INTERNATIONAL STANDARD

ISO 9459-3

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Solar heating — Domestic water heating systems —

Part 3:
Performance test for solar plus supplementary systems

Chauffage solaire — Systèmes de chauffage de l'eau sanitaire —

Partie 3: Essai de performance pour systèmes solaires comportant des systèmes d'appoint

Reference number
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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 9459-3 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*:

— *Part 1: Performance rating procedure using indoor test methods*

— *Part 2: Outdoor test methods for system performance characterization and yearly performance prediction of 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 and B form an integral part of this part of ISO 9459. Annexes C to E are 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 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 procedure

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" system test 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 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 ISO 11924.

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Solar heating — Domestic water heating systems —

Part 3:
Performance test for solar plus supplementary systems

1 Scope

This part of ISO 9459 establishes test procedures for characterizing the performance of solar domestic water heating systems with in-tank auxiliary boosting, and for predicting annual performance in any given climatic conditions. A "black box" approach is adopted which involves no assumptions about the type of system under test, and the procedures are therefore suitable for testing all types of systems, including forced circulation, thermosiphon, freon-charged and integrated collector-storage systems.

This part of ISO 9459 applies to solar domestic water heating systems designed to heat potable water to be supplied solely for domestic water usage and is not intended to be applied to other systems. It is not generally applicable to concentrating systems.

The solar-plus-auxiliary test procedures in clause 7 are carried out in typical operational conditions, the only restriction on the nature of systems that can be tested is that there shall be no long-term energy storage, and the storage capacity in the solar preheat section of the tank shall be less than twice the specified daily total load (7.2.4).

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 will not be determined.

This part of ISO 9459 is limited to systems in which the solar collector and the storage tank are exposed to the same ambient conditions, and to systems in which the auxiliary energy (thermal or electric) can be monitored separately from the solar energy input.

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 9459-1:1993, *Solar heating — Domestic water heating systems — Part 1: Performance rating procedure using indoor test methods.*

ISO 9059:1996, *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 9846:1993, *Solar energy — Calibration of pyranometer using pyrheliometer.*

ISO 9806-1:1994, *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 9488:—[1], *Solar energy — Vocabulary.*

Guide to Meteorological Instruments and Methods of Observation[2], 5th edition, WMO-8, World Meteorological Organization, Geneva, 1983, Chapter 9.

3 Definitions

For the purposes of this part of ISO 9459, the definitions given in ISO 9488 apply.

4 Symbols

The symbols given in ISO 9459-1 and the following symbols apply.

a_1, a_2, a_3	coefficients used in performance characteristic equations
f	fraction of hot water load supplied by solar energy = $(Q_L - Q_{AUX})/Q_L$, dimensionless
fr	fractional energy savings relative to a conventional water heater = $(Q_{AUX,NS} - Q_{AUX,S})/Q_{AUX,NS}$, dimensionless
H	daily solar irradiation on the collector aperture plane, in megajoules per square metre
$Q_{AUX,S}$	auxiliary energy used by solar water heater, in megajoules per day
$Q_{AUX,NS}$	auxiliary energy used by conventional water heater = load + Q_{LOS}, in megajoules per day
Q_B	gas burner capacity (primary energy input), in watts
Q_F	fossil fuel primary energy consumption, in megajoules per day
Q_L	useful energy extracted from the system under load cycle operation, in megajoules per day
Q_M	heat loss and pilot maintenance rate for a gas storage water heater, in watts
t_a	ambient or surrounding air temperature, in degrees Celsius
t_{main}	cold water supply temperature, in degrees Celsius
t_d	mean water temperature of load drawn off, in degrees Celsius
t_e	effective heat sink temperature = $t_a + (t_a - t_{main})/2$, in degrees Celsius
u	surrounding air speed, in metres per second
UA	product of heat loss coefficient x area for a conventional water heater tank, in watts per kelvin

1) To be published.

2) The World Radiometric Reference Scale, known as the WRR Scale, is related to the International Pyrheliometric Scale 1956 (IPS 1956) by the identity WRR = 1.022 (IPS 1956).

V_c	volume of daily hot water consumption, in litres
ρ_w	density of water, in kilograms per cubic metre
η_f	efficiency of fossil fuel auxiliary source

Subscript

NS	no solar energy input

5 System classifications

Solar domestic hot water systems are classified by seven attributes, each divided into two or three categories. The categories of each attribute 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 collector storage	Integral collector 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 — 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 collector storage** — system in which storage vessel abuts the collector, and is mounted on a common support frame.

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

6 Requirements

6.1 System requirements

6.1.1 System type

Before applying the test procedure to a system with an auxiliary heater the following must be considered.

6.1.1.1 Systems with separate auxiliary heating

The solar performance of systems which have the auxiliary heater separated from the solar-heated storage tank will not be influenced by the auxiliary heater. However the maximum load size will be influenced by the presence of the auxiliary heater. Therefore these types of systems shall be tested with both the solar preheater and separate auxiliary heater considered as part of the same system.

6.1.1.2 Systems with manual auxiliary heater control

Systems which have the auxiliary heater integrated in the solar-heated storage tank, and in which the auxiliary heater is provided only for irregular intermittent operation (manually operated switch) shall not be tested using the procedure given in this part of ISO 9459. In order to achieve reproducible test results, such systems should be tested with the auxiliary heater switched off using the test procedure given in ISO 9459-2.

6.1.1.3 Systems with integrated auxiliary boosting

Systems which have a continuous or nighttime-use auxiliary heater integrated in the solar-heated storage tank shall be assessed using the test procedure specified in this part of ISO 9459.

6.1.2 Test system installation

Tests shall be performed with the system components installed in accordance with manufacturer's installation instructions. Any controller included in the system shall be set in accordance with the manufacturer's instructions. In the absence of specific instructions from the manufacturer, the system shall be installed as follows.

The system shall be mounted in a manner such as to ensure safety to personnel. Due consideration shall be paid to the likelihood of glass failure and the leakage of hot liquids. Mountings shall be able to withstand the effects of wind gusts.

Whenever possible the system shall be mounted on a structure provided by the manufacturer. If no mounting is provided then, unless otherwise specified (for example when the system is part of an integrated roof array), an open mounting system shall be used. The system mounting shall in no way obstruct the aperture of the collectors and the mounting structure shall not significantly affect the back or side insulation of the collectors or storage vessel.

Except for systems where the storage vessel is fixed to the collectors in some way (for example integral collector-storage systems and close-coupled thermosiphon systems) the store shall be installed in the lowest position allowed in the manufacturer's installation instructions, or with the bottom of the store located 5 m below the bottom of the collector if no specification is supplied by the manufacturer.

For systems where the hot water store is separate from the collectors, the total length of the connecting pipes between the collector and store shall be 15 m (i.e. 2 × 7,5 m). The diameter and insulation of the pipes shall be in accordance with the manufacturer's installation instructions.

6.1.3 Collector installation

Systems shall be tested at tilt angles recommended by manufacturers or specified for actual installations, provided that the angle used is specified with the test results. The specified tilt angle shall remain constant throughout the test. The collector shall be mounted in a fixed position facing the equator to within ± 10°.

The collector shall be mounted in a fixed position facing the equator to within ± 10°.

The collector shall be located such that a shadow will not be cast onto the collector at any time during the test period.

The collector shall be located where there will be no significant solar radiation reflected onto it from surrounding buildings or surfaces during the tests, and where there will be no significant obstructions in the field of view.

The temperature of surfaces adjacent to the system shall be as close as possible to that of the ambient air. For example, the field of view of the system shall not include chimneys, cooling towers or hot exhausts.

6.1.4 Liquid flow system

A test loop of the type shown in figure 1 shall be used. The piping used in the loop shall be suitable for operation at temperatures up to 95 °C. Pipe lengths should be kept short. In particular, the piping between the outlet of the cold water temperature regulator and the inlet to the storage vessel shall be minimized, to reduce the effects of the environment on the inlet temperature of the water. This section of pipe shall be insulated to ensure a rate of heat loss of less than 0,2 W/K and be protected by a reflective weatherproof coating.

Pipework between the temperature-sensing points and the store (inlet and outlet) shall be protected with insulation and reflective weatherproof covers extending beyond the positions of the temperature sensors, such that the calculated temperature gain or loss along either pipe does not exceed 0,01 K under test conditions. Flow mixing devices such as pipe bends are required immediately upstream of temperature sensors.

The flow control device and flow meter shall be installed on the cold water inlet pipe, so that readings are not affected by temperature changes. The flowrate during the draw-off of hot water from the store is important, as it may influence the draw-off temperature profile. The flow controller shall maintain a constant flowrate through the storage vessel of (600 ± 50) l/h.

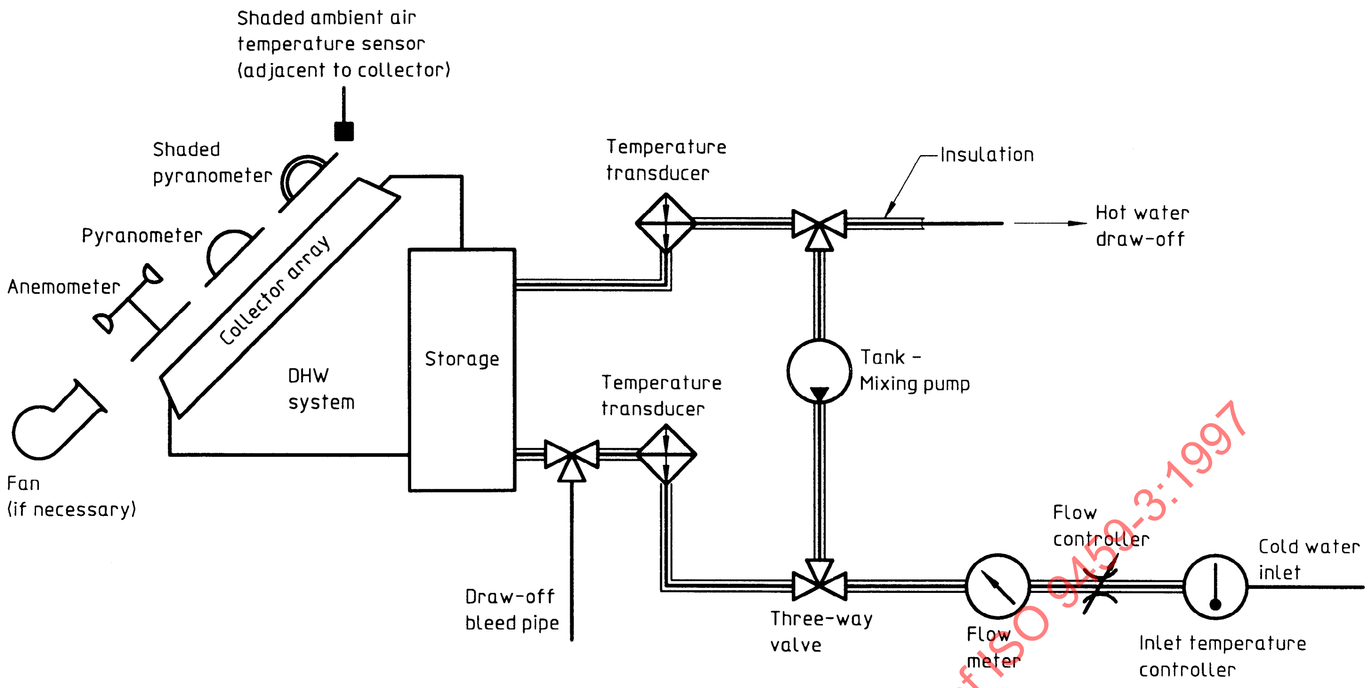

Figure 1 — Schematic representation of experimental apparatus for system performance test

When testing systems with pumped circulation, a flow meter shall be installed to measure the fluid flowrate in the collector loop to an accuracy of ± 5 %.

NOTE — This measurement is excluded from the requirements of 6.2.3 which require flow measurements to have an accuracy of ± 1 %.

The heat transfer fluid used in the system during testing shall be the fluid recommended by the manufacturer. When testing forced-circulation systems, the fluid flowrate recommended by the manufacturer shall be used. If the solar collector loop is designed to be used with non-freezing fluids, the test procedures in this standard shall be carried out with these fluids, according to the manufacturer's requirements.

6.2 Measurement requirements

6.2.1 Solar radiation

Solar radiation measurement shall be carried out in accordance with ISO 9060 and WMO No. 8.

A pyranometer shall be used to measure the solar radiation on the collector aperture plane. The pyranometer shall be a first class (or better) pyranometer as specified in ISO 9060. The recommended practice described in ISO/TR 9901 should be observed.

The pyranometer shall be calibrated using a standard pyrheliometer in accordance with ISO 9846 and ISO 9059. Any change in the responsivity of more than ± 1% over a 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 should also be checked.

6.2.2 Temperature

6.2.2.1 Accuracy, precision and response time

The accuracy and precision of the instruments including their associated readout devices shall be within the limits given in table 2. The response time shall be less than 5 s.

Table 2 — Accuracy and precision of instruments for temperature measurement

Parameter	Instrument accuracy	Instrument precision
Temperature, ambient air	± 0,5 °C	± 0,2 °C
Temperature, cold water inlet	± 0,1 °C	± 0,1 °C
Temperature difference across hot water system (cold water in to hot water out)	± 0,1 K	± 0,1 K
Temperature difference across auxiliary thermal energy source	± 0,1 K	± 0,1 K

6.2.2.2 Ambient temperature

The ambient air temperature shall be measured using a shaded aspirated sampling device approximately 1 m above the ground, not closer than 1,5 m to the tank and system components and not further away than 10 m from the system.

6.2.2.3 Input water temperature

The tests are carried out in typical domestic operational conditions hence there is no need to control the cold water supply temperature. The data correlation function accounts for the effect of cold water temperature. However, to avoid measurement errors due to abrupt changes in cold water temperature during a draw-off, the cold water should be drawn from a mixed reservoir of volume greater than the load volume. The temperature of the cold water reservoir should be typical of the location for which the tests are being performed.

6.2.3 Liquid flow

The accuracy of the liquid flowrate measurement shall be equal to or better than ± 0,1 % of the measured value, in mass units per unit time.

6.2.4 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 to 15 W·h, whichever is greater.

6.2.5 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 within ± 1 % of the reading. Where the energy is provided from gas, the accuracy of the calorific value of the gas fuel supplied shall be given.

If the auxiliary input to the solar tank is from a fossil fuel thermal source, the energy delivered into the solar tank shall be measured using temperature and flow transducers in accordance with 6.2.2 and 6.2.3.

6.2.6 Mass

Mass measurement shall be made with an accuracy of ± 1 %.

6.2.7 Elapsed time

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

6.2.8 Surrounding air speed

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

7 Test procedure

7.1 Principle

The procedure defined in this part of ISO 9459 accounts for mixing between the auxiliary-heated and solar-heated parts of the tank. The test is performed while the system is operating under a typical domestic load cycle. The load cycle consists of a fixed-energy draw-off pattern over each day for a range of daily loads. As the solar contribution is influenced by auxiliary heating, the tests are performed for a range of solar conditions ranging from a no-solar test (auxiliary only) to solar tests that give high solar contribution.

Each test consists of a series of measurements over a period of five to 15 days, selected so that the irradiation conditions are similar on the day before and the last day of the test period. The averaging process is necessary in order to minimize variability of the data due to changes in storage tank internal energy.

Due to the need to establish test data for a range of operating conditions under quasi-steady state conditions, the test period may be as long as 8 to 12 weeks. Monitoring of solar irradiation conditions shall be carried out for a minimum of 21 stable test periods, as detailed in 7.4.2.

The procedure requires long-term monitoring of daily performance for a period that is a function of the weather conditions at the test size. Testing shall be continued until the specfied number of stable test periods have been recorded.

7.2 Test conditions

7.2.1 Surrounding air speed

The performance of some collectors is sensitive to air speeds over the collector in the range ⩽ 3 m/s. In order to maximize the reproducibility of results, collectors that are sensitive to surrounding air speed shall be mounted such that air with a mean speed of between 3 m/s and 5 m/s will freely pass over the aperture, back and sides of the collector. Artificial wind generators shall be used as necessary to achieve these wind speeds. The average speed of the air flowing over the collector shall lie between 3 m/s and 5 m/s when measured in the plane of the collector at a distance of 50 mm from the surface of the cover, and at no point over the collector aperture shall the speed deviate from the mean by more than ± 25 %. The speed at any point over the collector aperture shall remain steady and the temperature of the air leaving the wind generator shall lie within ± 1 °C of the ambient air temperature.

Warm currents of air, such as those which rise up the walls of a building, shall not be allowed to pass over the system. Systems tested on the roof of a building shall be located at least 2 m away from the edge of the roof.

Collectors designed for integration into a roof may have their backs protected from the wind, although this shall be reported with the test results.

7.2.2 Auxiliary heater operation

The auxiliary heater may be operated on a continuously available basis or restricted by a time clock to simulate any required tariff supply system. Thermostat settings shall be as recommended by the manufacturer. The thermostat and time clock operation shall not be altered during the tests.

7.2.3 Draw-off schedule

The draw-off of hot water energy during the tests shall be specified in table 3.

NOTE — The draw-off schedule in table 3 is indicative of an evening peak load, which will show the effect of nighttime off-peak boosting on the no-solar capacity of the system. To facilitate comparison between different solar water heaters, it is important that a single draw-off schedule be used for all tests. The loads may be applied within 30 min of the times specified in table 3.

Each hot water energy draw-off episode shall be initiated at the specified time intervals by a time switch and shall be terminated by a heat-metering apparatus when the total specified amount of energy for that episode has been delivered.

Table 3 — Load draw-off schedule

Time of day h	Percentage of daily total load drawn off
07:00	15
08:00	15
11:00	10
13:00	10
15:00	12,5
16:00	12,5
17:00	12,5
18:00	12,5

7.2.4 Load size

The manufacturer shall specify a daily total load that the particular system is designed to deliver under no-solar conditions, and a minimum acceptable delivery temperature.

7.3 No-solar test

7.3.1 General

The purpose of the no-solar test is to determine if the system can meet the load and delivery temperature specified by the manufacturer when the solar input is zero (i.e. to ensure that the auxiliary heating system is adequate). While applying the load draw-off sequence specified in table 3, the ability of the system under test to meet the specified daily total load for the specified minimum temperature shall be assessed.

If the manufacturer elects to change the thermostat setting, electricity tariff or load because of failure to meet the original specifications, the no-solar test shall be repeated, in accordance with the new specifications. The new specifications shall also be applied in the solar test.

7.3.2 System configuration

For the no-solar test, all plumbing connections shall be as for a normal operating installation. The collector shall be shaded by an insulated cover supported 150 mm above the collector surface to leave a clear path for air movement over the collector. The cover should extend at least 200 mm beyond the edge of the collector to ensure that the collector is shielded from irradiation at all times. The underside of the cover should be black to reduce reflection from any surrounding roof surface.

The thermostat setting and auxiliary energy supply type selected for the no-solar tests shall be retained for the solar tests.

7.3.3 Test method

The system under test is connected to a cold water supply and filled with water at a temperature equal to the average annual water temperature ± 3 °C. The auxiliary energy source is switched on and the system is left to stabilize until the first thermostat cut-out occurs, following which the manufacturer's specified daily total load is verified using the draw-off sequence in table 3.

The system shall be operated with constant (within ± 2 %) daily energy draw-off for five days after the first thermostat cut-out. If the temperature of the water delivered falls below that specified, the draw-off shall be terminated at that point, and the test restarted with a lower load.

If the variation in daily auxiliary energy consumption among days 3, 4 and 5 is less than ± 2 % of the daily load, the performance shall be averaged over days 3, 4 and 5. If the variation in daily auxiliary energy consumption is greater than or equal to ± 2 %, the test period shall be extended to 8 days and the performance shall be averaged over days 3 to 8. Long test periods are necessary to account for daily variation in auxiliary energy consumption in systems that have large thermostat-dead bands.

Four no-solar test periods (each of duration three days or six days) should be evaluated.

7.4 Solar test

7.4.1 System loads

For the solar test, the performance of the system shall be evaluated for three (or more) different daily loads. The difference between the maximum and minimum loads shall be at least 0,5 times the load specified by the manufacturer for continuous boosting, and 0,75 times the specified load for nighttime boosting. Test loads may be selected in the range from approximately 0,5 times the specified system capacity to a maximum consistent with the specified minimum delivery temperature. The first load should be the specified system capacity. The other two loads should be selected so that the system operation is consistent with test period requirements and the specified minimum delivery temperature. The middle load shall be approximately halfway between the maximum and minimum loads. The exact relationship of the loads to the system capacity is not critical, provided the specified range of loads is used.

With the largest load, the delivery temperature may fall below the specified minimum temperature without this being considered as a failure. In such a case, the draw-off shall continue until either

a) the further volume of water drawn off is equal to the volume that would be required to complete the energy component of the draw-off cycle if the water remained at the limit temperature,

or

b) the temperature drops 5 K below the limit temperature,

whichever occurs first.

7.4.2 Test period

The system should be operated until seven stable test periods of five or more days' consecutive operation are recorded for each load.

The test periods may be based on a sliding 5-day to 15-day period. Thus, the first seven data points could be completed in a minimum of 11 days (plus two days initial stabilizing operation); however, the stability requirement of the test period may result in the rejection of some data.

To avoid selecting data from periods when there is a significant change of internal energy in the tank, and to minimize transient effects associated with outdoor operation, the performance data are averaged over consecutive sequences of 5 days' to 15 days' operation.

The test period shall meet the following requirements:

a) the system shall be operated with the required load for at least two days before the test period;

b) the change in daily auxiliary energy input to the system from the day before the test period to the last day of the test period shall be less than 3 % of the daily load;

c) the change in solar irradiation from the day before the test period to the last day of the test period shall be less than 5 MJ/(m^2·d);

d) daily loads shall be within ± 15 % of the average load over the test period;

e) the solar fraction f during the test period shall be less than 0,90;

NOTE — The purpose of this requirement is to avoid selecting test data from periods in which over-temperature safety devices may have operated.

f) The daily solar fraction f shall, on each day during the test period, be greater than the ratio of tank loss to load, where tank loss is the no-solar test tank loss, corrected to the ambient temperature during the solar test, i.e.:

$$(Q_{L,NS} - Q_{AUX,NS})\frac{(t_d - t_a)_S}{(t_d - t_a)_{NS}}$$

where

$Q_{AUX,NS}$ is the daily auxiliary energy consumption during the no-solar tests;

$Q_{L,NS}$ is the useful energy extracted from the daily load during no-solar tests;

t_d is the mean water temperature of load drawn off;

t_a is the ambient air temperature.

NOTE — The purpose of this requirement is to avoid selecting test data from periods of heavy rain or high winds when little solar energy is collected and the system operation may deviate from normal.

7.4.3 Measurements during test period

The performance of a solar water heater with integral auxiliary boosting is a function of the parameters $H/Q_{L,S}$ and $(t_d - t_e)/Q_{L,S}$ (see clause 4). To correlate outdoor test data, measurements shall cover a range of these two parameters. The specification of tests for three daily loads ensures a satisfactory range of the parameter $(t_d - t_e)/Q_{L,S}$. To ensure that a range of values of the parameter $H/Q_{L,S}$ is also included, the test periods shall satisfy the distribution specification in table 4. A minimum of four data points shall also be obtained from test period of medium to high solar contribution, i.e. four data points with $f > 0,4$.

If the initial 21 solar test measurements (at least seven for each load) fail to satisfy these distribution conditions, the tests should be continued with appropriate loads until the required distribution is obtained.

Table 4 — Required distribution of test measurements

Normalized ratio of solar irradiation to load energy $\frac{(H/Q_{L,S})}{(H/Q_{L,S})_{max}}$	Minimum number of data points
1 to 0,7 or 1 to 0,6	5
0,7 to 0,4 or 0,6 to 0,3	5
NOTE — $(H/Q_{L,S})_{max}$ = maximum value of $H/Q_{L,S}$ observed during the valid test periods.	

8 Analysis and presentation of results

8.1 Annual performance prediction

The results of the solar-plus-auxiliary system test are in the form of daily average measurements over stable test periods of 5 to 15 days. A large number of test periods are required (seven for each of the three loads for solar operation and four no-solar points) so that the variability of the data due to changes in storage tank internal energy over the test period can be minimized.

The correlation function developed from the test data can be used to predict the solar contribution to load energy for different values of

— solar irradiation
— ambient air temperature
— cold water supply temperature
— load energy

Extensive trials of the method have shown that the procedure has a repeatability of ± 3 % in relative solar contribution.

8.2 Calculation of annual energy savings

The data obtained from a minimum of 25 test periods shall be used to compute the annual energy savings as follows:

a) Determine, for a minimum of 25 valid solar test periods, the following factors:

i) average daily energy load, in megajoules per day, $\overline{Q}_{L,S}$

ii) mean hot water draw-off temperature, in degrees Celsius, $\overline{t}_d$

iii) mean cold water supply temperature, in degrees Celsius, $\overline{t}_{main}$

iv) average daily ambient temperature, in degrees Celsius, $\overline{t}_a$

v) average daily irradiation on the total aperture of the collector (measured in the plane of the aperture), in megajoules per square metre per day, $\overline{H}$

vi) average daily auxiliary energy used, in megajoules per day, $\overline{Q}_{AUX,S}$

b) Determine the solar fraction f over each test period as follows:

$$f = \frac{\overline{Q}_{L,S} - \overline{Q}_{AUX,S}}{\overline{Q}_{L,S}} \qquad \text{. . . (1)}$$

c) Use these data points to evaluate the constants in equation (2) by least-squares curve fitting:

$$f = \left(a_1 + a_2 \frac{\overline{t}_d - t_e}{Q_{L,S}} \right) \frac{\overline{H}}{Q_{L,S}} + a_3 \frac{\overline{t}_d - t_e}{Q_{L,S}} \qquad \text{. . . (2)}$$

d) Use equation (2) and monthly average solar radiation, ambient air temperature and cold water supply temperature for the location of interest to compute the monthly solar contribution of load f. Compute the monthly and annual auxiliary energy ($Q_{AUX,S}$) used by the solar water heater:

$$Q_{AUX,S} = Q_{L,S}(1 - f) \qquad \text{. . . (3)}$$

For a fossil fuel auxiliary system, the fossil fuel consumption is given by

$$Q_{AUX,S} = Q_{L,S}(1 - f)/\eta_f \qquad \text{. . . (4)}$$

where η_f is the thermal efficiency of the fossil fuel auxiliary energy source (not evaluated in this part of ISO 9459).

The ratio of daily solar irradiation to load energy ($H/Q_{L,S}$) used in the monthly analysis shall not be outside the range of $H/Q_{L,S}$ covered in the test data (see 7.4.3).

Evaluate the fractional energy savings relative to a conventional water heating system, fr, using equation (5):

$$fr = \frac{Q_{AUX,NS} - Q_{AUX,S}}{Q_{AUX,NS}} \qquad \text{... (5)}$$

where

$Q_{AUX,S}$ is the auxiliary energy consumed by the solar water heater [from equations (1) to (3)];

$Q_{AUX,NS}$ is the auxiliary energy consumed by a conventional water heater.

Examples of conventional water heater auxiliary energy consumption are given in annex C.

Annex A
(normative)

Format sheets for description of solar domestic water heating system and test results

System reference: ....

Testing laboratory:	
....	
Address:	
....	
Tel.:	Fax: ....
Accredited laboratory: ☐ Yes	☐ No
Date of issue:	

A.1 Description of the solar domestic hot water system (complete as applicable)

A.1.1 Manufacturer

Name of manufacturer: ....

Address: ....

A.1.2 Model

System model: ....

Serial number: ....

A.1.3 System classification

thermosiphon ☐	forced ☐	
direct ☐	indirect ☐	
open ☐	vented ☐	closed ☐
filled ☐	drainback ☐	draindown ☐
remote storage ☐	close-coupled collector storage ☐	
integral collector storage ☐		

Other (specify): ....

A.1.4 Heat transfer fluid

Type:

☐ water/glycol mixture, concentration of glycol: .... %

☐ oil

☐ chlorofluorocarbon

☐ air

Other (specify): ....

Specifications: ....

Total fluid content: .... kg

Alternative acceptable fluid: ....

System reference: ....

A.1.5 Antifreeze

Antifreeze protection Yes ☐ No ☐

Other: ....

A.1.6 Collector system

Number of collectors in the system: ....

Total collector gross area: .... m^2

A.1.7 Collector design

Type:

☐ flat plate ☐ evacuated tube

Other (specify): ....

Gross area: .... m^2

Aperture area: .... m^2

Absorber area: .... m^2

Number of covers: ....

Cover material(s): ....

Cover thickness(es): .... mm

Insulation material(s): ....

Insulation thickness(es): .... mm

Casing material: ....

Mass of collector without fluid: .... kg

Gross dimensions: .... mm

A.1.8 Absober

Material(s): ....

Construction type: ....

....

....

Surface treatment: ....

Number of tubes or channels: ....

Tube diameter or channel dimensions: .... mm

Distance between tubes or channels: .... mm

System reference: ....

A.1.9 Storage tank

Manufacturer: ....

Model: ....

Volume: l

Outside tank diameter: .... m

Outside tank length: .... m

Insulation material: ....

Insulation thickness: .... mm

Heat exchanger type:

☐ spiral pipe

☐ straight pipe

☐ double jacket

other (specify): ....

A.1.10 Pump

Manufacturer: ....

Model: ....

Rating: .... W

Speed: .... r/min

A.1.11 Controller

Manufacturer: ....

Model: ....

A.1.12 Schematic diagram of the system

System reference: ....

A.1.13 Connecting piping between the collector(s) and the tank

Diameter: .... mm
Length: .... m
Insulation material: ....
Insulation thickness: .... mm

A.1.14 System data

Collector tilt angle: .... degrees
Flowrate in collector loop: .... l/s
Controller setting: ....
....
....

A.1.15 Comments on the system design

....
....
....
....

A.1.16 Photograph of the system

System reference:...........................

A.2 System performance test

A.2.1 Schematic diagram of test loop

A.2.2 Photograph of the test rig

A.2.3 System performance test results and derived data

Test results and derived data shall be presented in table A.1.

Latitude: .... Collector azimuth angle: ....

Longitude: .... Collector tilt angle: ....

Table A.1

Measured data							Derived data			
Test measurement No.	t_a °C	H MJ/m²	$Q_{L,S}$ MJ	t_d °C	t_{main} °C	$Q_{AUX,S}$ MJ	$f = \frac{Q_{L,S} - Q_{AUX,S}}{Q_{L,S}}$	$\frac{H}{Q_{L,S}}$	t_e °C	$\frac{t_d - t_e}{Q_{L,S}}$ °C/MJ

The test results consist of the daily values of the solar contribution to load, f, $H/Q_{L,S}$ and $(t_d - t_e)/Q_{L,S}$. The performance of a solar-plus-auxiliary water heater system can be represented by the following equation:

$$f = \left(a_1 + a_2 \frac{t_d - t_e}{Q_{L,S}} \right) \frac{H}{Q_{L,S}} + a_3 \frac{t_d - t_e}{Q_{L,S}} \quad \text{... (A.1)}$$

The coefficients a_1, a_2 and a_3 for the system shall be determined from the test results using a least-squares fitting method (see 8.2).

a_1 = ...

a_2 = ...

a_3 = ...

A.2.4 No-solar capacity

Results of the no-solar test for assessment of the auxiliary heater shall be presented in table A.2.

Table A.2 — No-solar assessment of auxiliary heater

Parameter	Units	Value
Load $Q_{L,NS}$ (specified by the manufacturer)	MJ/d	
Auxiliary energy consumption, $Q_{AUX,NS}$	MJ/d	
Average delivery temperature, t_d	°C	
Average ambient temperature, t_a	°C	

Annex B
(normative)

Format sheets for annual performance prediction

Tests performed by: ....

Address: ....

Date:......................... Tel.: ....

B.1 Description of solar domestic hot water system

B.1.1 Name of system and manufacturer: ....

....

B.1.2 Serial number of system: ....

B.1.3 System classification (enter attribute defined in clause 5): ....

B.1.4 Collector

Type: ....

Aperture dimensions:..

Gross dimensions: ....

B.1.5 Storage tank

Manufacturer: .... Type: ....

Volume: .... litres Auxiliary heater rating .... kW

Time periods for which heater is on: ....

B.2 Annual performance of system

B.2.1 Location for which prediction is made

Place:..

Latitude: .... Longitude: ....

B.2.2 Climatic data and hot water load used in prediction

Reference for climatic data: ....