STANDARDS
ISO 98061
ISO 98O62
ISO 9459-2
for QUALITY

BASIC EUROPEAN AND INTERNATIONAL STANDARDS ON SOLAR THERMAL GLAZED COLLECTORS & SOLAR DOMESTIC HOT WATER SYSTEMS

A brief review addressed to:
Manufacturers, Retailers, Promoters, Installers, Authorities

European Commission
Directorate General for Energy and Transport

ENERGIE PROGRAMME

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SOL-MED II
Widening the use of European Solar Thermal Technologies in Mediterranean Countries following the Successful Model of Greece. PART B: Italy, France, Romania, Bulgaria, and Turkey

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Foreword

This document is intended to provide a brief review of the content of three standards (European and International) related to

• the performance of solar glazed liquid heating collectors,
• the qualification test procedures (those that are important and useful to manufacturers) of solar collectors,
• the performance of solar domestic hot water systems.

This material is addressed mainly to **Manufacturers, Retailers, Promoters, Designers,** etc. of solar systems for the production of hot water. It may be also useful to **Regional and Local Authorities**.

Standards usually include many details and are addressed to experts. The text included in this document is simple and covers only the basic parts of the standards that are of direct interest to previously mentioned actors of the solar thermal market.

The three standards cover the largest part of solar products that have been installed in Europe up to now and they are used extensively. Many national European Standards are based on them.

It is very important to note that the manufacturer himself can conduct most of the tests, included in the three standards, without the need of specialized measuring equipment. Of course he may not meet all the conditions of the standards, but definitely he will obtain useful test results in order to improve the design of his product.

1. Basic European And International Standards On Solar Thermal Glazed Collectors And Solar Domestic Hot Water Systems

1.1 STANDARDS

Three international (ISO) standards, which cover performance and reliability issues of solar collectors and performance issues of solar domestic water heating systems, have been used in Europe since early nineties. It is to be noted that the European Commission has funded the technical work for the development of these three standards (see Ref. [1] and [2]). They are:

- ISO 9806-1: *"Test methods for solar collectors – Part 1: Thermal performance of glazed liquid heating collectors including pressure drop".*
- ISO 9806-2: *"Test methods for solar collectors – Part 2: Qualifications test procedures"*
- ISO 9459-2: *"Solar heating – Domestic water heating, systems – Part 2: Outdoor test methods for system performance characterisation and yearly performance prediction of solar-only systems".*

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The Technical Committee CEN/TC 312 of the European Organisation for Standardization has prepared the following four standards for solar products. All four have been approved. Their titles are shown below, together with comments for their relationship to the previously mentioned ISO standards:

- *EN 12975-1:* *"Thermal solar systems and components – **Collectors** – Part 1: General requirements".*
- *EN 12975-2:* *"Thermal solar systems and components – **Collectors** – Part 2: Test methods".*

Note: It contains (a) **qualification test procedures** very similar to those included in **ISO 9806-2**,
(b) testing related to the **thermal performance of glazed liquid heating solar collectors** under steady state conditions, again very similar to those included in **ISO 9806-1**,
(c) testing related to the thermal performance of unglazed liquid heating solar collectors under steady state conditions and
(d) an additional test procedure for the performance of solar collectors (glazed, unglazed) under quasi-dynamic conditions.

- EN 12976-1: *"Thermal solar systems and components – **Factory made systems** – Part 1: General requirements".*
- EN 12976-2: *"Thermal solar systems and components – **Factory made systems** – Part 2: Test methods".*

Note: This standard specifies two test methods for the thermal performance characterisation of solar domestic hot water systems, by means of whole system testing. One in **accordance to ISO 9459-2** and is applied on solar only or preheat systems. The other is applied on solar-plus-supplementary systems and includes also computer simulation.
Additionally, the standard specifies test methods for requirements on durability, reliability and safety of factory made systems.

The Technical Committee CEN/TC 312 of the European Organisation for Standardization has also conducted work related to ***custom built systems***. It has prepared the following three "Draft" standards for solar products, but there is no decision yet whether to proceed further.

- ENV 12977-1: *"Thermal solar systems and components – **Custom built systems** – Part 1: General requirements".*

- ENV 12977-2: *"Thermal solar systems and components*
*– **Custom built systems***
– Part 2: Test methods".
- ENV 12977-3: *"Thermal solar systems and components*
*– **Custom built systems***
– Part 3: Performance characterization of stores for solar heating systems".

A brief review is presented, in clauses 2, 3 and 4 below, of the three ISO standards. This review covers also completely the relevant European standards. Some small differences will be mentioned in the relevant text.

2. Thermal Performance Of Glazed Liquid Heating Collectors (ISO 9806-1)

This standard provides test methods and calculation procedures for determining the steady-state thermal performance of solar collectors, as well as some other characteristics of them. It contains methods for conducting tests outdoors under natural solar irradiance and for conducting tests indoors under simulated solar irradiance. The standard contains basic specifications for the testing equipment, for the required instrumentation and the Test Report.

The following characteristics of the collector can be determined by conducting tests outdoors:

- Steady-state instantaneous efficiency;
- Time constant;
- Effective thermal capacity;
- Incident angle modifier;
- Pressure drop across the collector;

More details are presented next in this report only for the instantaneous efficiency.

2.1 Instantaneous Efficiency

It is noted here that the basic components of a glazed liquid heating solar collector are the glazing, the absorber (surface, piping, thermal contact), the insulation (back, sides) and the frame.
The measured efficiency can provide to the manufacturer information for the adequacy of the design and show points where improvements are possible.

The instantaneous efficiency of a glazed liquid heating collector is measured while the collector operates under the following steady-state conditions:

- the total solar irradiance at the plane of the collector is constant and greater than 800W/m^2 (standard EN 12976-2 specifies greater than 700W/m^2)
- the temperature of the heat transfer fluid at the inlet and outlet of the collector remains constant
- the heat transfer fluid flow rate is set at 0,02 kg/s per square meter of the collector area.

The energy transferred to the fluid can easily be determined by the flow rate and its temperature increase through the collector. The available solar energy can be found from the solar irradiance on the collector plane and the surface of the collector. The ratio of the two quantities mentioned previously is the instantaneous efficiency of the collector. The efficiency can be related either to the gross collector area or to absorber surface (standard EN 12976-2 specifies either the collector aperture area or the absorber area).

2.2 Test Conditions for Efficiency

The instantaneous efficiency is measured for at least four fluid temperatures at the inlet of the collector spaced evenly over the operating temperature range of the collector (i.e. from ambient up to 70°C - 90°C). At least four independent data points are obtained for each fluid inlet temperature, to give a total of at least 16 points.

2.3 Instantaneous Efficiency Curve. Linear Fit to Data

The 16 values of the instantaneous efficiency are used to determine (by least square regression) the following first-order curve (linear fit).

$$n = n_o - UT^* \quad (2.1)$$

where

$$T^* = (t_m - t_a)/G \quad (2.2)$$

t_m = mean temperature of heat transfer fluid (°C)
t_a = ambient air temperature
G = global solar irradiance

In equation (2.1) it is possible to use

$$T^* = (t_{in} - t_a) / G \quad (2.2)'$$

where t_{in} = temperature of the fluid at the inlet of the collector

Coefficients n_o and U are constant and they characterise the thermal performance of the collector.
Coefficient n_o is the maximum efficiency of the collector. It occurs when the collector fluid temperature is close to ambient air temperature (i.e. there are not heat losses from the collector to the ambient air). It depends on the following:

- the transmittance of the glazing (τ);
- the absorptance of the absorber surface (α);
- the quality of the thermal contact between piping and fins;

- the overall piping arrangement.

Coefficient U is directly related to the thermal losses of the collector. Various thermal losses take place in a collector, such as from the insulation (back, sides) from thermal bridges and through radiation from the absorber surface.

Note: Standard EN 12976-2 does not specify any "Linear Fit to Data"

2.4 Instantaneous efficiency curve. Second order fit to data

Alternatively the instantaneous efficiency can be determined (from the 16 measured values) by the following second order curve

$$n = n_o - a_1T^* - a_2G(T^*)^2 \quad (2.3)$$

where n_o, a_1 and a_2 are constants and the value of G is 800 W/m^2.

Note: Standard EN 12976-2 specifies T* only on the mean temperature of the heat transfer fluid [see equation (2.2)]

2.5 Efficiency curves in the Test Report

Standard ISO 9806-1

The Test Report includes eight curves of the instantaneous efficiency. This is due to the fact that we have

- two possible collector areas (gross, absorber)
- two possible temperatures of the fluid (mean, collector inlet)
- two forms (linear, second order).

Standard EN 12976-2

The Test Report includes two curves of the instantaneous efficiency. This is due to the fact that two possible collector areas (aperture, absorber) are considered.

3. Solar Collector Qualification Test Procedures (ISO 9806-2)

The standard establishes test methods for determining the ability of solar collectors to resist the influences of degrading agents. It covers liquid or air heating collectors with metallic or organic absorber. The qualification tests are

- Internal pressure test for absorbers;
- High temperature resistance test;
- Exposure test;
- External thermal shock test;
- Internal thermal shock test for liquid-heating collectors;
- Rain penetration test;
- Impact resistance test (optional);
- Freezing test (not necessary with antifreeze fluids).

The standard contains basic specifications for the testing equipment, for the required instrumentation and the Test Report. The standard defines procedures for testing the collectors under well-defined and repeatable conditions, but does not include pass/fail criteria for the test results.
A brief review of the more important test procedures follows next in this chapter.

It is to be pointed out that **the manufacturers**, without great difficulty, **can conduct all qualification tests to some extent.**

3.1 High Temperature Resistance Test

When collectors are first installed or for some reason drained of fluid, they may experience high irradiance levels and approach very high (stagnation) temperatures.

This test is intended to assess rapidly whether a collector can withstand high irradiance levels without failures such as glass breakage, collapse of plastic cover, melting of plastic absorber, or significant deposits on the collector cover from outgassing of collector material (absorber surface, insulation, other).

The standard foresees testing outdoors, in a solar irradiance simulator or in a hot fluid loop. Further details are provided for the outdoor testing.

The collector is mounted outdoors and it is not filled with fluid. All of its fluid pipes are sealed to prevent cooling by natural circulation of air except one, which is left open to permit free expansion of air in the absorber. A temperature sensor is attached to the absorber to monitor its temperature during the test.

The test is performed for a minimum of 1h after steady-state conditions have been established. For temperate climate, the global solar irradiance on the collector plane should be greater than 950 W/m^2 (Standard EN 12976-2 specifies only one value 1000 W/m^2), the surrounding air temperature greater than 25°C (Standard EN 12976-2 specifies 20°C - 40°C) and the wind speed smaller than 1m/s. The collector is inspected for degradation, shrinkage, outgassing and distortion.

3.2 Exposure Test (to Sun)

The exposure test provides a low-cost indication of the aging effects, which are likely to occur during a longer period of natural aging.

The collector is mounted outdoors, but is not filled with fluid. All of its fluid pipes are sealed to prevent cooling by natural circulation of air except one, which is left open to permit free expansion of air in the absorber. Global irradiance and ambient air temperature are recorded continuously.

The collector is exposed for a period of at least 30 days (which need not be consecutive) with a minimum daily irradiation of 14 MJ/m^2 (temperate climate). The collector is also exposed for at least 30h to a minimum irradiance level of 850 W/m^2 and ambient air temperature greater than 10°C.

At the end of the exposure test, the collector is inspected for damage or degradation.

The exposure test can be combined with the external thermal shock test. The first external shock is caused during the first 10 of the 30h period defined previously (irradiance greater than 850 W/m^2) and the second during the last 10 of the 30h.

It is to be noted that this is a very important test, which can reveal problems related to glazing, insulation, absorber surface and the design of the whole collector and the manufacturer can conduct it easily.

3.3 Rain Penetration Test

This test is intended to assess the extent to which collectors are resistant to rain penetration. Their design should not permit the entry of either free-falling rain or driving rain. Collectors may have ventilation holes and drain holes, but these shall not permit the entry of driving rain.

The collector is not filled and the inlet and outlet fluid pipes of the collector are sealed. The collector is weighed and it is placed in a test rig at a tilt of 45^o (Standard EN 12976-2 specifies 30^o) or less or at the shallowest angle to the horizontal plane recommended by the manufacturer.
The collector is sprayed on all sides for a test period of 4h. The collector is maintained at approximately the same temperature as the surrounding air, the water spray has a temperature of less than 25^{o}C (Standard EN 12976-2 specifies 30^{o}C) and a flow rate in the range of 0,03 l/s to 0,05 l/s per square meter of collector area (Standard EN 12976-2 specifies a flow rate more than 0,05 l/s/ m^2).

After the test, external surfaces of the collectors are wiped dry and the collector is reweighed. If the collector has drain holes, then is weighed after water has finished dripping from the drain holes.

The collector is inspected for water penetration and, if possible, for identification of the places where water penetrated it.

The manufacturer can conduct similar tests, even without applying the right spraying conditions. Having the collector facing the sun, any rain penetration will be apparent by the condensation of water inside the glazing.

4. Performance Of Solar Domestic Water Heating Systems (ISO 9459-2)

This standard establishes test procedures for characterising 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. The test procedures are applicable only to systems of 0,6m^3 of solar storage capacity or less.

The standard contains basic specifications for the testing equipment, for the required instrumentation and the Test Report.

The characteristics of the solar system that are determined through the application of this standard are listed below

- System performance diagram;
- System temperature increase diagram;
- Draw-off temperature profiles (low and high irradiation) and the corresponding normalized ones;
- Mixing draw-off temperature profile and the corresponding normalized one;
- Computed draw-off profiles temperature (low-high irradiation, low-high ambient and cold water temperature) for direct comparison;
- Storage tank heat loss coefficient with collector loop connected and collector loop disconnected (check for reverse flow);
- Predicted solar energy output of the system for a year (values for each month) for three load conditions (volume, two temperatures);
- Predicted average daily quantity of hot water (liters) per month available from the system for two temperatures.

There is a series of one-day tests, under conditions specified in the standard, that are the basis for the calculation of the performance diagram, the temperature increase diagrams and the draw-off temperature profiles. Additional testing is required for the mixing draw-off profile and the storage tank heat loss coefficients. All other parameters are found by calculation (methods included in the standard)

The next two sections of this report include some basic background for the performance of solar domestic water heating systems.

4.1 Factors that Influence Performance

The most important parameters affecting the performance of a solar domestic water heating system are:

- the collector (area, efficiency);
- the storage tank (volume, stratification, mixing);
- the system design (heat exchanger, controller if applicable);
- the climate (irradiation, air temperature);
- the load (cold water temperature, volume, demand temperature).

4.2 Daily Energy Output of the Solar System

The performance of solar domestic water heating systems has been studied extensively. From analytical models and experimental data, it has been shown that for a fixed system and a fixed large load at the end of the day (i.e. all energy has been removed from the system), the daily energy output of the system depends on:

- the daily solar irradiation H (total solar energy on collector plane)
- the mean ambient air temperature $t_{a,av}$;
- the cold water supply temperature (i.e. the storage temperature at the beginning of the day) t_c.

The corresponding equation for the daily energy output of the solar domestic water heating system is

$$Q_{out} = a_1 H + a_2 (t_{a,av} - t_c) + a_3 \quad (4.1)$$

where a_1, a_2, a_3 are constant coefficients characterising the system.

4.3 System Short Term Testing for Performance

The correlation expressed in equation (4.1) forms the basis of the test method and the long-term prediction method.

From the results of several days of testing employing different values of H, $t_{a,av}$, t_c and Q_{out}, the values of a_1, a_2, and a_3 can be determined.

4.3.1 Testing Procedure

The test procedure consists of a number of one-day tests, which are independent of each other. On each day of the test, the system is allowed to operate outdoors for 12 hours, from 6 hours before solar noon until 6 hours after solar noon, and a single draw-off is applied at the end of the day.

At the beginning of each day, the system is preconditioned by flushing it with water at constant temperature t_c, so that the whole system is brought to a uniform temperature. The collectors are shielded during the preconditioning of the system.

During the 12-hour operation of the system, measurements are made of the following parameters:

- global solar irradiance on the collector plane;
- ambient air temperature;
- other (diffuse solar irradiance, air speed).

At 6 hours after solar noon the collector is shielded and water is drawn off from the storage tank at a constant flow rate of 600 l/h. Water replacing this should be at the temperature tc defined during the preconditioning of the system. The temperature t_d of the water being drawn off is measured continuously. A volume of water equal to 3 times the tank volume is drawn off.

The measurements of the global irradiance during the 12-hour period are used to determine the solar irradiation H (MJ/m^2) of the specific day.
Similarly, the measurement of the ambient air temperature are used to determine its mean value $t_{a,av}$ (°C).

The measurements, at the end of the day, of:
- the flow rate of the water drawn off;
- the temperature of the water drawn off t_d (°C);
- the temperature of the water entering the storage t_c (°C)

are used to determine the energy contained in the total volume of the hot water drawn off, which is the net solar energy gained by the solar system Q_{out} (MJ). They are also used to determine the maximum temperature of the water drawn off $t_{d,max}$ (°C).

Finally, the measured value of the temperature of the cold water tc (°C) is used to determine the temperature differences ($t_{d,max}$ - t_c) and ($t_{a,av}$ - t_c).

The test days must cover a range of test conditions, regarding H and ($t_{a,av}$ - t_c), which are defined in the standard.

4.3.2 Draw-off Temperature Profile

At the end of each test day, measurements are made of the temperature of:

- the water being drawn off (t_d)
- the water entering the storage tank (t_c)

These measurements can be used to construct a draw off temperature profile as shown in Figure 4.1. It provides the temperature of the drawn off hot water as a function of the volume of the water drawn off. On the same diagram the temperature of the cold water entering the storage is shown.

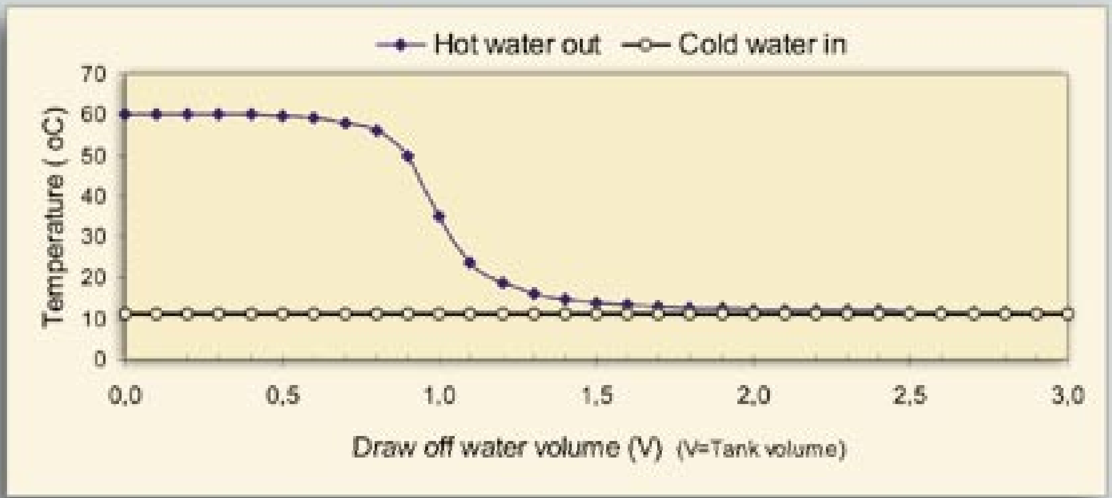
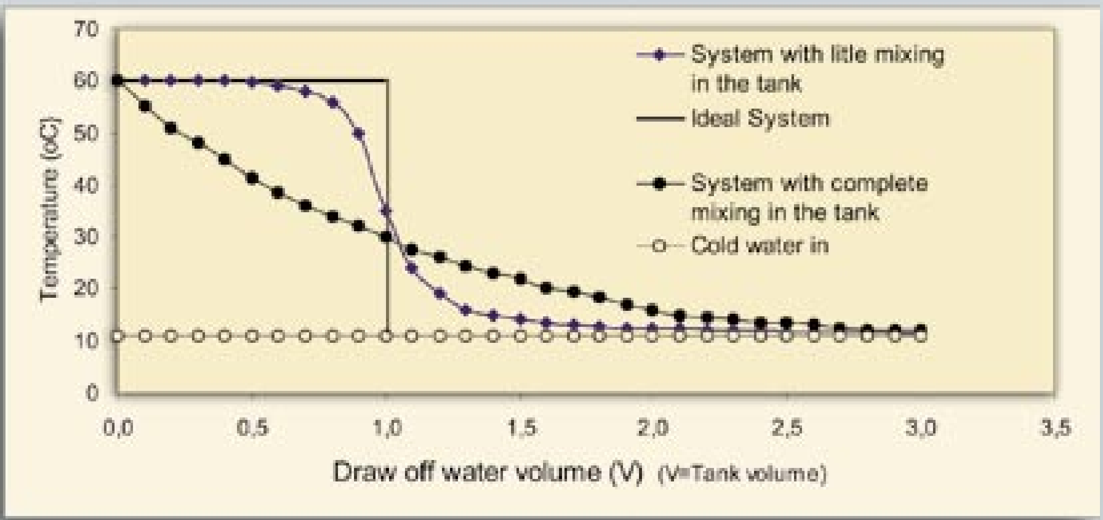


Figure 4.2 Draw off temperature profiles



This diagram shows combined the results of the stratification during operation and also the mixing during draw-off.
Referring to Figure 4.2, an ideal system and one with strong mixing are shown.

The standard requires that two temperature profiles be included in the test report, one with low irradiation and one with high irradiation.

4.3.3 Computed draw off temperature profiles

The draw off temperature profiles are used to determine four draw off temperature profiles for the condition shown in Table 1.

Table 1. *Conditions for computed draw off temperature profiles*

H MJ/m²	$t_{a,av}$ °C	t_c °C	Comments
10 20	25 25	20 20	Spring or summer day
10 20	10 10	10 10	Winter or spring day

These profiles are included in the Test Report and are useful for the evaluation of solar domestic water heating systems (standard climate conditions).

4.4 Determination of the Degree of Mixing in the Storage Tank During Draw-Off

The degree of mixing, which occurs in the storage tank during the draw off of hot water, is an important system characteristic. The occurrence of mixing destroys any stratification, which may be present in the storage tank and reduces the quality of the heat delivered by the system.

This test is carried out in addition to an overall system performance test. The test is designed to determine the amount of mixing between hot water in the tank and the water entering the tank, during a hot water draw off.

The mixing draw off profile is obtained by drawing off water from the tank, which is at a uniform high temperature. Test details are included in the standard. Using the measurement data, the draw off profile can be constructed (similar to the one shown in Fig. 4.1) and it is shown in the Test Report.

4.5 Storage Tank Heat Losses

The heat loss coefficient of the storage tank is determined for the solar system installed for normal operation. This heat loss coefficient is also including heat losses caused by reverse flow in the collector loop. It is used for the prediction of the long-term performance of the system and to determine heat losses of the storage tank during night.

The testing procedure includes the following steps:

- the storage tank water is preconditioned by being uniformly heated to a temperature above 60°C (t_i);
- the tank is left to cool for a period (Δt) between 12 h and 14 h {measurements are made of the surrounding air temperature (t_{as})};
- at the end of the test period, the water in the storage tank is circulated until it reaches a uniform temperature (t_f).

The water temperatures ti and tf, the cooling period Δt, the mean surrounding air temperature $t_{as,av}$ and the storage volume V_s are used to calculate the heat loss coefficient.

The heat loss coefficient is used to prepare a table, included in the Test Report, which provides data for the temperature of the tank after a 12 h cooling period

- for various initial water temperatures (30°C-70°C);
- for various average surrounding air temperatures (0°C-15°C).

A second identical test is carried out to determine the heat loss coefficient of the storage tank with the collector loop disconnected. The system is modified, as necessary, to ensure that there is no flow in the collector loop, eliminating this way the possibility of reverse flow.

4.6 Prediction of Long Term Performance

The results of the testing are given in the form of system performance characteristics, which are independent of the climatic conditions under which they were derived.

The system's characteristics can be used to determine the monthly and annual solar energy output (or other data) from the system at any location (climate conditions) and load demand. The standard includes the method for the long-term prediction and the corresponding software.

For the long-term performance prediction, the following climatic parameters are required (usually mean monthly values) for the location where the system is installed:

- daily solar irradiation on collector plane;
- mean ambient air temperature during the day and during the night;
- temperature of the mains cold water.

These data are included in the Test Report.

The energy output (each month, year) is determined in the Test Report for only one draw off at the end of the day and for following three load conditions:

- draw off of one tank volume
- draw off until the hot water temperature reaches 35°C;
- draw off until the hot water temperature reaches 40°C.

It is recommended in the standard to repeat these calculations for three locations in any country.

Finally, the calculation method can predict the average daily quantity of the hot water (for each month) delivered by the system. The Test Report includes the results for three locations and for the following load conditions

- draw off until the hot water temperature reaches 35°C;
- draw off until the hot water temperature reaches 40°C.

5. References

[1] "Solar Collectors – Test Methods and Design Guidelines", Solar Energy R&D in the European Community, Series A, Volume 6, D. Reidel Publishing Company, 1985

[2] "Recommendations for Performance and Durability Test of Solar Collectors and Water Heating Systems", Non Nuclear Energies, European Solar Collector and Systems Testing Group, EUR 11606EN, May 1989

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