determined by the horizontal and longitudinal centerline-to-centerline distances of four adjacent collectors installed in the array.)

collector, concentrating: a concentrating collector is a solar collector that uses reflectors, lenses, or other optical elements to concentrate the radiant energy passing through an aperture onto an absorber of which the surface area is smaller than the aperture area.

collector, flat-plate: a flat-plate collector is a nonconcentrating solar collector in which the absorbing surface is essentially planar.

collector, nonconcentrating: a nonconcentrating collector is a solar collector in which the absorber heat flux is not greater than the solar irradiance across the aperture area. It may or may not contain optical elements to direct the radiant flux onto the absorber.

concentration ratio: for purposes of this test standard, the concentration ratio of a concentrating solar collector is the ratio of the aperture area to the absorber area.

cover, collector: the collector cover glazing is the material covering the aperture to provide thermal and environmental protection.

efficiency, instantaneous thermal: the instantaneous thermal efficiency of a solar collector is the amount of energy removed by the transfer fluid per unit of gross collector area during the specified time period divided by the global total solar radiation incident on the collector per unit area during the same test period, under steady state or quasi-steady state.

irradiance, global: the global (or hemispheric) solar radiant energy is the quantity of solar energy incident upon a unit surface area in unit time through a unit hemisphere above the surface, expressed in W/m^2 ($Btu/[h·ft^2]$).

irradiance, instantaneous: instantaneous irradiance is the quantity of solar radiation incident on a unit surface area in unit time, measured in W/m^2 ($Btu/[h·ft^2]$).

irradiance, integrated average: the average integrated irradiance is the solar radiation incident on a unit surface area during a specified time period divided by the duration of that time period.

irradiance, total: the total irradiance is the quantity of radiant energy incident upon a surface over all wavelengths.

pyranometer: a pyranometer is a radiometer used to measure the global total solar radiation incident upon a surface per unit time per unit area. This energy includes the direct radiation, the diffuse sky radiation, and the solar radiation reflected from the foreground.

pyrgeometer: a pyrgeometer is a radiometer used for measuring the incoming atmospheric irradiance at wavelengths greater than approximately 4 μm on a black surface at ambient air temperature. The solar shortwave radiation is excluded from the energy measured.

pyrheliometer: a pyrheliometer is a radiometer used to measure the direct total radiation on a surface normal to the sun's rays.

quasi-steady state: "quasi-steady state" describes solar collector test conditions when the flow rate, fluid inlet temperature, collector temperature, solar irradiance, and ambient environment have stabilized to such an extent that these conditions may be considered essentially constant, as defined in Section 8. Further, the exit fluid temperature will, under these conditions, also be essentially constant.

simulator, solar irradiance: this is a device for simulating solar irradiance.

solar collector: a solar collector is a device designed to absorb incident solar radiation and to transfer the energy to a fluid passing through it.

standard air: standard air is air weighing 1.204 kg/m^3 (0.075 lbm/ft^3) and is equivalent in density to dry air at a temperature of 20°C (70°F) and a barometric pressure of 101.325 kPa (29.92 in. Hg).

standard barometric pressure: standard barometric pressure is 101.325 kPa (29.92 in. Hg).

temperature, ambient air: ambient air temperature is the temperature of the air immediately surrounding the solar collector being tested.

test period: the test period is the time over which quasi-steady-state conditions are maintained for each measured efficiency point.

time constant, collector: the collector time constant is the time required for the fluid leaving a solar collector to attain 63.2% of its steady-state change following a step change in irradiance.

transfer fluid, heat: the heat transfer fluid is the medium, such as air, water, or other fluid, that passes through the solar collector and carries the absorbed thermal energy away from the collector absorber plate.

3.2 Nomenclature

a,b,a',b'	=	constants used in incident angle modifier equations, dimensionless
A	=	cross-sectional area, m^2 (ft^2)
A_a	=	transparent frontal area for a nonconcentrating collector or the aperture area of a concentrating collector, m^2 (ft^2)
A_g	=	gross collector area, m^2 (ft^2)
A_r	=	absorbing area of a nonconcentrating collector or the receiving area of a concentrating collector, m^2 (ft^2)
b_o	=	constant used in incident angle modifier equation, dimensionless
B	=	effective angle for determining the equation of time, degrees
C_A	=	effective heat capacity of the solar collector, J/°C (Btu/[lbm·°F])
c_p	=	specific heat of the heat transfer fluid, J/(kg·°C) (Btu/[lbm·°F])
E	=	equation of time, min
$E_{\lambda i}$	=	solar spectral irradiance averaged over $\Delta\lambda_i$ centered at λ_i at air mass 1.5 W/(m^2·µm) (Btu/[h·ft^2·µm])
F'	=	absorber plate efficiency factor, dimensionless
F_R	=	solar collector heat removal factor, dimensionless
G	=	solar irradiance, W/m^2 (Btu/h·ft^2)
G_{bp}	=	direct solar irradiance component in the aperture plane, W/m^2 (Btu/h·ft^2)
G_{DN}	=	direct normal solar irradiance, W/m^2 (Btu/h·ft^2)
G_d	=	diffuse solar irradiance incident upon the aperture plane of collector, W/m^2 (Btu/h·ft^2)
G_{sc}	=	solar constant, 1,353 W/m^2 (429.2 Btu/h·ft^2)
G_t	=	global solar irradiance incident upon the aperture plane of collector, W/m^2 (Btu/h·ft^2)
h_a	=	enthalpy of the ambient air-water vapor mixture, J/kg (Btu/lbm)
$h_{f,e}$	=	enthalpy of the air-water vapor mixture at the exit of the air collector, J/kg (Btu/lbm)
$h_{f,i}$	=	enthalpy of the air-water vapor mixture at the inlet of the air collector, J/kg (Btu/lbm)
h_L	=	enthalpy of the leaking air-water vapor mixture, J/kg (Btu/lbm)
K	=	factor defined by Equation 8.11, dimensionless
$K_{\alpha\tau}$	=	incident angle modifier, dimensionless
K_d	=	diffuse irradiance incident angle modifier, dimensionless
K_1	=	incident angle modifier for biaxial collector, dimensionless
K_2	=	incident angle modifier for biaxial collector, dimensionless
L_{loc}	=	longitude, degrees west
L_{st}	=	standard meridian for local time zone, degrees west
LST	=	local standard time, decimal hours
LSTM	=	local standard time meridian, degrees west
AST	=	apparent solar time, decimal hours
m	=	air mass, dimensionless
$\dot{m}$	=	mass flow rate of the heat transfer fluid, kg/s (lbm/h)
$\dot{m}_e$	=	downstream air mass flow rate, kg/s (lbm/h)
$\dot{m}_i$	=	upstream air mass flow rate, kg/s (lbm/h)
$\dot{m}_L$	=	leakage air mass flow rate, kg/s (lbm/h)
n	=	day of year beginning with January 1 = 1
P	=	optical property, dimensionless
$p_{f,e}$	=	static pressure of heat transfer fluid at the outlet to the solar collector, Pa (lbf/in.^{2})
$p_{f,i}$	=	static pressure of heat transfer fluid at the inlet to the solar collector, Pa (lbf/in.^{2})
ΔP	=	pressure drop across the collector, Pa (lbf/ in.^{2})
Q_{mi}	=	measured volumetric airflow rate at the collector inlet, m^3/s (cfm)
Q_s	=	airflow rate corrected to standard conditions, m^3/s (cfm)
q_u	=	rate of useful energy extraction from the collector, W (Btu/h)
t_a	=	ambient air temperature, °C (°F)
t_f	=	$(t_{f,i} + t_{f,e})/2$, average fluid temperature, °C (°F)
$t_{f,e}$	=	temperature of the heat transfer fluid leaving the collector, °C (°F)
$t_{f,e,ss}$	=	temperature of the heat transfer fluid leaving the collector at a steady-state condition, °C (°F)
$t_{f,e,T}$	=	temperature of the heat transfer fluid leaving the collector at a specified time, °C (°F)
$t_{f,e,initial}$	=	temperature leaving collector at the beginning of time constant test period, °C (°F)
$t_{f,i}$	=	temperature of the heat transfer fluid entering the collector, °C (°F)
t_p	=	average temperature of the absorbing surface for a nonconcentrating collector, °C (°F)
t_r	=	average temperature of the absorbing surface for a concentrating collector, °C (°F)
Δt	=	temperature difference, °C (°F)
Δt_{ss}	=	temperature difference of inlet and outlet transfer fluid at steady state, °C (°F)
$\bar{t}$	=	effective temperature defined by Equation C-1, °C (°F)
$\bar{t}_{HHL}$	=	effective temperature for a given header heat

loss test flow rate, °C (°F)

T	=	time, decimal hours or seconds
T_1, T_2	=	time at the beginning and end of a test period, decimal hours or seconds
U_L	=	solar collector heat transfer loss coefficient W/($m^2 \cdot °C$) (Btu/[$h \cdot ft^2 \cdot °F$])
W_n	=	humidity ratio at the nozzle, kg H_2O/kg dry air (lbm H_2O/lbm dry air)
α	=	absorptance of the collector absorber surface for solar radiation, dimensionless
γ	=	fraction of specularly reflected radiation from the reflector or refracted radiation that is intercepted by the solar collector receiving area, dimensionless
θ	=	angle of incidence between direct solar rays and the normal to the collector surface or to the aperture, degrees
β	=	solar altitude angle, degrees
ϕ	=	solar azimuth angle, degrees
η_g	=	collector efficiency based upon gross collector area and inlet temperature,%
η'_g	=	collector efficiency based upon gross collector area and average fluid temperature,%
η_r	=	collector efficiency based upon absorber area and inlet temperature,%
η'_r	=	collector efficiency based upon absorber area and average fluid temperature,%
λ	=	wavelength, μm
λ_i	=	specific wavelength, μm
$\Delta\lambda_i$	=	wavelength interval, μm
ρ	=	reflectance of a reflecting surface for solar radiation, dimensionless
ρ_λ	=	spectral reflectance of a reflecting surface for solar energy, dimensionless
τ	=	transmittance of the solar collector cover plate, dimensionless
$(\tau\alpha)_e$	=	effective transmittance-absorptance product, dimensionless
$(\tau\alpha)_{e,n}$	=	effective transmittance-absorptance product at normal incidence, dimensionless
Ω	=	angle in Figure F.1
Γ	=	angle in Figure F.1
Ψ	=	angle in Figure F.1
Σ	=	angle in Figure F.1

4. CLASSIFICATIONS

4.1 Generic Collector Types

Solar collectors may be classified according to their collecting characteristics, the way in which they are mounted (i.e., stationary or sun tracking), and the type of transfer fluid they employ.

4.1.1 Collecting Characteristics. A nonconcentrating or flat-plate collector is one in which the solar radiation absorbing surface is essentially flat and in which the aperture and the absorber are similar in area and geometry. A concentrating collector is one that usually contains reflectors or other optical means to concentrate the energy entering through the aperture to be incident upon a heat absorber of surface area smaller than the aperture.

4.1.2 Mounting. A solar collector can be mounted in a stationary position with a fixed azimuth and tilt angle (measured from the horizontal) or it may be adjustable as to tilt angle to follow the annual changes in solar declination; it may also be designed to track the sun in altitude and azimuth (alt-azimuth mounting) or in its apparent daily rotation about the earth (polar or equatorial mounting).

4.1.3 Type of Fluid. A collector may use either a liquid or a gas as the transfer medium.

4.2 Test Site Locations

All the specifications for collector orientation relative to the solar irradiance are given for test site locations in the Northern Hemisphere and western longitudes.

5. REQUIREMENTS

5.1 Solar collectors shall be tested in accordance with the provisions set forth in this section and in Section 8.

5.1.1 Testing of full-scale modules is preferred. The size of the collector to be tested shall be large enough so that the performance characteristics determined will be indicative of those that would occur when the collector is part of an installed system. If the collector is modular and the test is being done on one module, it should be mounted and insulated in such a way that the back and edge losses will be characteristic of those that will occur during operation on a structure.

5.1.2 For tests conducted outdoors to determine thermal efficiency, the collector shall be mounted in a location such that there will be no significant energy reflected or reradiated onto the collector from surrounding buildings or any other surfaces in the vicinity of the test stand for the duration of the test period. Care shall be taken to conduct the tests in a location or manner such that a condition of high ground reflectance is avoided. If significant reflection can occur, provision shall be made to shield the collector by the use of a nonreflective shield. In addition, the test stand shall be located so that no shadow will be cast onto the collector by any obstruction at any time during the test period.

5.1.3 The heat transfer fluid used in the solar collector during testing shall be the same fluid as recommended by the collector manufacturer and shall be the same fluid used throughout the entire test and shall have a known temperature dependence for its density and specific heat over the temperature range of the fluid during the test period. The mass flow rate of the heat transfer fluid shall be the same throughout the test sequence used to determine a thermal efficiency curve, time constant, and incident angle modifiers for a given collector.

However, when the manufacturer specifies a highly viscous heat transfer fluid (such as oil) for the heat transfer fluid, such fluids may be impractical to use when near ambient