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ISO 9459-1

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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
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Contents

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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 $[kJ/(h \cdot m^2 \cdot °C)]$;

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 $[kJ/(kg \cdot °C)]$;

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

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

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 $[kJ/(m^2 \cdot h)]$;

G_d diffuse irradiance from solar irradiance measured in a plane parallel to the collector aperture, in kilojoules per square metre hour $[kJ/(m^2 \cdot h)]$;

G_t total (global) irradiance incident upon the aperture plane of the collector, in kilojoules per square metre hour $[kJ/(m^2 \cdot h)]$;

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

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

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.

c) **Integral storage** — system in which the functions of collection and storage of solar energy are performed within the same device.

6 Requirements for indoor testing of solar domestic hot water systems

6.1 System requirements

6.1.1 Test system configuration

The test configuration to be utilized is to be determined by the classification of the system as described in clause 5.

A representative test configuration is shown in figure 1 for the case of a non-irradiated collector array and a collector loop heater downstream of the non-irradiated collector array. The purpose of the bypass loop is to circulate the transfer fluid through the collector loop heater during those times when solar irradiance occurs but the solar domestic hot water system controller does not require the collector loop pump to be on. The bypass loop pump should not operate when the collector loop is on.

For the case where a solar irradiance simulator is used, the heater and bypass loop shown in the solar collector loop of figure 1 shall not be used.

Figure 1 is a schematic only; all components shall be installed according to manufacturer's instructions.

6.1.2 Test system installation

Tests shall be performed with the system components installed in accordance with manufacturer's installation instructions. In the absence of specific instructions from the manufacturer and if the collectors are normally mounted remote from the storage, the tests shall be performed with the total pipe length connecting the storage tank and the collectors a minimum of 15 m (7,5 m in the supply line and 7,5 m in the return line). In the case of an air collector array, the total duct length shall be specified by the manufacturer and the total of the duct and pipe lengths shall be a minimum of 15 m. The connection piping and ducting shall be insulated in accordance with the manufacturer's installation instructions. The collectors shall be mounted at the tilt angle specified by the manufacturer. If the system is to be tested using a non-irradiated solar collector array, a black radiation shield shall be mounted approximately

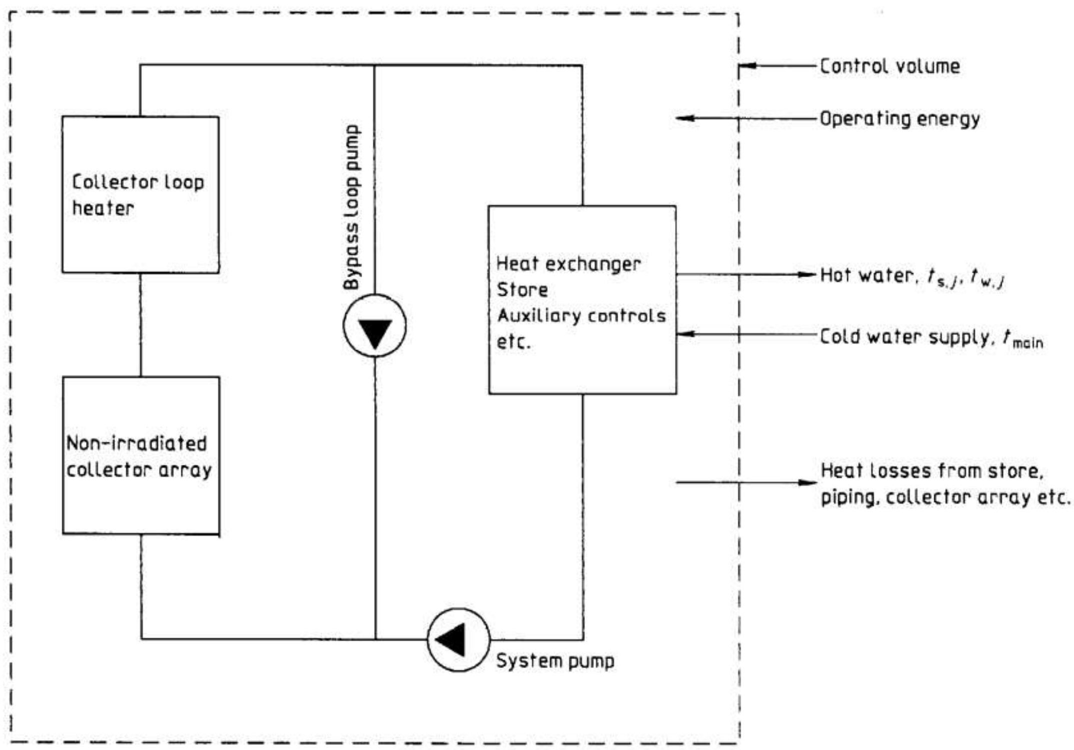

Figure 1 — Schematic representation of experimental apparatus for indoor test with non-irradiated collector array

0,6 m above the collector array and shall extend approximately 0,6 m beyond the perimeter on all sides. The shield shall consist of very low thermal capacity/insulative capacity material (e.g. poster board).

6.1.3 Liquid flow system

The water supply shall be capable of delivering water at conditions as specified for the test.

The cold water inlet and hot water outlet piping to and from the system being tested shall turn to a horizontal position through the shortest possible vertical distance practical when the fittings are in a vertical plane. The hot water outlet shall be provided with a quick-acting valve located beyond the point of temperature measurement and as close to the tank as possible.

Inlet and outlet connections and all piping to the point of temperature measurement in the system being tested shall be insulated with a material having a thermal resistance, R, not less than 0,70 °C·m²/W based on the outside area of pipe surface.

A flow control valve shall be installed to provide flow as required for the test.

6.1.4 Storage tank mounting

When provided as a separate component, the storage tank(s) shall be placed upon a 19 mm thick plywood platform supported by 50 mm × 100 mm runners. This mounting requirement is necessary for interlaboratory comparisons since heat losses from the bottom of storage tanks can be significant.

6.1.5 Fossil-fuel-fired auxiliary energy sources

Natural draft auxiliary water heaters shall be equipped with a vertical extension of flue pipe connected to the draft hood outlet pipe as specified by the prevailing building code. In the absence of a building code, use the manufacturer's specifications.

6.2 Measurement requirements

6.2.1 Solar radiation

A pyranometer shall be used to measure the short-wave radiation from the solar irradiance simulator. The pyranometer shall be a first class pyranometer as specified in ISO 9060, and shall be calibrated using a standard pyrheliometer according to ISO 9059 and ISO 9846. Any change in responsivity of more than ± 1 % over a one-year period shall warrant the use of more frequent calibration, or replacement of the instrument if the instability is permanent. If an instrument is damaged in any significant manner, it shall be recalibrated to check the stability of the calibration factor and the time constant. In case of replacement of one of the domes, the cosine response shall also be checked.

6.2.2 Temperature

6.2.2.1 Accuracy and precision

The accuracy and precision of the instruments for temperature measurement, including their associated readout devices, shall be within the limits given in table 2.

Table 2 — Accuracy and precision of instrument for temperature measurement

Values in degrees Celsius

Parameter	Instrument accuracy	Instrument precision
Temperature	± 0,5	± 0,2
Temperature difference across collector (and loop heater if used)	± 0,1	± 0,1
Temperature difference across hot water system (entering cold water to leaving hot water)	± 0,5	± 0,2

6.2.2.2 Ambient air temperatures

The average ambient air temperature surrounding the collector array to be used in the test shall be specified for the test solar day (see A.4).

For solar simulator testing, the allowable range of the ambient temperature shall be between 15 °C and 30 °C. During any test period, the ambient temperature shall not vary by more than ± 2 °C.

The average ambient air temperature at the storage tank and components during the test shall be controlled to a value specified to within ± 2 °C on a continuous 24 h basis (see A.4). Significant temperature differences can occur over short distances, therefore, in particular applications, the method of measurement shall be specified.

The ambient air temperature shall be measured in an aspirated enclosure using a sampling device shielded from direct irradiance, approximately 1,2 m from the floor and not closer than 1,5 m to the tank and system components.

NOTE 9 In most quasi-steady state test cases the time response of the temperature sensors is of secondary concern. Cases where the response time may be important are during the transient time constant tests and the incidence angle modifier tests at high incident angles using 6.3.2.6 b). From experience, thermocouples and thermopiles with time constants of less than 1 are preferred and resistance thermometers with time constants of less than 10 s are adequate.

6.2.2.3 Input water temperature

The temperature of the water supply to the system shall be controlled to t_{main}, as specified in annex A, within ± 2 °C.

6.2.3 Liquid flow

The accuracy of the liquid flowrate measurement, using the calibration if furnished, shall be ⩾ ± 1,0 % of the measured value in mass units per unit time.

6.2.4 Air flow

If the collector is an air heater and the test is being conducted with a non-irradiated array, the air flow in the collector loop shall be measured to an accuracy of ± 2 % or better.

6.2.5 Electrical energy

The electrical energy used shall be measured with an instrument and associated readout devices that are accurate to within ± 1 % of the reading or 15 W·h, whichever is greater.

6.2.6 Fossil fuels

The quantity of fuel used for auxiliary energy by the solar hot water system shall be measured with an instrument and associated readout device that is accurate to within ± 1 % of the reading. Where the supplementary energy is provided from gas, the accuracy of the calorific value of the gas fuel supplied shall be given.

6.2.7 Mass

Mass measurements shall be made to an accuracy of ± 1 %.

6.2.8 Elapsed time

Elapsed time measurements shall be made to an accuracy of ± 0,20 %.

6.2.9 Wind speed

Wind speed shall be measured with an instrument and associated readout device that can determine the integrated average wind speed for each test period to an accuracy of ± 0,5 m/s.

6.2.10 Data recorders

Analog and digital recorders used shall have an accuracy equal to or better than ± 0,5 % of the full scale reading and have a time constant ⩽ 1 s. The peak signal indication shall be between 50 % and 100 % of full scale.

Digital techniques and electronic integrators used shall have an accuracy ⩾ 1,0 % of the measured value.

The input impedance of data recorders shall be greater than 1 000 times the impedance of the sensors or 10 MΩ, whichever is higher.

In no case should 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, the smallest scale division shall not exceed 0,2 °C.

6.3 Test method requirements

6.3.1 Solar irradiance simulator

A solar irradiance simulator may be used for indoor testing, in lieu of a non-irradiated collector array in series with a conventional heat source, to determine the steady state thermal performance of a solar collector under controlled conditions of wind and ambient temperature. Typical simulators used for testing the thermal performance of solar collectors are described in the bibliography (see annex E).

Solar simulators employed in the testing procedure shall be used in accordance with the stated guidelines and limitations, and shall have the following minimum characteristics.

6.3.1.1 Spectral qualities

The simulator shall provide a spectral distribution of irradiance which duplicates the standard global radiation spectrum as given in ISO 9845-1 for air mass 1,5 for a 37° tilted surface and a total irradiance of 958,931 2 W/m^2.

Measurement of the solar simulator's spectral qualities shall be made in the plane of the collector over the wavelength range of 0,3 µm to 3 µm and shall be determined in 0,1 µm or smaller bandwidths.

The spectrum-weighted value of the transmittance–absorptance product at normal incidence or any other product of optical properties that characterizes the collector under test, calculated using the measured solar simulator spectrum, shall not differ by more than 3 % from the value of the transmittance–absorptance product calculated using the standard spectrum. The relevant spectral optical properties shall be provided by the manufacturer of the collector under test. Spectrum-weighted values of the optical properties shall be reported for both the standard and solar simulator spectrum. A method for calculating spectrum-weighted values is presented in annex C.

Solar simulator spectral measurements shall be obtained for each new set of lamps installed. With certain lamp types, such as filament lamps, the simulator spectrum may change significantly during the lifetime of the lamps. Measurements should be made as often as necessary to ensure that the calculated spectrum-weighted value of the transmittance–absorptance product for the system under test does not differ by more than 3 % from the value calculated using the standard spectrum.

6.3.1.2 Irradiance and irradiance uniformity

The simulated solar irradiance shall be measured in the test plane of the solar collector. The test plane shall be taken as the front cover of a glazed flat collector, the absorber plate of an unglazed flat plate collector, or the aperture plane of a concentrating collector. The collector array may be shaded during this measurement provided the shaded area is less than 3 % of the irradiated collector area during any hourly simulation period.

Since simulated solar radiation usually varies somewhat in intensity over the collector aperture, the value of irradiance over the test plane shall be representative of the average of measurements of irradiance taken on a uniform rectangular grid of maximum spacing of 15,0 cm. The instrument used to measure the test plane irradiance shall be equivalent to that specified for outdoor testing, or shall be calibrated in the simulated solar radiation against such a device. The uniformity of the irradiance shall be such that the highest and lowest measured values of irradiance shall not deviate from the average value by more than ± 10 %.

Variations in irradiance may occur during the test interval due to instability of the electrical supply and changes in the lamp output with temperature and age. The average value of irradiance shall not vary by more than ± 2 % over the duration of the test interval. The value of irradiance reported and used in the calculation of thermal performance shall be representative of the mean of the values experienced over the duration of each test interval.

6.3.1.3 Collimation

For typical flat plate collectors, the collimation shall be such that at least 90 % of the energy received at any point in the collector test plane shall have emanated from a region of the solar simulator contained within a subtended angle of 20° or less, when viewed from the point. This constraint limits the use of simulators to concentrating collectors with concentration ratios less than 3:1. However, it should be noted that a higher degree of collimation may be required for certain concentrating collectors, particularly those with the higher concentration ratios (near 3:1) and for collectors composed of glass tubes, such as evacuated tubular collectors. In these cases it shall be demonstrated that there is sufficient collimation relative to the collector. This might be demonstrated by indoor and outdoor test correlations.

6.3.1.4 Air flow across collector(s)

Fans or other means shall be used to simulate a predominantly uniform air flow across the collector during the pretest steadying and actual test periods. The temperature of the flowing air shall be within ± 1,0 °C of the ambient temperature measured as specified in 6.2.2. The air flow direction shall originate in a horizontal plane and be directed toward the collector within 30° from the vertical plane containing the centreline of the test collector (array). This simulated wind shall be maintained at a mean speed of 4,0 m/s ± 0,5 m/s and shall be measured before and after each test period in a plane parallel to the collector aperture and between 50 mm and 150 mm from the outer cover of the collectors. The air speed value is to be an average value measured over at least the central one-square-metre of the aperture, with a non-uniformity of not more than ± 0,5 m/s of the mean value.

6.3.1.5 Tilt angle

The tilt angle of the collector during testing shall be between 30° and 60° unless otherwise specified by the manufacturer of the collector. The specified tilt angle shall remain constant throughout the test.

6.3.1.6 Solar irradiance simulator incident angles

During simulation, the incident angle shall not exceed 60°. The incident angle during test shall be within 5° of the specified incident angle for a given hour of the test day (see annex A, table A.1).

6.3.1.7 Solar irradiance simulator output

The daily total integrated irradiance shall be within ± 5 % of the specified daily irradiation for the testing day, see annexes A and D.

6.3.1.8 Long-wave radiation

The long-wave (thermal) irradiance between 4 µm and 50 µm shall be measured in the plane of the collector aperture by a pyrgeometer or other equivalent instrument. The long-wave irradiance as measured during the test in the plane of the collector aperture shall not exceed that from a theoretical black body at ambient temperature by more than 50 W/m^2.

6.3.2 Non-irradiated collector array in series with a conventional heat source

A non-irradiated collector array in series with a conventional heat source may be used to simulate an irradiated solar collector array, in lieu of a solar irradiance simulator as described in 6.3.1. The collector is tested separately to provide the information required in 6.3.2.5 and the array's thermal output in the system test is obtained by using a combination of the non-irradiated collector array and a heat source in series in the collector loop.

6.3.2.1 Collector controller temperature sensor

The temperature sensor, designed to be installed on or in the vicinity of the solar collector array and connected to the system controller for starting and stopping the collector loop pump or blower, shall be installed on the surface or inside of the pipe or duct (under the insulation) downstream of the non-irradiated array and collector loop heater but as close to the exit of the second device as is practical.

6.3.2.2 Electric heaters

If an electrical heating element is used in the collector loop heater, the heating element shall be immersed in the fluid stream of the transfer fluid and the thermal losses shall be less than 2 % of the input. Under these conditions, the measured collector heater input can be taken as the heater output. If the losses are more than 2 % of the input, a means of measuring the energy delivered to the fluid by the heater shall be provided.

6.3.2.3 Peak thermal output

The collector loop heater shall be sized to deliver the peak rate of solar collector absorbed energy.

6.3.2.4 Pressure drop

The pressure drop across the collector loop heater shall be less than the pressure drop in an equivalent 6 m length of pipe or duct in the collector loop.

6.3.2.5 Time constant

The time constant of the collector loop heater shall be less than 2 min.

6.3.2.6 Separate test for solar collector

The solar collector shall have been previously tested and the following data obtained:

a) a curve of collector efficiency as a function of $(t_{f,i} - t_a)/G_t$ with the collector operating at near-normal incidence to the beam of the sun;

b) a curve of incident angle modifier as a function of incident angle θ or the parameter $[(1/\cos\theta) - 1]$;

c) the mass flowrate and the specific heat of the fluid used during the collector tests.

The collector heat transfer fluid used in the solar water heating system shall be the same as that used in the collector tests.

NOTE 10 See ISO 9806-1.

If a solar system is designed to be used with non-freezing (anti-freezing inhibitor) fluids, the test procedures described in this part of ISO 9459 must use these fluids according to the manufacturer's instructions.

6.3.2.7 Control of collector loop heater

The thermal output of the collector loop heater is calculated and regulated in accordance with the time intervals (see annexes A and D) specified by the test day, using the equations governing the thermal output (see annex B) and the values of $t_{f,i}$, $\dot{m}_s$ and $c_{p,s}$ that are measured (or calculated) prior to every change in input energy.

The calculation procedure to determine the desired *thermal output of the collector loop heater* is as follows:

a) the incident radiation on the collector surface, G_t, shall be specified as a function of time for the test solar day (see annex A);

b) the incident angle shall be specified or calculated as a function of time throughout the test day (see annex A);

c) using the results of step b) and the incident angle modifier data, the incident angle modifier shall be calculated as a function of time throughout the day;

d) the value of F_R shall be calculated as a function of time throughout the test day using equation (B.24);

e) the quantity Q_{lh} shall be calculated as a function of time throughout the test day using equation (B.15).

6.3.2.8 Collector loop thermal output

The collector loop thermal output, $t_{f,i}$ and $\dot{m}_s$, shall all be monitored as a function of time during the test. After the test is completed, a calculation of total daily collector array thermal output is required using the known variations of G_t and t_a throughout the test solar day, the measured values of $t_{f,i}$ and $\dot{m}_s$, and the collector thermal performance characteristics determined from the collector tests. The measured value of total daily collector loop thermal output from the system test shall be within ± 5 % of this calculated value.

7 Indoor test procedures

Procedures are described in this clause for testing the performance of three categories of solar domestic hot water systems: solar-only systems, solar-preheat systems, and solar-plus-supplementary systems. The test can be done by assembling the complete system and irradiating the collector array by use of a solar irradiance simulator as described in 6.3.1. Alternatively, the collector array may be non-irradiated if a controlled heating device (collector loop heater) is added in series with the collector array as described in 6.3.2. For either case, the system shall be tested for a test day with no solar input.

7.1 Solar-only and solar-preheat systems

7.1.1 Purpose

The purpose of this test is to determine the performance of a solar-only hot water system or of a solar-preheat hot water system. This test may also be used to consider the "solar-only" performance capabilities of a system that has supplementary heating.

7.1.2 Test procedure

The storage device(s) shall be filled with water at a specified temperature, on the morning of the first day (see annex A). The system shall be energized and shall be allowed to operate in its normal mode during the day and each successive day of the test. Any device which is intended to limit or control the operation of the solar energy collection equipment shall be set as recommended by the manufacturer. On each test day, water shall be withdrawn from the system at times, rates and duration as specified for the test day (see annex A). The energy content of the water withdrawn shall be determined by installed flowmeters and temperature sensors. The delivery temperature shall be measured and recorded at flow intervals no greater than 4,5 kg throughout the withdrawal period (see annex A).

The test shall be performed until the daily system solar energy contribution [see equation (3)] is ± 3 % of the value on the previous test day. If after the end of the fourth test day this convergence criterion is not met, data for day 5 shall be obtained. Then the test shall be stopped and the data for days 3, 4 and 5 averaged.

7.1.3 Measurements

During the test period, measurements of the daily energy consumed by the circulation system (pumps, controls, solenoid valves, etc.) shall be made, and daily thermal energy output from the collector loop heater (if used) shall be determined from measurements. These shall be recorded at the end of each test day. The energy consumed by the bypass loop controls, pump, fan and valves, if applicable, shall be obtained separately from the energy consumed by the solar domestic hot water system components.

During the withdrawal period, the mixed temperature of the incoming water and the mass and mixed temperature of each withdrawal shall be measured. If the collector loop heater is used, the thermal energy output from the heater, the mass flowrate through the collector array, and the entering fluid temperature to and temperature increase across the collector loop, which consists of the non-irradiated solar collector array and conventional heat source, shall all be determined for time intervals specified by the test day (see annex A).

7.1.4 Calculations

The daily system hot water load shall be calculated as:

$$Q_L = \sum_{j=1}^{n} c_{p,w}(t_{set} - t_{main})m_j \qquad \ldots (1)$$

The daily net energy supplied by solar energy shall be calculated as:

$$Q_S = \sum_{j=1}^{n} c_{p,w}(t_{s,j} - t_{main})m_j \qquad \ldots (2)$$

The daily solar contribution is given as:

$$SC = Q_s/Q_L \qquad \ldots (3)$$

All measurements used in this calculation shall be those for the final test day when convergence according to 7.1.2 is met. Otherwise average the data for days 3, 4 and 5.

7.2 Solar-plus-supplementary systems

7.2.1 Purpose

The purpose of this test is to determine the performance of a solar hot water system with integral supplemental heaters (solar-plus-supplementary system) for both a test day with solar energy input and a test day with no solar energy input.

7.2.2 Test procedure with solar energy input

The storage device(s) shall be filled with water at a specified temperature (see annex A) on the morning of the first day. The system, including integral heaters and controls, shall be energized and shall be allowed to operate in its normal mode during the day and each successive day of the test. The time for the beginning of the first and subsequent 24 hour test days shall be specified for the test day (see annex A).

Any device which is intended to limit or control the operation of the solar energy collection equipment shall be set as recommended by the manufacturer. If the system is designed so that the temperature of the delivered water is controlled by a thermostatic control on the auxiliary energy delivery system, this thermostat shall be set to deliver water at t_{set}. If the system is designed so that the temperature of the delivered water is controlled by a mixing valve, the mixing valve shall be set to deliver water at t_{set} and the control of the auxiliary heating system shall be set as recommended by the manufacturer. On each test day, water shall be withdrawn from the system at times, rates, duration and temperature t_{set} as specified by the test day (see annex A). If the outlet water temperature from the system is not maintained at t_{set}, an energy integrator may be used and the length of the time of the draw adjusted so that the same total amount of thermal energy output, measured above t_{main}, is delivered. The energy content of the water withdrawn shall be determined by the use of installed flowmeters and temperature sensors. The delivery temperature shall be measured and recorded at intervals, throughout the withdrawal period, for which the water mass removed is less than 4,5 kg. The solar energy input (via 6.3.1 or 6.3.2) shall follow the specifications given in table A.1, annex A.

The test shall be performed until the daily system supplemental energy required (Q_{AUX}) is within 3 % of the value on the previous test day. If after the end of the fourth test day, this convergence criterion is not met, data for day 5 shall be obtained. Then the test shall be stopped and the data for days 3, 4 and 5 averaged.

7.2.3 Test procedure with no solar energy input

All of the specifications in 7.2.2 shall be followed, except that there shall be no solar energy input.

7.2.4 Measurements

All of the specifications in 7.1.3 shall be followed. In addition, the energy consumed for auxiliary heating shall be recorded and reported (see annex A).

7.2.5 Calculations

The daily system hot water load with and without solar energy input shall be calculated respectively, as follows.

a) With solar input:

$$Q_{L,S} = \sum_{j=1}^{n} c_{p,w}(t_{w,j} - t_{main})m_j \qquad \ldots (4)$$

b) Without solar input:

$$Q_{L,NS} = \sum_{j=1}^{n} c_{p,w}(t_{w,j} - t_{main})m_j \qquad \ldots (5)$$

A rating number R has been defined and is given by:

$$R = (Q_{AUX,S} + Q_{PAR,S})/Q_{L,S} \quad \ldots (6)$$

The daily net energy supplied by solar energy can be estimated by:

$$Q_S = Q_{L,S} + Q_{LOS} - Q_{AUX,S} - Q_{PAR,S} \quad \ldots (7)$$

where

$$Q_{LOS} \approx (Q_{AUX,NS} + Q_{PAR,NS}) - Q_{L,NS} \quad \ldots (8)$$

NOTE 11 The actual Q_{LOS} is a function of the temperature distribution in the store(s), which may be quite different when there is solar energy input. Hence, the solar contribution is only a good estimate without knowing Q_{LOS} during a test day with solar input.

The performance of the solar energy system shall be determined and reported using procedures in annex A and the test data sheet in table 4.

7.3 Hot water — Continuous draw test — Solar energy only

7.3.1 Purpose

The purpose of this test is to determine the capability of the solar hot water system to deliver hot water with no auxiliary energy source operating and during a continous draw-down.

7.3.2 Test procedure

The solar hot water system shall be installed, adjusted and operated as described in 7.1.2 or 7.2.2. Ten minutes after the last draw on the final test day, a special draw test shall be conducted. All auxiliary energy source thermostats (if any) shall be disabled. The cold water supply shall be adjusted to supply water at $t_{main} \pm 1{,}0$ °C. Water shall be withdrawn at a uniform flow rate as specified for the test day (see annex A).

7.3.3 Measurements

The temperature of the water shall be measured at a point as close to the storage tank(s) as possible and recorded immediately at the start of the draw and at not more than 4,5 kg intervals of water mass thereafter. The draw shall continue until the discharge temperature equals the inlet temperature ± 3,0 °C.

7.3.4 Calculations

A curve with outlet water temperature as the ordinate and quantity of water withdrawn as the abscissa shall be drawn using the test results.

8 Recording and reporting of data

Table 3 lists the measurements which shall be made during the tests to determine the fraction of the daily total hot water load supplied by solar energy. Table 4 specifies the data and information that shall be reported in testing the solar domestic hot water system.

Table 3 — Necessary data for indoor testing of solar domestic hot water systems

Item	Solar-only or solar-preheat systems	Solar-plus-supplementary systems
Date	×	×
Observers	×	×
Equipment nameplate data for system components	×	×
Number of collectors in system	×	×
Collector aperture area (m^2)	×	×
Collector gross area (m^2)	×	×
Storage tank outside dimensions (m)	×	×
Storage tank volumetric capacity (m^3)	×	×
Number and location of integral heating elements	O	×
Rating of integral heating elements	O	×
1) Mass flowrate through collector during the collector tests, $\dot{m}_C$ (kg/s)	×	×
1) Specific heat of heat transfer fluid used during the collector tests, $c_{p,c}$ [kJ/(kg·°C)]	×	×

	Item	Solar-only or solar-preheat systems	Solar-plus-supplementary systems
1)	Intercept of the collector efficiency curve determined in accordance with collector tests, $(A_a/A_g)F_R(\tau\alpha)_{e,n}$, dimensionless	×	×
1)	Slope of the collector efficiency curve determined in accordance with collector tests determined at a value of $(t_{set} - t_{a,t})/G_t$ at solar noon during the system test, $(A_a/A_g)F_RU_L$ [kJ/(h·m²·°C)]	×	×
1)	Effective transmittance–absorptance product at normal incidence as specified in 6.3.1 (and annex B), $(\tau\alpha)_{e,n}$, dimensionless	×	×
1)	Collector heat removal factor as determined in annex B, F_R, dimensionless	×	×
1)	Collector overall heat transfer coefficient as determined in annex B, U_L [kJ/(h·m²·°C)]	×	×
1)	Collector efficiency factor as determined in annex B, F', dimensionless	×	×
1)	Mass flowrate of the transfer fluid through the solar collector array during the system test (recorded at the specified time increments), m_s (kg/s)	×	×
1)	Specific heat of the transfer fluid through the solar collector array during the system test (determined at the specified time increments), $c_{p,s}$ [kJ/(kg·°C)]	×	×
1)	Temperature of the transfer fluid entering the solar collector array during the system test (recorded at the specified time increments), $t_{f,i}$ (°C)	×	×
1)	Temperature difference across the solar collector loop during the system test (recorded at the specified time increments), $t_{f,e} - t_{f,i}$ (°C)	×	×
	Ambient air temperature surrounding the system during the test (recorded at the specified time increments), $t_{a,i}$ (°C)	×	×
1)	Energy output from the collector loop heater (if used) during the test (recorded at the specified time increments), Q_{OUTPUT} (kJ)	×	×
	Energy consumed for auxiliary heating (recorded at the specified time increments) (kWh)	O	×
	Inlet water temperature to the system during the test (recorded during every draw), t_{main} (°C)	×	×
	Outlet water temperature from the system during the test (recorded during every draw), $t_{w,j}$ (°C)	×	×
	Mass of water withdrawn from the system during the test (recorded during every draw), m_j (kg)	×	×
1)	Daily energy output from the collector loop heater (if used), Q_{OUTPUT} (kJ)	×	×
	Daily energy consumed by the circulation and control apparatus (pumps, controls, solenoid valves, etc.), Q_{PAR} (kJ)	×	×
	Daily energy consumed for auxiliary heating, Q_{AUX} (kJ)	O	×
2)	Spectrum-weighted values of the transmittance–absorptance product for normal incidence for the standard spectrum, dimensionless	×	×
2)	Spectrum-weighted values of the transmittance–absorptance product for normal incidence for the solar simulator spectrum, dimensionless	×	×

1) Only recorded if the collector loop heater is used.

2) Only recorded if the solar irradiance simulator is used.

Table 4 — Sample test data sheet

General information

Name of manufacturer: ....

Solar domestic hot water system No.: ....

Construction details of the system

Collector aperture dimensions (m) and area (m^2): ....

Collector gross dimensions (m) and area (m^2): ....

Number of collectors in system: ....

$(A_a/A_g)F_R(\tau\alpha)_{e,n}$ (from collector tests): ....

$(A_a/A_g)F_R U_L$ determined at a value of $(t_{set} - t_{a,t})/G_t$ at solar noon during the system test (from collector tests):

....

Storage tank dimensions including insulation thickness (m)

Diameter: .... Height: .... Insulation thickness: ....

Description of the solar domestic hot water system including insulation, valves, circulation, piping, controls, and control set points: ....

....

....

Transfer fluid used and its thermal-physical properties

Fluid: ....

Specific heat: .... Density: .... Viscosity: ....

Description of the test apparatus, including configuration and instrumentation used in testing (include photographs). For a thermosiphon system, include the piping size and elevation of the storage tank above the solar collector array:

....

....

....

Tests

The solar contribution shall be determined and reported for the system under test.

At the beginning of the tests to determine solar contribution and thereafter in time increments specified in the test day, the following shall be reported if the collector loop heater is used:

Q_{OUTPUT} .... kJ

$t_{f,i}$ .... °C

$\dot{m}_s$ .... kg/s

For each withdrawal of water from the system during the tests to determine solar contribution, the following shall be reported:

m_j .... kg

$t_{W,J}$ .... °C

t_{main} .... °C

On a daily basis during the test to determine solar contribution, the following shall be reported:

$Q_{L,NS}$ .... kJ

$Q_{L,S}$ .... kJ

$Q_{AUX,NS}$ .... kJ

$Q_{AUX,S}$ .... kJ

$Q_{PAR,NS}$ .... kJ

$Q_{PAR,S}$ .... kJ

Q_{LOS} .... kJ

Q_S .... kJ

R ....

SC ....

For the hot water supply rating tests, a curve of outlet water temperature as the ordinate versus quantity of water withdrawn as the abscissa shall be reported, both with (if appropriate) and without the use of an auxiliary energy source.

Annex A
(normative)

Test day specifications

This annex provides a standardized set of test conditions for comparing the performance of different domestic water heating systems.

A.1 Energy load or energy content of hot water delivered by system

Q_L Solar-only $= \Sigma m_j c_{p,w}(t_{set} - t_{main})$

Q_L Solar-preheat $= \Sigma m_j c_{p,w}(t_{set} - t_{main})$

Q_L Solar-plus-supplementary $= \Sigma m_j c_{p,w}(t_{w,j} - t_{main})$

A.2 Energy supplied by solar energy

Q_S Solar-only $= \Sigma m_j c_{p,w}(t_{s,j} - t_{main})$

Q_S Solar-preheat $= \Sigma m_j c_{p,w}(t_{s,j} - t_{main})$

Q_S Solar-plus-supplementary $= \Sigma m_j c_{p,w}(t_{s,j} - t_{main})$

A.3 Test period

The test period can be shortened by at least one day if the system is preheated with 45 °C water. Since the test is carried out indoors, the time at which each 24 hour period is begun is arbitrary. However, in the rating day specifications given below, the clock time for beginning the first and subsequent test days for energy calculations is 1700 hours.

A.4 Test conditions

The test conditions shall be set as follows:

a) collector tilt angle: 45° from horizontal unless manufacturer specifies differently;

b) average ambient air temperature, t_a: 20 °C ± 2 °C;

c) input water temperature, t_{main}: 15 °C ± 2 °C;

d) set temperature for auxiliary tank, t_{set}: specified by manufacturer but not less than 49 °C;

e) water draw rate: 10 l/min ± 1 l/min;

f) wind speed: see 6.3.1.4;

g) water draw schedule: see table A.1. Five equal volume draws for a total draw of 100 l, 200 l or 300 l shall be used. For solar-plus-supplementary systems, determine the draw volume during the no-solar-input test. In performing this test, first establish equilibrium. Take first draw at the specified flowrate. Monitor delivery temperature. Record the volume at which the temperature drops to 35 °C. Choose the daily draw volume to be that which is immediately below the volume at which the temperature dropped to 35 °C.

For solar-only systems, the test volume shall be selected by the manufacturer from 100 l, 200 l or 300 l. The laboratory shall test for the specified conditions and monitor the temperature during the draws. The solar energy contributed and the quantity of energy below and above 35 °C delivery temperature shall be recorded with the results.

h) solar radiation schedule: see table A.1. Diffuse irradiance shall be constant at 160 W/m^2 throughout the solar day.

Table A.1 — Conditions for thermal performance test of SDHW systems

Time	Incident radiation			Hour angle, ω	Incident angle, θ	Load, V
	Non-solar day	Solar day				
(h)	[kJ/(m²·h)]	G_{bp} [kJ/(m²·h)]	G_d [kJ/(m²·h)]	(°)	(°)	(litres)
0800-0900	0	694	576	− 60	60	0,2 V
0900-1000	0	1 224	576	− 45	45	
1000-1100	0	1 624	576	− 30	30	
1100-1200	0	1 884	576	− 15	15	
1200-1300	0	1 964	576	0	0	0,2 V
1300-1400	0	1 884	576	15	15	
1400-1500	0	1 624	576	30	30	
1500-1600	0	1 224	576	45	45	
1600-1700	0	694	576	60	60	0,2 V
1700-1800						0,2 V
1800-1900						
1900-2000						0,2 V
Total	0	12 816	5 184			V

Annex B
(normative)

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

As outlined in clause 6 and clause 7 of this part of ISO 9459, the solar hot water system may be tested in the laboratory using a non-irradiated solar collector array with a collector loop heater installed downstream of the array and controlled to supply the collector absorbed energy to the flow loop. The purpose of this annex is to derive the governing equations to be used in controlling the thermal output of the heater. The derivations are taken mainly from references [11], [32] and [33] (see annex E).

B.1 Irradiated solar collector — Thermal performance

The thermal performance of an irradiated solar collector operating under quasi-steady-state conditions can be described by either of the following equations:

$$\frac{\dot{Q}_u}{A_a} = [K_{\alpha\tau} F_R (\tau\alpha)_{e,n} G_t] - [F_R U_L (t_{f,i} - t_a)] \qquad \text{... (B.1)}$$

or

$$\frac{\dot{Q}_u}{A_a} = [K_{\alpha\tau} (\tau\alpha)_{e,n} G_t] - [U_L (t_{p,m} - t_a)] \qquad \text{... (B.2)}$$

Equating the two equations and solving for $t_{p,m}$:

$$t_{p,m} = F_R (t_{f,i} - t_a) + \frac{K_{\alpha\tau} G_t (\tau\alpha)_{e,n}}{U_L} (1 - F_R) + t_a \qquad \text{... (B.3)}$$

If the collector were in the laboratory and not irradiated, equation (B.3) would reduce to:

$$t_{p,m,non} = F_R (t_{f,i} - t_{a,l}) + t_{a,l} \qquad \text{... (B.4)}$$

The above equations can be used to derive the equations for the required net energy output of a collector loop heater that will result in the same performance as with the irradiated collector.

B.2 Collector loop heater downstream of non-irradiated collector array

In order for the net energy output of the collector loop to be the same when using a collector loop heater and non-irradiated collector, compared to when using an irradiated collector, then:

$$\frac{\dot{Q}_{lh}}{A_a} - U_L (t_{p,m,non} - t_{\alpha,l}) = K_{\alpha\tau} F_R (\tau\alpha)_{e,n} G_t - F_R U_L (t_{f,i} - t_{a,t}) \qquad \text{... (B.5)}$$

The left side of equation (B.5) represents the net energy output from the collector loop in the laboratory when the collector loop heater supplies energy to the loop and heat loss occurs from the non-irradiated collector. The right side of the equation represents the net output that would occur from an irradiated collector. Note that the loss coefficient for the collector, U_L, is assumed to be the same for both configurations. Since the collector loop heater is downstream of the non-irradiated collector, the inlet temperature of the fluid to the non-irradiated collector is identical to the inlet temperature of the fluid that would occur in the irradiated collector. Consequently, equation (B.4) can be introduced into the left side of equation (B.5) and the resulting equation solved for $\dot{Q}_{lh}$:

$$Q_{\text{lh}} = K_{\alpha\tau} \frac{A_{\text{a}}}{A_{\text{g}}} F_{\text{R}}(\tau\alpha)_{\text{e,n}} G_{\text{t}} A_{\text{g}} - \frac{A_{\text{a}}}{A_{\text{g}}} F_{\text{R}} U_{\text{L}} A_{\text{g}} (t_{\text{a,l}} - t_{\text{a,t}}) \qquad \text{. . . (B.6)}$$

Equation (B.6) is for a one-collector module array. The analysis is readily extended to a combination of M parallel rows of N collectors connected in series. Consider the situation where there are M collectors connected in parallel and no collectors connected in series ($N = 1$). Equation (B.6) becomes:

$$\dot{Q}_{\text{lh}} = K_{\alpha\tau} \frac{A_{\text{a}}}{A_{\text{g}}} F_{\text{R}}(\tau\alpha)_{\text{e,n}} G_{\text{t}} A_{\text{g}} - \frac{A_{\text{a}}}{A_{\text{g}}} F_{\text{R}} U_{\text{L}} M A_{\text{g}} (t_{\text{a,l}} - t_{\text{a,t}}) \qquad \text{. . . (B.7)}$$

Collector modules connected in series requires that the heat removal factor, F_{R}, in equation (B.7) be modified. For a one-solar-collector module:

$$F_{\text{R}} = \frac{\dot{m}c_{\text{p}}}{U_{\text{L}} A_{\text{a}}} \left[1 - \exp\left(- \frac{A_{\text{a}} F' U_{\text{L}}}{mc_{\text{p}}} \right) \right] \qquad \text{. . . (B.8)}$$

Where two collector modules are connected in series, each module has the same mass flowrate; however, the aperture area is doubled. With the assumption that the U_{L}s and Fs are equal for the two collectors, equation (B.8) becomes:

$$F_{\text{R2}} = \frac{\dot{m}c_{\text{p}}}{U_{\text{L}} 2A_{\text{a}}} \left[1 - \exp\left(- \frac{2A_{\text{a}} F' U_{\text{L}}}{\dot{m}c_{\text{p}}} \right) \right] \qquad \text{. . . (B.9)}$$

Algebraic manipulation of equations (B.8) and (B.9) yields:

$$F_{\text{R2}} = F_{\text{R}} \left[1 - \frac{(A_{\text{a}}/A_{\text{g}}) F_{\text{R}} U_{\text{L}} A_{\text{g}}}{2\dot{m}c_{\text{p}}} \right] \qquad \text{. . . (B.10)}$$

Thus for two collectors in series:

$$(F_{\text{R}} U_{\text{L}})_2 = (F_{\text{R}} U_{\text{L}}) \left[1 - \frac{(F_{\text{R}} U_{\text{L}}) A_{\text{a}}}{2\dot{m}c_{\text{p}}} \right] \qquad \text{. . . (B.11)}$$

and

$$[F_{\text{R}}(\tau\alpha)_{\text{e,n}}]_2 = [F_{\text{R}}(\tau\alpha)_{\text{e,n}}] \left[1 - \frac{(F_{\text{R}} U_{\text{L}}) A_{\text{a}}}{2\dot{m}c_{\text{p}}} \right] \qquad \text{. . . (B.12)}$$

Generalizing to any number, N, of identical collectors in series:

$$(F_{\text{R}} U_{\text{L}})_N = \frac{\dot{m}c_{\text{p}}}{NA_{\text{a}}} \left\{ 1 - \left[1 - \frac{(F_{\text{R}} U_{\text{L}}) A_{\text{a}}}{\dot{m}c_{\text{p}}} \right]^N \right\} \qquad \text{. . . (B.13)}$$

and

$$[F_{\text{R}}(\tau\alpha)_{\text{e,n}}]_N = \frac{[F_{\text{R}}(\tau\alpha)_{\text{e,n}}] \dot{m}c_{\text{p}}}{(F_{\text{R}} U_{\text{L}}) A_{\text{a}N}} \left\{ 1 - \left[1 - \frac{(F_{\text{R}} U_{\text{L}}) A_{\text{a}}}{\dot{m}c_{\text{p}}} \right]^N \right\} \qquad \text{. . . (B.14)}$$

Therefore, in the most general case where the heat source is located downstream of M rows of N collectors connected in series:

$$\dot{Q}_{\text{lh}} = \left\{ K_{\alpha\tau} \frac{A_{\text{a}}}{A_{\text{g}}} [F_{\text{R}}(\tau\alpha)_{\text{e,n}}] N\, G_{\text{t}}\, MN\, A_{\text{g}} \right\} - \left\{ \frac{A_{\text{a}}}{A_{\text{g}}} (F_{\text{R}} U_{\text{L}}) N\, MNA_{\text{g}} (t_{\text{a,l}} - t_{\text{a,t}}) \right\} \qquad \text{. . . (B.15)}$$

B.3 Collector loop heater upstream of non-irradiated collector array

Equating the net energy output from the collector loop for the two alternative test configurations (collector loop heater plus non-irradiated collector and irradiated collector), as was done above:

$$\frac{\dot{Q}^{\bullet}_{\mathrm{lh}} - U_{\mathrm{L}}}{A_{\mathrm{a}}}(t^{\bullet}_{\mathrm{p,m,non}} - t_{\mathrm{a,l}}) = K_{\alpha\tau}F_{\mathrm{R}}(\tau\alpha)_{\mathrm{e,n}}G_{\mathrm{t}} - F_{\mathrm{R}}U_{\mathrm{L}}(t_{\mathrm{f,i}} - t_{\mathrm{a,t}}) \quad \text{... (B.16)}$$

where $^{\bullet}$ indicates that $t_{\mathrm{p,m,non}}$ is different from the previous case because the collector loop heater is now upstream of the irradiated collector. Equation (B.4) is still valid except the inlet temperature of the fluid to the non-irradiated collector is also different from the previous case, due to the location of the collector loop heater:

$$t^{\bullet}_{\mathrm{p,m,non}} = F_{\mathrm{R}}(t^{\bullet}_{\mathrm{f,i}} - t_{\mathrm{a,l}}) + t_{\mathrm{a,l}} \quad \text{... (B.17)}$$

An energy balance on the collector loop heater results in the following expression for the exit temperature of the fluid from the heater (inlet temperature of the fluid to the non-irradiated collector, $t^{\bullet}_{\mathrm{f,i}}$) in terms of the inlet temperature of the fluid to the heater (identical to the inlet temperature of the fluid to the non-irradiated collector in the previous case, $t_{\mathrm{f,i}}$):

$$t^{\bullet}_{\mathrm{f,i}} = t_{\mathrm{f,i}} + \frac{\dot{Q}^{\bullet}_{\mathrm{lh}}}{\dot{m}_{\mathrm{s}}c_{\mathrm{p,s}}} \quad \text{... (B.18)}$$

Solving equations (B.16), (B.17) and (B.18) simultaneously:

$$\dot{Q}^{\bullet}_{\mathrm{lh}} = \frac{K_{\alpha\tau}(A_{\mathrm{a}}/A_{\mathrm{g}})F_{\mathrm{R}}(\tau\alpha)_{\mathrm{e,n}}G_{\mathrm{t}}A_{\mathrm{g}} - (A_{\mathrm{a}}/A_{\mathrm{g}})(F_{\mathrm{R}}U_{\mathrm{L}})A_{\mathrm{g}}(t_{\mathrm{a,l}} - t_{\mathrm{a,t}})}{1 - [(A_{\mathrm{a}}/A_{\mathrm{g}})(F_{\mathrm{R}}U_{\mathrm{L}})A_{\mathrm{g}}]/(\dot{m}_{\mathrm{s}}c_{\mathrm{p,s}})} \quad \text{... (B.19)}$$

Equation (B.19) is for a one-collector-module array. For the case where there are M collectors connected in parallel and no collectors connected in series ($N = 1$), equation (B.19) becomes:

$$\dot{Q}^{\bullet}_{\mathrm{lh}} = \frac{K_{\alpha\tau}(A_{\mathrm{a}}/A_{\mathrm{g}})F_{\mathrm{R}}(\tau\alpha)_{\mathrm{e,n}}G_{\mathrm{t}}MA_{\mathrm{g}} - (A_{\mathrm{a}}/A_{\mathrm{g}})F_{\mathrm{R}}U_{\mathrm{L}}MA_{\mathrm{g}}(t_{\mathrm{a,l}} - t_{\mathrm{a,t}})}{1 - [(A_{\mathrm{a}}/A_{\mathrm{g}})(F_{\mathrm{R}}U_{\mathrm{L}})MA_{\mathrm{g}}]/(\dot{m}_{\mathrm{s}}c_{\mathrm{p,s}})} \quad \text{... (B.20)}$$

In the most general case of M rows of N collectors connected in series:

$$\dot{Q}^{\bullet}_{\mathrm{lh}} = \frac{K_{\alpha\tau}(A_{\mathrm{a}}/A_{\mathrm{g}})F_{\mathrm{R}}(\tau\alpha)_{\mathrm{e,n}}G_{\mathrm{t}}MNA_{\mathrm{g}} - (A_{\mathrm{a}}/A_{\mathrm{g}})(F_{\mathrm{R}}U_{\mathrm{L}})MNA_{\mathrm{g}}(t_{\mathrm{a,l}} - t_{\mathrm{a,t}})}{1 - [(A_{\mathrm{a}}/A_{\mathrm{g}})(F_{\mathrm{R}}U_{\mathrm{L}})_{N}MNA_{\mathrm{g}}]/(\dot{m}_{\mathrm{s}}c_{\mathrm{p,s}})} \quad \text{... (B.21)}$$

Within the limits of the assumptions made in the above analysis, either configuration using the non-irradiated solar collector array can be used, provided the appropriate equation is used to control the collector loop heater [equation (B.15) or (B.21)]. However, locating the collector loop heater downstream of the collector array was chosen due to the simpler expression for $\dot{Q}_{\mathrm{l,h}}$, equation (B.15).

B.4 Flowrate correction techniques

It should be noted with reference to equations (B.1) and (B.15) that the value of F_{R} is dependent upon mass flowrate and the specific heat of the transfer fluid. Therefore, if the flowrate of the transfer fluid through the collector in the operation of the solar hot water system is different from the value used during the tests on the collector, then the value of F_{R} used in equation (B.15) must be modified from that value obtained from the collector tests. This can be done utilizing the following procedure:

a) Calculate $(\tau\alpha)_{\mathrm{e,n}}$ for the solar collector. For an ordinary flat-plate collector:

$$(\tau\alpha)_{\mathrm{e,n}} = \frac{\tau_{\mathrm{n}}\alpha_{\mathrm{p}}}{1 - (1 - \tau_{\mathrm{n}})\rho_{\mathrm{d}}} \quad \text{... (B.22)}$$

where

ρ_d = 0,16 for a one-cover glass system;

ρ_d = 0,24 for a two-cover glass system;

ρ_d = 0,29 for a three-cover glass system.

For concentrating or other types of collectors, the value of $(\tau\alpha)_{e,n}$ must be determined based on the geometrical and optical properties of the collector.

b) Calculate the value of F_R from the collector tests by:

$$F_R = \frac{y}{(A_a/A_g)\,(\tau\alpha)_{e,n}}$$

where

y is the intercept of the efficiency curve;

$(\tau\alpha)_{e,n}$ is calculated from equation (B.22).

c) Calculate the value of the U_L from the collector tests by:

$$U_L = \frac{(A_a/A_g)F_R U_L}{(A_a/A_g)F_R}$$

where $(A_a/A_g)F_R U_L$ is the absolute value of the slope of the efficiency curve at a value of $(t_{set} - t_{a,t})/G_t$ at solar noon during the system test.

d) Calculate the collector efficiency factor, F' by:

$$F' = \frac{-\dot{m}_c c_{p,c}}{A_a U_L} \ln\left[1 - \frac{F_R A_a U_L}{\dot{m}_c c_{p,c}}\right] \qquad \ldots (B.23)$$

e) Once F' is determined, F_R can be calculated for transfer fluid flowrate and specific heat of any system by using:

$$F_R = \frac{\dot{m}_s c_{p,s}}{M A_a U_L}\left[1 - \exp\left(-\frac{M A_a U_L F'}{\dot{m}_s c_{p,s}}\right)\right] \qquad \ldots (B.24)$$

It should be noted that the above correction technique is based on the assumption that the collector absorber plate efficiency factor, F', is not a function of flowrate. However, when using air as the transfer fluid the assumption is not valid. The correction technique should not be used under such conditions unless the flowrate per unit collector area of air through the array during the system test differs from that used in the collector tests by less than 25 %. Otherwise, the collector tests should be repeated using the collector flowrates per unit area existing in the test system.

Annex C
(normative)

Calculation of spectrum-weighted values of optical properties

The spectrum-weighted value of an optical property P can be computed as:

$$P = \frac{\sum_{i=1}^{n} P(\lambda_i) E_{\lambda_i} \Delta\lambda_i}{\sum_{i=1}^{n} E_{\lambda_i} \Delta\lambda_i} \qquad \ldots (C.1)$$

where

E_{λ_i} is the spectral irradiance at the wavelength λ_i;

$\Delta\lambda_i$ is the wavelength interval;

$P(\lambda_i)$ is the average value of the optical property in the wavelength interval;

n is the number of wavelengths for which each E_λ is known.

The wavelength intervals are given by:

$$\Delta\lambda_i = \frac{\lambda_{i+1} - \lambda_{i-1}}{2}$$

except for the first and last intervals, which are given by:

$$\Delta\lambda_1 = \lambda_2 - \lambda_1$$

and

$$\Delta\lambda_n = \lambda_n - \lambda_{n-1}$$

Values of λ_i and E_{λ_i} for the standard air mass 1,5 solar spectrum are tabulated in ISO 9845-1. Values of E for the simulator shall be measured in accordance with 6.3.1.1.

This spectrum-weighting procedure shall be applied to the relevant product of spectral optical properties (e.g. $\tau\alpha$, $\rho\tau\alpha$).

Annex D
(normative)

Calculation of equivalent irradiance

During thermal performance testing of SDHW systems, the effects of diffuse irradiance and the incident angle of beam irradiance occurring throughout the day should be accounted for. Table A.1 of annex A gives values of diffuse and beam incident solar radiation to be applied to the solar collector array and the corresponding incident angles for beam irradiance. When testing with a solar simulator, it is often not practical or possible to produce these conditions by varying the simulator lamp-to-collector orientation or the level of diffuse radiation in the simulator enclosure. In these cases or when using a thermal simulator, it is necessary to use an "equivalent irradiance". This is the power level (in the case of a thermal simulator) or radiation level that, when applied normal to the plane of the collector by a solar irradiance simulator, represents the irradiance that would have resulted had the conditions listed in table A.1 (annex A) actually occurred, including the effects of direct and diffuse irradiance and incident angle.

The thermal performance of an irradiated solar collector operating under quasi-steady-state conditions can be described using equation (B.1):

$$\frac{\dot{Q}_u}{A_a} = [K_{\alpha\tau} F_R (\tau\alpha)_{e,n} G_t] - [F_R U_L (t_{f,i} - t_a)]$$

or, letting $t_{f,m} = (t_{f,i} - t_{f,e})/2$:

$$\frac{\dot{Q}_u}{A_a} = [K_{\alpha\tau} F' (\tau\alpha)_{e,n} G_t] - [F' U_L (t_{f,m} - t_a)] \quad \text{... (D.1)}$$

In both cases the value of $K_{\alpha\tau} G_t$ can be approximated [26] as:

$$K_{\alpha\tau} G_t = K_{\alpha\tau} G_{bp} + K_d G_d \quad \text{... (D.2)}$$

or for a particular incident angle θ,

$$K_{\alpha\tau}(\theta) G_t = K_{\alpha\tau}(\theta) G_{bp} + K_d G_d \quad \text{... (D.3)}$$

where

$K_{\alpha\tau}(\theta)$ is the value of the incident angle modifier at an angle θ to a normal to the collector aperture plane;

G_{bp} and G_d are values of direct beam and diffuse solar irradiance incident on the aperture plane of the collector.

For most cases, values of K_d may be estimated from:

$$K_d = \int_{\theta=0}^{90°} K_{\alpha\tau}(\theta) \sin(2\theta) d\theta \quad \text{... (D.4)}$$

For collectors with essentially planar glazings and absorber surfaces, the value of K_d can be approximated by the value of $K_{\alpha\tau}(60°)$, i.e.:

$$K_d = K_{\alpha\tau}(60°) \quad \text{... (D.5)}$$

For systems that use collectors in which the value of $K_{\alpha\tau}$ is not symmetrical, K_d may vary depending on the axis in which it is evaluated (e.g. horizontal versus vertical incidence angles). It may be necessary to complete a more complex calculation of K_d. These effects may be most significant for tubular collectors or collectors employing trough structures, mirrors or lenses such that the geometries are characterized by biaxial symmetry. Cases of this type are described in Appendix E of reference [34].

To estimate the "equivalent irradiance" it is necessary to know the variation of incident angle modifier, $K_{\alpha\tau}$, with respect to the incident angle of beam irradiance, θ, for the solar collector array used in the SDHW system under evaluation. Using these values, the "equivalent irradiance" may be calculated as described below, for each of the following cases.

D.1 Case 1 — Using a solar simulator

When a solar irradiance simulator is used and the lamp-to-collector orientation is adjusted to a value θ_m but the irradiance is effectively all direct beam radiation, the effects of diffuse irradiance as specified in table A.1 should be accounted for. In this case the "equivalent irradiance", G_{eq}, (measured in the aperture plane of the collector) is given by:

$$G_{eq}K_{\alpha\tau}(\theta_m) = G_{bp}K_{\alpha\tau}(\theta) + G_dK_d \qquad \ldots (D.6)$$

or

$$G_{eq} = [G_{bp}K_{\alpha\tau}(\theta) + G_dK_d]/K_{\alpha\tau}(\theta_m) \qquad \ldots (D.7)$$

The "equivalent irradiance" can be related to the direct normal irradiance measured in a plane perpendicular to the direction of beam irradiance coming from the solar simulator, $G_{DN,m}$, according to:

$$G_{eq} = G_{DN,m}\cos(\theta_m) \qquad \ldots (D.8)$$

D.2 Case 2 — Using a solar simulator

For the case in which the lamp-to-collector orientation is adjusted each hour of the test such that $\theta_m = \theta$, where θ represents the values given in table A.1 corresponding to the test hour, then:

$$G_{eq} = G_{bp} + [G_dK_d/K_{\alpha\tau}(\theta)] \qquad \ldots (D.9)$$

where G_{dp} and G_d are specified in table A.1 for the corresponding value of θ during the test hour of the test day.

D.3 Case 3 — Using a solar simulator

For the case in which the lamp-to-collector orientation is fixed such that the radiation coming from the solar simulator is directly normal to the aperture plane of the solar collector, i.e. $\theta_m = 0°$, then:

$$G_{eq} = [G_{bp}K_{\alpha\tau}(\theta) + G_dK_d]/K_{\alpha\tau}(0°) \qquad \ldots (D.10)$$

which, since by definition $K_{\alpha\tau}(0°) = 1$, gives:

$$G_{eq} = G_{bp}K_{\alpha\tau}(\theta) + G_dK_d \qquad \ldots (D.11)$$

D.4 Case 4 — Using a thermal simulator

When testing with a thermal simulator, the power output of the heater shall be determined by the method described in annex B, accounting for the effects of diffuse irradiance and the incident angle of beam irradiance as specified in table A.1. In this case the value of $K_{\alpha\tau}G_t$ used in the calculation of the thermal simulator output (annex B) shall be given by:

$$K_{\alpha\tau}G_t - K_{\alpha\tau}(\theta)G_{bp} + K_dG_d \qquad \ldots (D.12)$$

where the values of θ, G_{bp} and G_d are the values given in table A.1 corresponding to the hour of the test day.

Annex E
(informative)

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