INTERNATIONAL STANDARD

ISO 9459-5

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Solar heating — Domestic water heating systems —

Part 5:
System performance characterization by means of whole-system tests and computer simulation

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

Partie 5: Caractérisation de la performance des systèmes au moyen d'essais effectués sur l'ensemble du système 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 9459-5 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— *Part 3: Performance test for solar plus supplementary systems* (withdrawn)

— *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*

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 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.

ISO 9459 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 1 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 9459-2:1995, *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.

ISO 9459-3:1997, *Solar heating — Domestic water heating systems — Part 3: Performance test for solar plus supplementary systems* (now withdrawn), applied to solar plus supplementary systems. The performance test was a 'black-box' procedure which produced coefficients in a correlation equation that could 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 was limited to predicting annual performance for one load pattern.

Testing and computer simulation

ISO/AWI 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 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.

This part of ISO 9459 (i.e. ISO 9459-5) presents a procedure for dynamic testing of complete systems to determine system parameters for use in the "Dynamic System Testing Program" (reference [2]). 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 9459-3, 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 9459-3 permitted annual system 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 protection from extreme temperatures and pressures*.

Introduction to ISO 9459-5

The expanding market for Solar Domestic Hot-water (SDHW) systems demands a standardized test method for SDHW systems, which makes possible accurate long-term performance prediction for arbitrary conditions from a test as short, simple and cheap as possible.

Two facts make this goal difficult to reach.

a) The SDHW system gain depends on many different conditions (e.g., irradiance, ambient temperature, draw-off profile and cold-water temperature). Therefore, a sufficient number of parameters are needed to predict the yearly system gain sufficiently accurately for arbitrary conditions.

b) The system state, that is, the temperature profile inside the store, needs a long time to 'forget' initial conditions; a typical time constant may be one day or more. Since several parameters need to be determined, several system states must occur during the test. If a test method did not take into account the system state dependence on the past, and thus the dynamic behaviour of the system, the minimum testing times would be quite long (up to several months).

The objective of the method described in this part of ISO 9459 is to minimize experimental effort by keeping the test duration short and avoiding extensive measurements. To compensate for the relatively small amount of experimental data, mathematical tools are used to extract as much information as possible from the test data, while being robust enough to avoid being misled by unimportant transient effects.

There are no requirements for steady-state conditions in the tests, and, due to the 'black-box' approach, no measurements inside the store or inside the collector loop are required.

Experience has shown that the variability of system states encompassed by the test sequence is the most important precondition for the correct determination of all system parameters with minimum errors and cross correlation between parameters. Only if the system is driven into many different states, is the influence of each parameter of the model shown on the performance of the system. Therefore, the overall design criterion of a draw-off test sequence is that the system shall be driven into as many different states as possible in a minimum time. Here, system state means a combination of the store temperature distribution and weather conditions. The system states should include all states that may occur in actual operation. For testing purposes, it is much more important to have a large variability of system states than to perform draw-offs according to 'normal user behaviour'. Accurate parameter identification will be achieved only if the range of system states in actual operation is covered by the range of system states set up during the tests. The method is applicable to in-situ monitoring, but difficulties arise during in-situ testing, as the operator cannot control the operating conditions. Monitoring of 'normal user behaviour' needs to be carried out over a long time to ensure that all relevant system states are covered, i.e. testing times can be much longer to achieve the same performance prediction accuracy.

This part of ISO 9459 may be applicable to a wide range of systems, including systems with relatively large collectors which have to be cooled by large, frequent draw-offs to prevent overheating, and systems with relatively large storage tanks which need to be operated with low loads for days, in order to reach the high store and collector temperatures needed for accurate parameter identification. No single draw-off profile can meet these demands for all systems, since the ratio of storage volume and collector aperture area (V_S/A_C) may vary up to a factor of 20 for the systems considered in this this part of ISO 9459. Therefore, the draw-off volumes have been made dependent on V_S and V_S/A_C.

Experience has shown that the system state variability is especially important for the determination of the effective collector area A_C^*, the effective collector loss coefficient u_C^* and the store-loss coefficient U_S.

To discern between optical and thermal collector properties, the store (and thus the collector inlet temperature) must be kept cold for some intervals with substantial irradiance (Test A) and then be allowed to become hot while irradiance is sufficient to keep the collector loop operational (Test B).

To discern between store losses (which happen all the time) and collector losses (which happen only when there is sufficient irradiance), the store must be operated at high temperatures during some periods with low irradiance.

Solar heating — Domestic water heating systems —

Part 5: System performance characterization by means of whole-system tests and computer simulation

1 Scope

This part of ISO 9459 specifies a method for outdoor laboratory testing of solar domestic hot-water (SDHW) systems. The method may also be applied for in-situ tests, and also for indoor tests by specifying appropriate draw-off profiles and irradiance profiles for indoor measurements. The system performance is characterized by means of whole-system tests using a 'black-box' approach, i.e. no measurements on the system components or inside the system are necessary. Detailed instructions are given on the measurement procedure, on processing and analysis of the measurement data, and on presentation of the test report.

The theoretical model described in reference [1] is used to characterize SDHW system performance under transient operation. The identification of the parameters in the theoretical model is carried out by a parameter-identification software program (see Annex A). The program finds the set of parameters that gives the best fit between the theoretical model and the measured data.

A wide range of operating conditions shall be covered to ensure accurate determination of the system parameters. Measured data shall be pre-processed before being used for identification of system parameters. The identified parameters are used for the prediction of the long-term system performance for the climatic and load conditions of the desired location, using the same model as for parameter identification. The system prediction part of the theoretical model requires hourly values of meteorological data (e.g. test reference years) and specific load data, as described in Annex C.

This part of ISO 9459 can be applied to the following SDHW systems including:

a) systems with forced circulation of fluid in the collector loop;

b) thermosiphon systems;

c) integral collector storage (ICS) systems;.

provided that for b) and c) the validation requirements described in Clause B.2 of Annex B are satisfied.

Systems are limited to the following dimensions[1)].

— The collector aperture area of the SDHW system is between 1 and 10 m^2.

— The storage capacity of the SDHW system is between 50 and 1 000 litres.

— The specific storage-tank volume is between 10 and 200 litres per square metre of collector aperture area.

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1) In general there are no restrictions on the size of a system being tested however validation tests of the method for systems with more than 10 m^2 collector area are not available. The system size may affect details of the procedure, hence application to systems outside of the specified range requires validation tests (see Annex B).

Limits to the application of this International Standard.

1) This part of ISO 9459 is not intended to establish any safety or health requirements.

2) This part of ISO 9459 is not intended to be used for testing the individual components of the system. However, it is permitted to obtain test data of components in combination with a test according to the procedure described here.

3) The test procedure cannot be applied to SDHW systems containing more than one storage tank. This does not exclude preheat systems with a second tank in series. However, only the first tank is considered as part of the system being tested.

4) Systems with collectors having non-flat plate-type incident-angle characteristics can be tested if the irradiance in the data file(s) is multiplied by the measured incident-angle modifier prior to parameter identification. The same irradiance correction should, in this case, also be used during any performance predictions based on the identified parameters.

5) The test procedure cannot be applied to SDHW systems with overheating protection devices that significantly influence the system behaviour under normal operation[2].

6) The test procedure cannot be applied to integrated auxiliary solar systems, with a high proportion of the store heated concurrently by the auxiliary heater. The results of the tests are only valid when the resulting parameter $f_{aux} < 0,75$.

7) The test procedure cannot be applied to SDHW systems with an external load-side heat exchanger in combination with a temperature-dependent pump.

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

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

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*

ISO 9488:1999, *Solar energy — Vocabulary*

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

3 Terms and definitions

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

3.1
capacitance rate
product of volume draw-off rate, density and mass specific heat of the heat transfer fluid, i.e. the potential of a fluid flow to carry thermal power per unit temperature increase between inlet and outlet

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2) These systems can be tested if the predicted performance is corrected for the influence of the overheating device. A validation test would be required to extend the procedure to such systems.

3.2
cold-water mixer
device providing potable water of constant temperature to the user by mixing draw-off water and mains water

3.3
collector azimuth angle
azimuth angle of the collector defined similarly to the solar azimuth angle

See 1.4 in ISO 9488:1999.

3.4
components
parts of the solar hot-water system

EXAMPLES Collectors, store, pumps, heat exchanger, controls.

3.5
differential temperature controller
device that is able to detect a small temperature difference, and to control pumps and other electrical devices according to this temperature difference

3.6
draw-off temperature
temperature of hot water withdrawn from the system

3.7
dynamic system testing
procedure which uses the same analytical basis to account for time-varying processes in parameter identification and performance prediction

3.8
external auxiliary heating
auxiliary heater located outside of the storage tank and having no impact on the operation of the solar heating system

3.9
integrated auxiliary heating
auxiliary heater that can influence the operation of the solar heating system

3.10
load-side heat exchanger
device to transfer the heat from a solar store containing non-potable water to potable mains water drawn off

3.11
test duration
total elapsed time for a particular test sequence

3.12
transient conditions
meteorological and system operation conditions varying in time

3.13
parameters
coefficients of the mathematical model characterizing the system as identified by the test procedure

3.14
heat capacity of the store
amount of sensible heat that can be stored per kelvin of temperature increase

3.15
test sequence
continuous measurement including compulsory conditioning at the beginning

3.16
threshold temperature
temperature below which the water is considered to be unsuitable for use

4 Symbols, units and nomenclature

Symbols marked by (**P**) denote model parameters to be determined by the parameter identification.

Symbol	Units	Meaning
A_C	[m²]	Collector aperture area
A_C^*	[m²]	Effective collector loop area, $A_C^* = F_R^* (\alpha\tau) A_C$ (**P**)
$c_w (T_{cw}, T_S)$	[kJ/kgK]	Specific heat of water, averaged over the temperature interval [T_{cw}; T_S] (see Annex D)
C_F	[MJK⁻¹]	Filter constant with regard to the load draw-off
C_S	[MJK⁻¹]	Heat capacity of the store (**P**)
D_L	[-]	Draw-off mixing parameter (**P**)
$\dot{C}_S$	[WK⁻¹]	Load-side heat capacitance rate through the store
f_{aux}	[-]	Fraction of the store heated by the auxiliary heater (**P**)
F_R^*	[-]	Heat removal factor of the collector loop
G_t	[Wm⁻²]	Solar irradiance in the collector plane
h	[rad]	Solar elevation
I_0	[Wm⁻²]	Solar constant
P_{aux}	[W]	Auxiliary power entering store
P_{cp}	[W]	Collector loop pumping power
P_L	[W]	Load power, $P_L = \dot{C}_S (T_S - T_{cw})$
P_{net}	[W]	Net system power, $P_{net} = P_L - P_{aux}$
Q_L	[MJ]	Load energy
Q_{aux}	[MJ]	Energy from auxiliary heating
Q_{net}	[W]	Net system gain $Q_{net} = \int P_{net} dt = \int \left(\dot{C}_S (T_S - T_{cw}) - P_{aux} \right) dt$
R_L	[K/W]	Thermal resistance of load-side heat exchanger (**P**)
S_C	[-]	Collector loop stratification parameter (**P**)
t	[h:min:s]	Time
t_0	[h:min:s]	Actual start time of the first draw-off of the day
T_{ca}	[°C]	Ambient air temperature in vicinity of collectors

T_{cw}	[°C]	Cold (mains) water temperature
T_D	[°C]	Temperature demanded by the user
T_S	[°C]	Outlet temperature of the store
T_{minS}	[°C]	Minimum outlet temperature of the store
T_{sa}	[°C]	Ambient air temperature in vicinity of the store
u_C	[Wm⁻²K⁻¹]	Heat-loss coefficient of the collector loop
u_C^*	[Wm⁻²K⁻¹]	$u_C^* = u_C/(\alpha\tau)$ (**P**)
U_S	[WK⁻¹]	Heat-loss rate of the store per unit temperature difference (**P**)
u_v	[Jm⁻³K⁻¹]	Dependence of u_C on surrounding air velocity (**P**)
v	[ms⁻¹]	Surrounding air velocity
V_S	[l]	Storage-tank volume
$\dot{V}_S$	[l/min]	Volumetric flow through the store
v_{ignore}	[ms⁻¹]	Wind velocity over the collector as used in the in situ software (reference [2]) (not used but is recorded)
v_{force}	[ms⁻¹]	Wind velocity over the collector as used in the in situ software (reference [2]) (forced to a certain range and not taken into account in the parameter identification)
v_{fit}	[ms⁻¹]	Wind velocity over the collector as used in the in situ software (reference [2]) (varied, and the wind dependence of the collector losses is determined)
$(\alpha\tau)$	[-]	Effective transmittance-absorptance product of the collector
ΔT_{off}	[K]	Temperature difference for deactivating the collector loop pump
ΔT_{on}	[K]	Temperature difference for activating the collector loop pump
β	[rad]	Collector tilt angle
γ	[rad]	Collector azimuth angle
$\rho_w(T_S)$	[kg/l]	Density of water at temperature T_S
θ	[rad]	Angle of incidence
τ_F	[s]	Filter time constant

5 Apparatus

5.1 Mounting and location of the SDHW system

5.1.1 System mounting

The requirements for mounting and location are consistent with ISO 9459-2. The complete system shall be mounted in accordance with the manufacturer's guidelines. Whenever possible, the system shall be mounted on the mounting structure provided by the manufacturer. If no mounting is provided, then, unless otherwise specified (e.g., when the system is part of an integrated roof array), an open mounting system shall be used. Such mounting shall not obstruct the aperture of collectors and shall not significantly affect the back or side insulation of the collectors or the storage tank. Mounting shall be able to withstand the effects of wind gusts.