INTERNATIONAL STANDARD

ISO 9459-1

First edition
1993-11-01

Solar heating — Domestic water heating systems —

Part 1: Performance rating procedure using indoor test methods

Chauffage solaire — Systèmes de chauffage de l'eau sanitaire — Partie 1: Méthodes d'essai à l'intérieur pour l'évaluation des performances

Reference number
ISO 9459-1:1993(E)

Contents

Page

1 Scope 1
2 Normative references 1
3 Definitions 2
4 Symbols and units 4
5 System classifications 5
5.1 Attribute 1 6
5.2 Attribute 2 6
5.3 Attribute 3 6
5.4 Attribute 4 6
5.5 Attribute 5 6
5.6 Attribute 6 6
5.7 Attribute 7 6
6 Requirements for indoor testing of solar domestic hot water systems 7
6.1 System requirements 7
6.2 Measurement requirements 8
6.3 Test method requirements 9
7 Indoor test procedures 12
7.1 Solar-only and solar-preheat systems 12
7.2 Solar-plus-supplementary systems 13
7.3 Hot water — Continuous draw test — Solar energy only 14
8 Recording and reporting of data 14

Annexes

A Test day specifications 18

International Organization for Standardization
Case Postale 56 • CH-1211 Genève 20 • Switzerland
Printed in Switzerland

B Collector loop heater — Equations to be used in controlling thermal output **20**

C Calculation of spectrum-weighted values of optical properties **24**

D Calculation of equivalent irradiance **25**

E Bibliography **27**

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

International Standard ISO 9459-1 was prepared by Technical Committee ISO/TC 180, *Solar energy*, Subcommittee SC 4, *Systems — Thermal performance, reliability and durability*.

ISO 9459 consists of the following parts, under the general title *Solar heating — Domestic water heating systems*:

- *Part 1: Performance rating using indoor test methods*
- *Part 2: Performance test for solar only systems*
- *Part 3: Performance test for solar plus supplementary systems*
- *Part 4: System performance characterization by means of component tests and computer simulation*
- *Part 5: System performance characterization by means of whole system tests and computer simulation*

Annexes A, B, C and D form an integral part of this part of ISO 9459. Annex E is for information only.

Introduction

International Standard ISO 9459 has been developed to help facilitate the international comparison of solar domestic water heating systems. Because a generalized performance model which is applicable to all systems has not yet been developed, it has not been possible to obtain an international consensus for one test method and one standard set of test conditions. It has therefore been decided to promulgate the currently available simple methods while work continues to finalize the more broadly applicable procedures. The advantage of this approach is that each part can proceed on its own.

ISO 9459 is divided into five parts within three broad categories, as described below.

Rating test

ISO 9459-1, *Performance rating using indoor test methods*, involves testing for periods of one day for a standardized set of reference conditions. The results, therefore, allow systems to be compared under identical solar, ambient and load conditions.

Black box correlation procedures

ISO 9459-2 is applicable to solar-only systems and solar-preheat systems. The performance test for solar-only systems is a "black box" procedure which produces a family of "input-output" characteristics for a system. The test results may be used directly with daily mean values of local solar irradiation, ambient air temperature and cold water temperature data to predict annual system performance.

ISO 9459-3 applies to solar plus supplementary systems. The performance test is a "black box" procedure which produces coefficients in a correlation equation that can be used with daily mean values of local solar irradiation, ambient air temperature and cold water temperature data to predict annual system performance. The test is limited to predicting annual performance for one load pattern.

Testing and computer simulation

ISO 9459-4, a procedure for characterizing annual system performance, uses measured component characteristics in the computer simulation program "TRNSYS". Procedures for characterizing the performance of system components other than collectors are also presented in this part of ISO 9459. Procedures for characterizing the performance of collectors are given in ISO 9806-1, ISO 9806-2 and ISO 9806-3.

ISO 9459-5 presents a procedure for dynamic testing of complete systems to determine system parameters for use in a computer model. This model may be used with hourly values of local solar irradiation, ambient air temperature and cold water temperature data to predict annual system performance.

The procedures defined in ISO 9459-2, ISO 9459-3, ISO 9459-4 and ISO 9459-5 for predicting yearly performance allow the output of a system to be determined for a range of climatic conditions.

The results of tests performed in accordance with ISO 9459-1 provide a rating for a standard day.

The results of tests performed in accordance with ISO 9459-2 permit performance predictions for a range of system loads and operating conditions, but only for an evening draw-off.

The results of tests performed in accordance with ISO 9459-4 or ISO 9459-5 are directly comparable. These procedures permit performance predictions for a range of system loads and operating conditions.

System reliability and safety will be dealt with in a future standard.

Solar heating — Domestic water heating systems —

Part 1:
Performance rating procedure using indoor test methods

1 Scope

This part of ISO 9459 establishes a uniform indoor test method for rating solar domestic water heating systems for thermal performance, under benchmark conditions.

It applies only to solar water heating systems designed solely to heat potable water to be supplied for domestic water usage.

The test procedures described in this part of ISO 9459 are applicable to systems of solar storage capacity of 0,6 m^3 or less. It includes procedures for testing solar domestic hot water systems either with solar irradiance simulators or thermal simulation (non-irradiated) methods.

The test procedures in this part of ISO 9459 which employ a non-irradiated solar collector array in series with a conventional heat source do not apply to integral collector storage systems, nor to systems in which thermosiphon flow occurs, nor to any system employing a collector/heat transfer fluid combination which cannot be tested in accordance with the collector test.

The test procedures in this part of ISO 9459 do not require the solar water heating system to be subjected to freezing conditions. Consequently, the energy consumed or lost by a system while operating in the freeze-protection mode is not determined.

This part of ISO 9459 is not generally applicable to concentrating or evacuated tube systems, unless the collimation requirements of 6.3.1.3 are met.

It is not intended to be used for testing the individual components of the system, nor is it intended to abridge any safety or health requirements.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this part of ISO 9459. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this part of ISO 9459 are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 9059:1990, *Solar energy — Calibration of field pyrheliometers by comparison to a reference pyrheliometer.*

ISO 9060:1990, *Solar energy — Specification and classification of instruments for measuring hemispherical solar and direct solar radiation.*

ISO 9806-1:—[1)], *Test methods for solar collectors — Part 1: Thermal performance of glazed liquid heating collectors including pressure drop.*

ISO 9845-1:1992, *Solar energy — Reference solar spectral irradiance at the ground at different receiving conditions — Part 1: Direct normal and hemispherical solar irradiance for air mass 1,5.*

ISO 9846:—[1)], *Solar energy — Calibration of a pyranometer using a reference pyrheliometer.*

1) To be published.

World Meteorological Organization, *Guide to Meteorological Instruments and Methods of Observation*, No. 8, 5th edition, WMO, Geneva, 1983, Chapter 9 — World radiometric reference, known as the WRR.

3 Definitions

For the purposes of this part of ISO 9459, the following definitions apply.

3.1 absorber: That part of a collector that receives radiant energy and transforms it into thermal energy.

3.2 accuracy: Ability of an instrument to indicate the true value of the measured physical quantity.

3.3 ambient air: Air in the space (either indoors or outdoors) surrounding the thermal energy storage device or solar collectors, whichever is applicable.

3.4 angle of incidence (of direct solar radiation): Angle between the solar radiation beam and the outward-drawn normal from the plane considered.

3.5 aperture area: Of a solar thermal collector, maximum projected area through which the unconcentrated solar radiation is admitted.

NOTE 1 For concentrating collectors, the gross aperture area includes any area of the reflector or refractor shaded by the receiver and its supports and including gaps between reflector segments within a collector module. Net aperture area, sometimes called effective aperture area, excludes any shaded area or gaps between reflector segments.

3.6 aperture plane: Plane at or above the solar collector through which the unconcentrated solar radiation is admitted.

3.7 area, gross collector: Maximum projected area of a completed solar collector module, exclusive of integral means of mounting and connecting fluid conduits. For an array of collectors, including devices such as evacuated tube or concentrating collectors, gross area includes the entire area of the array.

3.8 auxiliary energy: Energy provided by an auxiliary thermal (heat) source.

3.9 auxiliary thermal (heat) source: Source of thermal energy, other than solar, used to supplement the output provided by the solar energy system; usually in the form of electrical resistance heat or thermal energy derived from combustion of fossil fuels.

3.10 collector, solar; solar thermal collector: Device designed to absorb radiant energy and to transfer the thermal energy so gained to a fluid passing through it.

3.11 collector, concentrating: Solar collector that uses reflectors, lenses or other optical elements to redirect and concentrate the solar radiation passing through the aperture onto an absorber of which the surface area may be smaller than the aperture area.

3.12 collector, flat-plate: Non-concentrating solar collector in which the absorbing surface is essentially planar.

3.13 collector loop: Continuous path followed by the primary heat transfer fluid in a solar energy system.

3.14 collector loop heater: Heater installed within the collector loop when testing the solar domestic water heating system with a non-irradiated array.

3.15 collector tilt angle: Lower angle between the aperture plane of a solar collector and the horizontal plane.

3.16 control: Device for regulation of the solar thermal system or component in normal operation; can be manual or automatic.

3.17 direct irradiance: Irradiance produced by direct radiation on a given plane.

3.18 direct solar radiation: Radiation received from a small solid angle centred on the sun's disc, on a given plane.

NOTE 2 In general direct solar radiation is measured by instruments with field-of-view angles of up to 15°. Therefore a part of the scattered radiation around the sun's disc (circumsolar radiation) is included. More than 99 % of the direct solar radiation on the earth's surface is contained within the wavelength range from 0,3 µm to 3,0 µm.

3.19 domestic: For use in residential and small commercial buildings.

3.20 draw rate; water draw rate: Rate at which hot water is withdrawn from a system at a specified time.

3.21 equivalent length: Length of a straight section of pipe or duct causing the same pressure drop as that which actually occurs within the system at the same flowrate.

3.22 fluid transport: Transfer of air, water or other fluid between components of the system.

3.23 heat exchanger: Device specifically designed to transfer heat between two physically separated fluids. Heat exchangers may have either single or double walls.

3.24 heat transfer fluid: Fluid that is used to transfer thermal energy between components in a system.

3.25 irradiance: Power density of radiation incident on a surface, i.e. the radiant flux incident on a surface divided by the area of that surface, or the rate at which radiant energy is incident on a surface per unit area of that surface.

NOTE 3 Solar irradiance is often termed "incident solar radiation intensity", "instantaneous insolation", or "incident radiant flux density"; the use of these terms is deprecated.

3.26 load: Daily system hot water load defined as the product of the mass, specific heat and temperature increase of the water as it passes through the solar hot water system.

3.27 potable: Suitable for human consumption; drinkable.

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

3.29 preheating: See solar preheat system [5.1 b)].

3.30 pyranometer: Radiometer for measuring the irradiance on a plane receiver surface which results from the radiant fluxes incident from the hemisphere above within the wavelength range 0,3 µm to 3 µm.

NOTE 4 The spectral range given represents roughly the spectral range of solar radiation (also called solar or short-wave range) at the ground and is only nominal. Depending on the material used for the domes which protect the receiver surface of a pyranometer, the spectral limits of its responsivity approximate to the limits mentioned above.

3.31 pyrgeometer: Instrument for determining the irradiance on a plane receiving surface which results from the radiant fluxes incident from the hemisphere above within the approximate wavelength range 4 µm to 50 µm.

NOTE 5 The given spectral range is nearly identical with that of so-called terrestrial radiation or long-wave radiation, and is only nominal. Depending on the material used for the domes which protect the receiving surface of a pyrgeometer, the spectral limits of its responsivity approximate to the limits mentioned above.

3.32 pyrheliometer: Radiometer for measuring direct (solar) irradiance which results from the radiant fluxes incident from a well-defined solid angle whose axis is perpendicular to the plane receiver surface.

NOTE 6 According to this definition pyrheliometers are applied to the measurement of direct solar irradiance at normal incidence. The field-of-view angle of pyrheliometers ranges typically from 5° to 10°.

3.33 solar energy: Energy emitted by the sun in the form of electromagnetic radiation (primarily in the wavelength range 0,3 µm to 3 µm), or any energy made available by the reception and conversion of solar radiation.

3.34 solar contribution: Ratio of the energy supplied by the solar part of a system to the total load of the system.

3.35 solar noon: Local time of day, for any given location, when the sun is at its highest altitude for that day, i.e. the time when the sun crosses the observer's meridian.

3.36 solar radiation: Radiation emitted by the sun, practically all of which is incident at the earth's surface at wavelengths less than 3 µm; often termed "short-wave radiation".

3.37 solar irradiance simulator: Artificial source of radiant energy simulating solar radiation (usually an electric lamp or an array of such lamps).

3.38 solar storage capacity: Quantity of sensible heat that can be stored per unit volume of store for every degree of temperature change.

3.39 solar hot water system: Complete assembly of subsystems and components necessary to convert solar energy into thermal energy for the heating of water; may include an auxiliary heat source.

3.40 standard air: Air weighing 1,204 kg/m^3 which approximates dry air at a temperature of 20 °C and a barometric pressure of 101,325 kPa.

3.41 standard barometric pressure: Barometric pressure of 101,325 kPa at 0 °C.

3.42 storage device (thermal): Container(s) plus all contents of the container(s) used for storing thermal energy.

NOTE 7 The transfer fluid and accessories such as heat exchangers, flow switching devices, valves and baffles which are firmly fixed to the thermal storage container(s) are considered a part of the storage device.

3.43 storage tank volumetric capacity: Measured volume of the fluid in the tank when full.

3.44 temperature, ambient air: Temperature of the air surrounding the thermal energy storage device or solar collectors being tested.

3.45 time constant: Time required for a first-order system to change output by 63,2 % of its final change in output following a step change in input.

3.46 thermopile: Set of thermocouples wired consistently in series or parallel to measure small or average temperature differences.

4 Symbols and units

A_a collector module aperture area, in square metres;

$\frac{A_a F_R(\tau\alpha)_{e,n}}{A_g}$ intercept of the collector efficiency curve determined in accordance with collector tests, dimensionless;

$\frac{A_a F_R U_L}{A_g}$ slope of the collector efficiency curve determined in accordance with collector tests, in kilojoules per hour square metre degree Celsius [kJ/(h·m²·°C)];

A_g gross collector area, in square metres;

$c_{p,c}$ specific heat of the transfer fluid used in the collector during the collector tests, in kilojoules per kilogram degree Celsius [kJ/(kg·°C)];

$c_{p,s}$ specific heat of the transfer fluid used in the collector during the solar hot water system test, in kilojoules per kilogram degree Celsius [kJ/(kg·°C)];

$c_{p,w}$ specific heat of water, in kilojoules per kilogram degree Celsius [kJ/(kg·°C)];

D nozzle throat diameter, in metres;

F collector absorber plate efficiency factor, dimensionless;

F_R collector heat removal factor, dimensionless;

G_{bp} beam irradiance from solar irradiance measured in a plane parallel to the collector aperture, in kilojoules per square metre hour [kJ/(m²·h)];

G_d diffuse irradiance from solar irradiance measured in a plane parallel to the collector aperture, in kilojoules per square metre hour [kJ/(m²·h)];

G_t total (global) irradiance incident upon the aperture plane of the collector, in kilojoules per square metre hour [kJ/(m²·h)];

$K_{\alpha\tau}$ incident angle modifier, dimensionless;

M number of rows of collector modules in parallel in the collector array, dimensionless;

$\dot{m}_c$ mass flowrate of the transfer fluid through the collector during the collector tests, in kilograms per second;

m_j mass of the jth withdrawal of water, in kilograms;

$\dot{m}_s$ mass flowrate of the transfer fluid through the collector array during the solar hot water system test, in kilograms per second;

N number of collector modules in series in each parallel row in the collector array, dimensionless;

Q_{AUX} daily energy consumed for auxiliary heating in the solar hot water system, in kilojoules;

$Q_{L,NS}$ daily system hot water load defined as the product of the mass, specific heat, and temperature increase of the water as it passes through the solar hot water system for the case of no solar energy input, in kilojoules;

Q_{LOS} thermal losses from solar system during the test day, in kilojoules;

$Q_{L,S}$ daily system hot water load defined as the product of the mass, specific heat, and temperature increase of the water as it passes through the solar hot water system for the case of solar energy input, in kilojoules;

$\dot{Q}_{lh}$ rate of energy output from the collector loop heater in series with the non-irradiated solar collector array (if used), in kilojoules per hour;

Q_{PAR} daily energy consumed for parasitic power by pumps, controls, solenoid valves, etc. in the solar hot water system, in kilojoules;

Q_{OUTPUT} energy output from the collector loop heater (if used) during the test, in kilojoules;

Q_S daily net energy supplied by solar energy for the system during the test day, in kilojoules;

$\dot{Q}_u$ rate of useful heat output from the collector, in kilojoules per hour;

R rating number which is the ratio of the auxiliary plus parasitic energies to the daily system load during the solar day $[(Q_{AUX} + Q_{PAR})/Q_L]$, dimensionless;

sf fraction of hot water load supplied by solar energy, dimensionless;

t_a ambient air temperature, in degrees Celsius;

$t_{a,l}$ ambient air temperature in the laboratory during the system test, in degrees Celsius;

$t_{a,t}$ ambient air temperature specified for the test solar day, in degrees Celsius;

$t_{f,i}$ temperature of the transfer fluid entering the collector, in degrees Celsius;

$t_{f,e}$ temperature of the transfer fluid leaving the collector, in degrees Celsius;

t_i mixed temperature of the water withdrawn from the solar hot water system, in degrees Celsius;

$t_{p,m}$ mean plate temperature of the collector absorber, in degrees Celsius;

$t_{p,m,non}$ mean plate temperature of the collector absorber under non-irradiated conditions, in degrees Celsius;

t_{set} ultimate desired hot water delivery temperature after the addition of supplemental energy, in degrees Celsius;

$t_{w,j}$ mixed temperature of the jth withdrawal of water to the load, in degrees Celsius;

$t_{s,j}$ mixed temperature of the jth withdrawal of water from the solar tank, in degrees Celsius;

t_{main} temperature of the incoming cold water supply to the solar hot water system, in degrees Celsius;

U_L collector heat transfer loss coefficient, in kilojoules per hour square metre degree Celsius $[kJ/(h \cdot m^2 \cdot °C)]$;

V total volume draw as determined from no-solar-input test, in litres;

Subscripts

NS no solar energy input;

S solar energy input;

Greek symbols

α_n absorptance of the collector absorber coating to the solar spectrum at normal incidence, dimensionless;

θ angle of incidence between the direct solar beam and the normal to the collector aperture, in degrees;

θ_m angle of incidence between the beam irradiance from the solar irradiance simulator and the normal to the collector aperture, in degrees;

ρ_d specular reflectance of the cover plate assembly at an incident angle of 60°, dimensionless;

τ_n transmittance of the cover plate assembly to the solar spectrum at normal incidence, dimensionless;

$(\tau\alpha)_{e,n}$ effective transmittance–absorptance product for the collector at normal incidence, dimensionless;

$\sum_{j=1}^{n}$ summation over all water withdrawal periods during a test day.

5 System classifications

Solar domestic hot water systems are classified by seven attributes, each divided into two or three categories. The categories of each attributed are defined as shown in table 1.

Table 1 — Classification of solar domestic hot water systems

Attribute	Category		
	a	b	c
1	Solar only	Solar preheat	Solar plus supplementary
2	Direct	Indirect	
3	Open	Vented	Closed
4	Filled	Drainback	Draindown
5	Thermosiphon	Forced	
6	Circulating	Series-connected	
7	Remote storage	Close-coupled storage	Integral storage

5.1 Attribute 1

a) **Solar only** — system designed to provide solar heated domestic water without use of supplementary energy other than that required for fluid transport and control purposes.

b) **Solar preheat** — system not incorporating any form of supplementary heating and installed to preheat cold water prior to its entry into any other type of household water heater.

c) **Solar plus supplementary** — system which utilizes both solar and auxiliary energy sources in an integrated way and is able to provide a specified hot water service independently of solar energy availability.

5.2 Attribute 2

a) **Direct** — system in which the heated water that will ultimately be consumed passes through the collector.

b) **Indirect** (heat exchange) — system in which a heat transfer fluid other than the heated water ultimately consumed passes through the collector.

5.3 Attribute 3

a) **Open** — system in which the heat transfer fluid is in extensive contact with the atmosphere.

NOTE 8 In the USA the term "open system" encompasses both open and vented systems as herein defined.

b) **Vented** — system in which contact between the heat transfer fluid and the atmosphere is restricted either to the free surface of a feed and expansion cistern or to an open vent pipe only.

c) **Closed** (sealed or unvented) — system in which the heat transfer fluid is completely sealed from the atmosphere.

5.4 Attribute 4

a) **Filled** — system in which the collector remains filled with the heat transfer fluid.

b) **Drainback** — system in which, as part of the normal working cycle, the heat transfer fluid is drained from the collector into a storage vessel for subsequent reuse.

c) **Draindown** — system in which the heat transfer fluid can be drained from the collector and run to waste.

5.5 Attribute 5

a) **Thermosiphon** — system which utilizes only density changes of the heat transfer fluid to achieve circulation between collector and storage.

b) **Forced** — system in which heat transfer fluid is forced through the collector either by mechanical means or by externally generated pressure.

5.6 Attribute 6

a) **Circulating** — system in which heat transfer fluid circulates between the collector and a storage vessel or heat exchanger during operating periods.

b) **Series-connected** — system in which the water to be heated passes directly from a supply point through the collector to a storage vessel or to a point of use.

5.7 Attribute 7

a) **Remote storage** — system in which the storage vessel is separate from the collector and is located at some distance from it.

b) **Close-coupled storage** — system in which the storage vessel abuts the collector, and is mounted on a common support frame.