INTERNATIONAL STANDARD

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Solar heating — Domestic water heating systems —

Part 2: Outdoor test methods for system performance characterization and yearly performance prediction of solar-only systems

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

Partie 2: Méthode d'essai en extérieur pour la caractérisation de la performance des systèmes "tout solaire" et la prédiction de leur performance annuelle

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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 9459-2 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 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*

Annex A forms an integral part of this part of ISO 9459. Annexes B, C and D 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.

ISO9459 is divided into five parts within three broad categories, as described below.

Rating test

ISO 9459-1:1993, *Solar heating — Domestic water heating systems — Part 1: Performance rating procedure 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 other International Standards.

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 ouput 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 9459-3 permit annual system performance predictions for one daily load pattern.

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 ISO 11924:—, *Solar heating — Domestic water heating systems — Test methods for the assessment of reliability and safety*.

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Solar heating — Domestic water heating systems —

Part 2:
Outdoor test methods for system performance characterization and yearly performance prediction of solar-only systems

1 Scope

This part of ISO 9459 establishes test procedures for characterizing the performance of solar domestic water heating systems operated without auxiliary boosting, and for predicting annual performance in any given climatic and operating conditions, but only for an evening draw-off. A "black box" approach is adopted which involves no assumptions about the type of system under test; 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 is not intended to be used for testing solar heating systems which have an auxiliary heater as an integral part of the system, since the operation of the auxiliary input may influence the performance of the solar heating system. To quantify the interaction between the energy inputs, the test procedure described in ISO 9459-3 is recommended.

This part of ISO 9459 applies to solar-only domestic water heating systems designed to heat potable water to be supplied for domestic water usage and is not intended to be applied to other systems. The test procedures are applicable only to systems of 0,6 m^3 of solar storage capacity or less.

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 systems.

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

ISO 9459-3:—[1], *Solar heating — Domestic water heating systems — Part 3: Performance test for solar plus supplementary systems.*

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

ISO 9847:1992, *Solar energy — Calibration of field pyranometers by comparison to a reference pyranometer.*

ISO/TR 9901:1990, *Solar energy — Field pyranometers — Recommended practice for use.*

ISO 11924:—[1], *Solar heating — Domestic water heating systems — Test methods for the assessment of reliability and safety.*

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

As stated in the Introduction, each part of ISO 9459 has been conceived as a self-contained document. Therefore, some of the terms with their definitions given in this clause may also appear in other part(s) of ISO 9459.

For the purposes of this International Standard, the following definitions apply.

3.1 absorber: Device within a solar collector for absorbing radiant energy and transferring this energy as heat into a fluid.

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 a thermal energy storage device, a solar collector, or any object being considered.

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

NOTE 1 Angle of incidence is often termed "incidence angle" or "incident angle". The use of these terms is deprecated.

3.5 aperture area: Maximum projected area through which the unconcentrated solar radiation enters a collector.

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

3.7 auxiliary energy: See auxiliary (heat) source.

3.8 auxiliary (heat) source: Source of heat, other than solar, used to supplement the output provided by the solar energy system.

3.9 collector: Device containing an absorber.

3.10 collector tilt angle: Angle between the aperture plane of a solar collector and the horizontal plane.

3.11 components: Parts of the solar hot water system including collectors, storage, pumps, heat exchanger, controls, etc.

1) To be published.

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

3.13 differential temperature controller: Device that is able to detect a small temperature difference, and to control pumps and other electrical devices in accordance with this temperature difference.

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

3.15 draw-off rate; water draw-off rate: Rate at which water is withdrawn from a water heating system.

3.16 draw-off temperature: Temperature of hot water withdrawn from the system.

3.17 evacuated tube [tubular] collector: Solar collector employing transparent tubing (usually glass) with an evacuated space between the tube wall and the absorber.

The absorber may consist of an inner tube or another shape, with means for removal of the thermal energy. The pressure in the evacuated space is usually less than 1 Pa.

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

3.19 fluid transport: Transfer of air, water, or other fluid between components.

3.20 gross collector area: Maximum projected area of a complete solar collector, excluding any integral means of mounting and connecting fluid pipework.

For an array or assembly of flat plate collectors, evacuated tubes or concentrating collectors, the gross area includes the entire area of the array, i.e. also borders and frame.

3.21 heat exchanger: Device specifically designed to transfer heat between two physically separated fluids.

Heat exchangers can have either single or double walls.

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

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

It is expressed in watts per square metre.

NOTE 2 Solar irradiance is often termed "incident solar radiation intensity", "instantaneous insolation", "insolation" or "incident radiant flux density"; the use of these terms is deprecated.

3.24 irradiation: Incident energy per unit area of a surface, found by integration of irradiance over a specified time interval, often an hour or a day.

It is expressed in megajoules per square metre.

NOTE 3 Solar irradiation is often termed "radiant exposure" or "insolation"; the use of these terms is deprecated.

3.25 load: Heat supplied to the user, for example in the form of hot water.

NOTE 4 Because of heat losses in the distribution system, the location of the heat delivery must be specified.

3.26 long-wave radiation: Radiation at wavelengths greater than 3 µm, typically originating from sources at terrestrial temperatures (e.g. ground and other terrestrial objects); sometimes called "thermal radiation".

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

3.28 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 and 3 µm.

3.29 pyrgeometer: Instrument for determining the irradiance on a plane receiving surface which results from the radiant fluxes incident from the hemisphere above, within the wavelength range 3 µm to 50 µm.

NOTE 5 The given spectral range is similar to that of atmospheric 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 meet more or less accurately the limits mentioned above.

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

NOTE 6 Pyrheliometers are used to measure direct solar irradiance at normal incidence. Typical field-of-view angles of pyrheliometers range from 5° to 10°.

3.31 radiant energy: Energy in the form of electromagnetic waves.

3.32 radiant flux: Power emitted, transferred or received in the form of radiation.

3.33 radiation: Transfer of radiant energy in the form of electromagnetic waves.

3.34 radiometer: Instrument for measuring radiant energy.

Its output can be either irradiance or irradiation.

3.35 solar (thermal) collector: Device designed to absorb solar radiation and to transfer the thermal energy so gained to a fluid passing through it.

NOTE 7 Sometimes called a solar "panel". This term is deprecated to avoid potential confusion with photovoltaic panels.

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

3.37 solar contribution: Heat supplied by the solar part of a system.

3.38 solar noon: Local time of day at which the sun crosses the observer's meridian.

NOTE 8 For the solstices, solar noon occurs when the sun is at its highest altitude for that day.

3.39 solar radiation: Radiation emitted by the sun, practically all of which is incident at the earth's surface at wavelengths less than 3 µm.

NOTE 9 It is often termed "short-wave radiation". Use of the term "insolation" to mean solar radiation is deprecated.

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

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

3.42 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.

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

NOTE 10 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.

3.44 surrounding air speed: Air speed measured in a specified location near a collector or system.

3.45 tank capacity: Measured volume of the fluid in the tank when full.

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

NOTE 11 Significant differences in ambient air temperature can occur over short distances; therefore, in a particular application the method of measurement should be specified.

3.47 time constant: Time required for a system, whose performance can be approximated by a first-order differential equation, to change output by 63,2 % of its final change in output, following a step change in input.

3.48 thermopile: Set of thermocouples connected in series which can measure small temperature differences by means of enhancement of the voltage signal per unit temperature change.

4 Symbols

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

a_1, a_2, a_3 coefficients used in equation (2) (system performance)

b_1, b_2, b_3 coefficients used in equation (3) (water temperature increase)

c_{pw} specific heat capacity of water, in joules per kilogram kelvin [J/(kg·K)]

$f(V)$ normalized draw-off temperature profile, dimensionless

$g(V)$ normalized mixing draw-off temperature profile, dimensionless

H daily solar irradiation (radiance exposure) in the collector aperture, in megajoules per square metre

H_d daily diffuse solar irradiation in the collector aperture, in megajoules per square metre

H_h monthly average daily solar irradiation on a horizontal plane, in megajoules per square metre

H_{tilt} monthly average daily solar irradiation on a tilted plane, in megajoules per square metre

Q useful energy extracted from the system, in megajoules

Q_c energy contained in a volume of water V_c, in megajoules

Q_{LOS} thermal loss from the store, in megajoules

Q_R energy remaining in the store, in megajoules

t_a ambient or surrounding air temperature, in degrees Celsius

$t_{a,s}$ ambient air temperature adjacent to the store, in degrees Celsius

t_d water temperature of load drawn off, in degrees Celsius

t_f final water temperature [equation (1)], in degrees Celsius

t_h required hot water temperature, in degrees Celsius

t_i initial water temperature [equation (1)], in degrees Celsius

t_{main} cold water supply temperature, in degrees Celsius

t_n average ambient air temperature during the night, in degrees Celsius

t_s average temperature of water in the store, in degrees Celsius

u surrounding air speed, in metres per second

U_s storage tank heat loss coefficient, in watts per kelvin

V_c volume of daily hot water consumption, in litres

V_d volume of water drawn off, in cubic metres

V_s fluid capacity of the store, in litres

Δt time interval, in seconds

ρ_w density of water, in kilograms per cubic metre

Subscripts

(av) average (mean) value of parameter

(day) average (mean) value of parameter during the period 6 h before solar noon to 6 h after solar noon

(max) maximum value of parameter

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.

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.

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

5.2 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 12 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

Only the solar part of the system shall be tested using the test procedure. The solar performance of systems which have an auxiliary heater separated from the solar-heated storage tank will not be influenced by the auxiliary heater. However, the load size will be influenced by the presence of the auxiliary heater. Therefore, if the system is to be tested with both the solar preheater and separate auxiliary heater considered as part of the same system, the test procedure described in ISO 9459-3 shall be used.

6.1.1.2 Systems with manual auxiliary heater control

Systems which have an 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 be tested with the auxiliary heater switched off.

6.1.1.3 Systems with integrated auxiliary boosting

The test procedure does not apply to systems which have a continuous or nighttime-use auxiliary heater integrated in the solar-heated storage tank. Such systems should be assessed using the test procedure defined in ISO 9459-3 or other suitable International Standard.

6.1.2 Test system installation

Tests shall be performed with the system components installed in accordance with the 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 the mounting 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.

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

6.1.3 Collector installation

The collector shall be mounted in a fixed position facing the equator to within $\pm$ 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 performance of some collectors is sensitive to air speeds over the collector in the range 0–3 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.

Warm currents of air, such as those which rise up the walls of buildings, 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, though this shall be reported with the test results.

6.1.4 Liquid flow system

A test loop of the type shown in figure 1 shall be used. The piping material used in the loop shall be appropriate to the fluid used in the system and 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 (inlet) temperature controller 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 controller and flow meter shall be installed on the cold water inlet pipe, so that readings are not affected by temperature changes.

A draw-off bleed pipe shall be installed on the cold water pipe just before the store inlet.

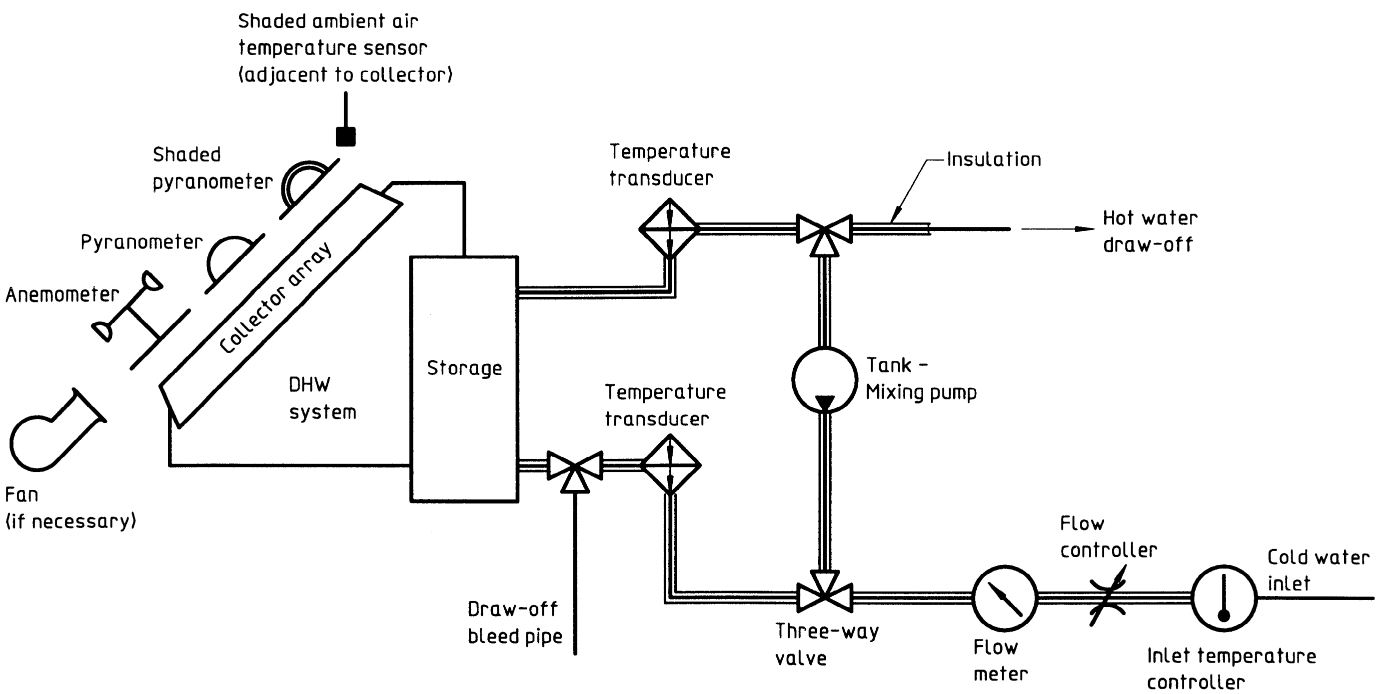

Figure 1 — Schematic representation of experimental apparatus for daily system performance test