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Solar heating — Domestic water heating systems —

Part 4:
System performance characterization by means of component tests and computer simulation

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

Partie 4: Caractérisation de la performance des systèmes au moyen d'essais effectués sur les composants et par simulation sur ordinateur

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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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. 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.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 9459-4 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 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*

0 Introduction

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 test 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.

0.1 General

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

0.2 Rating test

ISO 9459-1, *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.

0.3 Black box correlation procedures

ISO 9459-2, *Solar heating — Domestic water heating systems — Part 2: Outdoor test methods for system performance characterization and yearly performance prediction of solar-only systems*, 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.

0.4 Testing and computer simulation

ISO 9459-4, *Solar heating — Domestic water heating systems — Part 4: System performance characterization by means of component tests and computer simulation*, a procedure for characterizing annual system performance, uses measured component characteristics in a computer simulation program. 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, *Solar heating — Domestic water heating systems — Part 5: System performance characterization by means of whole-system tests and computer simulation*, presents a procedure for dynamic testing of complete systems to determine system parameters for use in the “Dynamic System Testing Program”. This software has been validated on a range of systems; however, it is a proprietary product and cannot be modified by the user. Implementation of the software requires training from a test facility experienced with the application of the product. 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 9459-4 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.

0.5 Introduction to ISO 9459-4

ISO 9549-4 presents a procedure predicting the annual performance of a solar thermal system using a numerical simulation programme. The parameters of the characterisation of the thermal behaviour of the key components such as solar collector, store and controller are derived from physical tests of the components.

Because testing of the complete system as a whole is especially expensive and time consuming for system families, this approach offers the opportunity to determine the annual performance of a family of systems with limited effort.

NOTE A system family is characterised by a series of hot water systems that are identical with regard to their construction and only differ in their collector and storage dimension. An identical construction is given if the set-up of the system is similar (pipes, electrical pump, hydraulic connections, type but not mandatorily size of the heat exchanger), the insulation concept is similar (material, thickness) and the collectors installed are from the same type.

Procedures exist for testing most solar thermal system components. Where they exist, they are referenced. In case no standardised component test procedures are available appropriate procedures have to be used to determine the thermal characteristics of the components.

The intention of this International Standard is to determine the thermal performance of the system. Therefore, it is assumed that all key components (e.g., collectors, stores, heat exchangers, etc.) used in the system are subjected to relevant durability tests (e.g., collector qualification tests, pressurization of the collector side of the heat exchanger, etc.) before they are tested for thermal performance.

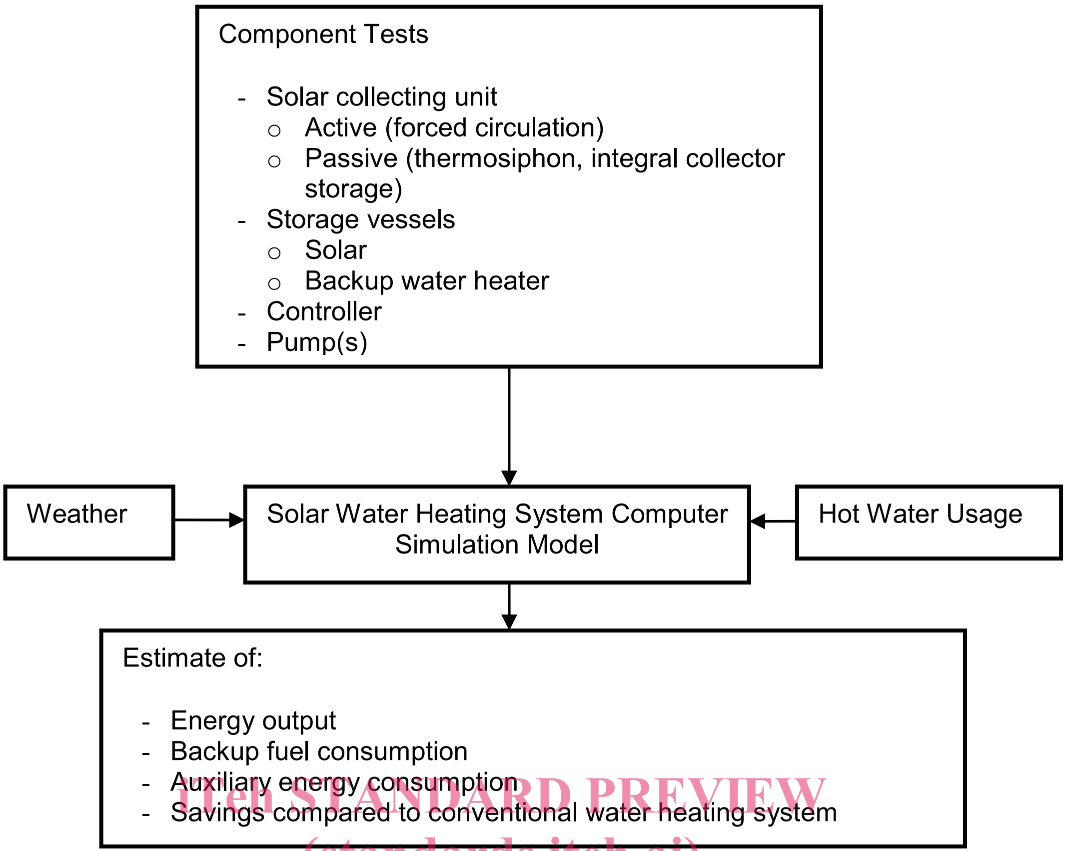
In order to ensure a proper operation of the entire system additional durability tests may be required of the complete system to determine operation under extreme conditions such as freezing or overheating based on corresponding standards.

The performance evaluation procedure defined in this International Standard has been designed to provide a means of evaluating the annual task performance of heated water systems.

This International Standard sets out a method of evaluating the annual energy performance of heated water systems using a combination of test results for component performance and a mathematical model to determine an annual load cycle task performance. This International Standard defines a procedure for evaluating the task performance of conventional electric and gas domestic water heaters so that the energy savings of solar and heat pump water heaters can be evaluated relative to conventional water heaters operated under the same annual task load.

The performance evaluations are based on modelling annual performance in a range of climatic conditions using a simulation program. The chosen simulation program shall have flexibility and the capacity to model the wide range of renewable energy water heaters used worldwide.

The procedure for using this International Standard is illustrated in the figure below. The general concept is to develop computer models that describe the performance of every component of the solar water heating system. These models can be based on specific tests (listed herein and in EN 12977-2 and AS/NZS 4234). These models are then combined in a system simulation that can be used to estimate the performance of the complete solar heating system under specified hot water usage and weather conditions. Information for users of this International Standard is presented in Annexes I and J.



It is the intent of this part of ISO 9459 to be compatible with EN 12977-2, “Thermal solar systems and components, Custom built systems, Test methods” such that tests conducted for use by certification bodies can be done in accordance with either one interchangeably.

The terms “normative” and “informative” have been used in this International Standard to define the application of the annex to which they apply. A “normative” annex is an integral part of an International Standard, whereas an “informative” annex is only for information and guidance.

Solar heating — Domestic water heating systems —

Part 4: System performance characterization by means of component tests and computer simulation

1 Scope

This International Standard specifies a method of evaluating the annual energy performance of solar water heaters using a combination of test results for component performance and a mathematical model to determine an annual load cycle task performance under specified weather and load conditions. The procedure is applicable to solar water heaters with integral backup or preheating into a conventional storage or instantaneous water heater and to integral collector storage water heaters.

System operating requirements specified in this International Standard are for the purpose of determining an annual performance rating for domestic water heaters. There are no product design or operation requirements in this International Standard.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 9488:1999, *Solar energy — Vocabulary*

ISO 9806 (all parts), *Test methods for solar collectors*

EN 12977 (all parts):2012, *Thermal solar systems and components — Custom built systems*

EN 12975 (all parts):2006, *Thermal solar systems and components — Solar collectors*

EN 12976 (all parts):2006, *Thermal solar systems and components — Factory made systems*

AS 1056.1:1991, *Storage water heaters — General requirements*

AS/NZS 2712:2007, *Solar and heat pump water heaters — Design and construction*

AS/NZS 2535:2007, *Test methods for solar collectors*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 9488 and the following apply.

There are two differences with ISO 9488-1999:

- auxiliary energy is used here to represent energy consumed by pumps, fans, and controls in a solar heating system
- backup energy refers to energy contributed by a source other than solar

3.1
tilt angle
angle between the absorbing surface of the collector and the horizontal

3.2
container
vessel including fittings, in which the heated water is stored; sometimes referred to as a store, storage container, cylinder, storage vessel, or tank

3.3
electricity supply options

3.3.1
continuous
continuously available electricity supply

3.3.2
limited time of supply
electric supply available at limited times, as follows:

3.3.2.1
night rate
electricity supply at restricted night hours (see Annexes A and B for typical availability times)

3.3.2.2
extended off-peak
electricity supply during extended hours (see Annexes A and B for typical availability times)

3.4
dual element tanks
tanks incorporating dual electric elements at different levels in the tank

Note: Each element may be connected to a different electric supply or be operated under local control.

3.5
heat pump water heater, solar assisted
a system incorporating a compressor (vapour compression), an evaporator exposed to ambient air or solar radiation, or both, a condenser and a water container heated either directly or indirectly by the condenser

3.6
one-shot backup
operation of a backup heat source for one heating cycle

Note: The heater is returned to normal control after one heating cycle.

3.7
factory-made solar water heater
package systems are batch products, sold as complete and ready to install kits with fixed configurations

Note: Systems of this category are considered as a single product and assessed as a whole.

3.8
reference water heater
a conventional water heater used to define annual purchased energy use for the purpose of computing energy savings of other products

3.9
tank nodes
horizontal sections of a storage tank

Note: Used in the simulation program to model thermal stratification in the storage tank.

3.10
tank modelling options

3.10.1
fixed inlet positions
fluid flows into the storage tank are considered to mix with the contents of the tank node at the same level with the inlet fitting

3.10.2
variable inlet positions
fluid flows into the storage tank are considered to rise or fall to the level of the tank node with the closest temperature to the inlet flow

3.11
computer simulation model
TRNSYS or equivalent computer program used to simulate the performance of solar water heating components and systems

4 Symbols, units and nomenclature

Symbol	Units	Meaning
a, b, c	[-]	correlation coefficients for solar collector efficiency
B_c	[MJ/year]	annual energy used by a conventional water heater
B_e	[MJ/year]	annual electrical energy used by water heater
B_g	[MJ/year]	annual gas energy used by water heater
B_s	[MJ/year]	annual backup energy for a solar or heat pump water heater
C_p	[kJ/(kg C)]	heat capacity
C_{rmod}	[-]	modified capacity ratio
DE	[MJ]	difference in energy content of a tank between the start and the end of a heat loss or warm-up test
d	[m]	diameter
e_n	[W]	electrical power use during burner operation
e_{sb}	[W]	electrical power use during standby
E	[%]	thermal efficiency of gas water heater

E_g	[MJ/year]	integrated energy added to tank from gas combustion
f_R	[-]	purchased energy savings relative to a conventional water heater (*Bc*–*Bs*)/*Bc*
G_b	[Wm^{-2}]	beam irradiance on the collector aperture
G_L	[Wm^{-2}]	net long wave irradiance (λ>3μm) ($Gs - \sigma T_a^4$)
G_o	[Wm^{-2}]	extraterrestrial solar irradiance
G_r	[-]	Grashoff number
G_S	[Wm^{-2}]	long wave thermal irradiance (λ>3μm)
G_T	[Wm^{-2}]	hemispherical solar irradiance on the collector aperture
h	[W/m^{2}K]	heat loss coefficient
$K_{\tau\alpha}$	[-]	solar collector angle modifier
K_{NS}, K_{EW}	[-]	bi-axial incidence angle modifiers
K_T	[-]	average clearness index for specified test
M	[MJ/h]	maintenance rate [standing or stand-by heat loss rate from a heated water tank]
M_{drawn}	[kg]	mass withdrawn from the storage vessel
M_{rate}	[kg/s]	mass flow rate
M_{sys}	[kg/s]	mass flow rate through a system
M_{tank}*C_p	[kJ/K]	capacitance
n	[-]	Julian day of the year (1-365)*N* [-] number of events
ΔP	[Pa]	pressure drop
Pr	[-]	Prandtl number
Q_{del}	[kJ]	energy purged from the system after the wait or irradiance period
$Q_{initial}$	[Lj]	initial charge energy of a tank or system when subjected to an instantaneous purge between two set temperatures.
R	[MJ/h]	determined gas consumption
Re	[-]	Reynolds number
t	[h:min:s]	duration of test
Time_{decay}	[s]	decay test duration
T	[°C]	temperature
$\bar{T}$	[°C]	mean collector fluid temperature

T_a	[°C]	ambient temperature
$\bar{T}_{a, avg}$	[°C]	annual average ambient outdoor air temperature T_{db} [K] thermostat dead band
T_{del}	[°C]	temperature of the water delivered from the DHW system at the outlet of the system
T_i	[°C]	collector inlet fluid temperature
$\bar{T}_W$	[°C]	mean temperature of water in the storage tank
T_{env}	[°C]	environment temperature (ie. temperature of air surrounding the storage vessel)
$T_{env\ ave}$	[°C]	average environment temperature
T_{high}	[°C]	temperature of the water in a test system at the beginning of a high-temperature test (typically 55 – 60 °C)
T_{in}	[°C]	temperature of the liquid entering the storage vessel
$T_{initial}$	[°C]	temperature of the water in the test system at the beginning of a test (heat loss or warm-up)
T_{low}	[°C]	temperature of the water in a test system at the beginning of a low-temperature test (preferably near ambient temperature)
$T_{tank\ ave}$	[°C]	average tank fluid temperature
$T_{tank\ ave\ final}$	[°C]	final average tank fluid temperature after the decay or irradiation, period
$T_{tank\ ave\ ini}$	[°C]	initial average tank fluid temperature before the decay or irradiation period
$T_{tank\ ave\ purge}$	[°C]	final average tank fluid temperature after the purge period. This value is usually estimated by averaging the tank inlet temperature and $T_{del.}$
Δt	[s]	change in time
T_{set}	[°C]	manufacturer's recommended thermostat setting
T_{sky}	[°C]	sky temperature
u	[ms^{-1}]	surrounding air speed over the solar collector (or evaporator)
U	[W/m^{2}K]	heat loss coefficient
UA	[W/K]	heat loss coefficient × area product for the tank
$UA_{isolated\ loss\ total}$		total UA loss of the storage tank from a decay test with the system piping installed
$UA_{installed\ loss\ total}$		installed total UA loss of the storage tank from a decay test
α	[-]	unglazed collector hemispherical absorber absorptance, short wave

β	[-]	slope or tilt, the angle between the plane of the collector and the horizontal
ε	[-]	unglazed collector hemispherical absorber emittance, long wave
ε_{mod}	[-]	modified effectiveness
η	[-]	solar collector efficiency
ϕ	[-]	latitude, the angular location north or south of the equator
θ	[rad]	incidence angle relative to the collector aperture normal
γ	[-]	orientation angle, the direction which a collector faces, expressed as the azimuth angle of the horizontal projection of the surface normal
λ	[W/mK]	thermal conductivity

5 Application

The procedure in this International Standard uses a mathematical model to assess annual energy task performance; hence the application of the procedure is restricted only by the availability of suitable mathematical models. Weather data and typical modelling data files are specified in Annex G. The operating conditions and product configurations to be used for evaluating the energy performance of a water heater are specific to certification or incentive programs and are not defined in this International Standard.

This International Standard can be applied to solar water heaters with the following:

a) flat plate, concentrating or evacuated tubular solar collectors,

b) thermosiphon or forced fluid circulation through the solar collectors,

c) collector loop heat exchangers,

d) systems for combined domestic hot water preparation and space heating (combisystems),

e) integral collector storage,

f) horizontal or vertical water storage tanks,

g) storage with one or more electrical heating elements,

h) storage tanks with internal gas backup heaters,

i) solar preheat systems in series with instantaneous water heaters,

j) solar thermal systems combined with heat pumps (e.g., solar collectors acting as the refrigerant evaporator).

Other water heater configurations incorporating the above components may also be modelled.

For limited time-of-supply electric storage water heaters, the temperature stratification in the storage tank is evaluated throughout the day and used to quantify the variation of tank heat loss with time, due to cooling of the bottom of the tank. Mixing during load draw off and conduction between the hot and cold layers in the tank is also included. All storage tanks shall be rated for standing heat loss and maintenance rate. The operational heat loss accounting for non-uniform insulation around the tank and thermal stratification in the tank is determined by the annual load cycle performance model.

6 Test method

6.1 Introduction

This International Standard defines a means of evaluating the purchased energy use of water heaters operating under specified weather and load conditions.

For solar water heaters, this standard can be used for any system type that can be reasonably modelled in a computer simulation model. The performance of individual components is evaluated under ISO 9806, AS 4552, AS/NZS 4692.1, AS 1056.1, EN 12975, EN 12976, and EN 12977. The performance of heat pump water heaters with evaporators exposed directly to solar radiation is evaluated using test results for the evaporator evaluated under ISO 9806 and performance of the compressor is evaluated under ASHRAE Standard 23-93.

The purchased energy use calculated is only representative of the product model described in Annex A.

6.2 Component testing

6.2.1 Storage vessels

There are a wide variety of storage vessels available. They range from simple single-wall tanks to double-wall (mantle) vessels with multiple integral heat exchangers and backup energy input. As the complexity of the vessel increases, so does the complexity of the method necessary for adequately characterizing the vessel.

6.2.1.1 Simple storage tanks

The standing heat loss of simple storage vessels without a heat exchanger and/or backup energy input may be evaluated in accordance with Annex B or in accordance to 6.3.1.4.1 of EN 12977-3.

6.2.1.2 Complex storage vessels

6.2.1.2.1 Storage vessels with electric backup heating

The standing heat loss of complex storage vessels may be evaluated using EN 12977-3.

NOTE Electric backup heaters in solar water heater storage tanks may be located above the bottom of the tank to separate the functions of solar and backup heating. Evaluation of the standing loss and rated delivery of such tanks requires a test with a special electric element fitted in the bottom of the tank to minimize thermal stratification in the tank during the standing heat loss test.

6.2.1.2.2 Storage vessels with gas backup

The following performance factors may be evaluated using the test methods in AS 4552.

a) thermal efficiency (%),

b) determined gas consumption (MJ/h),

c) maintenance rate (MJ/h),

d) electric power usage during standby (W),

e) electric power usage during burner operation (W).

