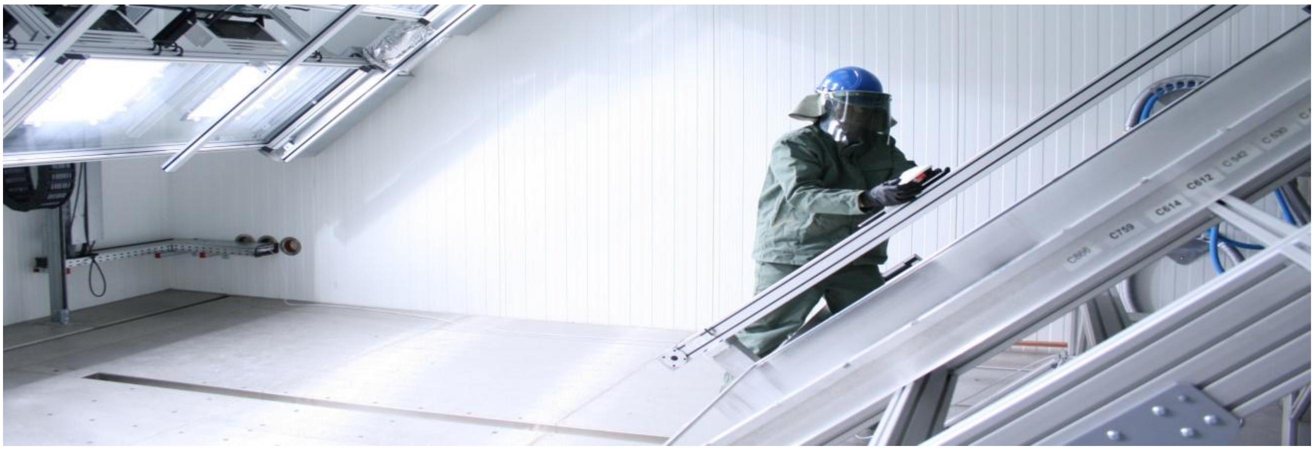
Quality Assurance in Solar Heating and Cooling Technology

A GUIDE TO THE STANDARD EN 12975



INTELLIGENT ENERGY EUROPE

QAiST
Quality Assurance in Solar Heating and Cooling Technology

Quality Assurance in solar thermal heating and cooling technology – keeping track with recent and upcoming developments

A guide to the standard EN 12975

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PURPOSE AND SCOPE

The purpose of this guide is to form a complement to the EN 12975 standard, focusing on part 2 related to testing of solar thermal collectors. It is intended to support in the interpretation and application of the standard. The guide has been developed with two different target groups and objectives in mind.

1. **A guide directed to established and new test laboratories for collector testing.** The main purpose here is to give a quick introduction to the standard for new laboratories and in general to contribute to a uniform interpretation of the standard and presentation of results. These parts are mainly covered in sections 2- 8.
2. **A guide directed to manufacturers and importers of collectors.** Here, the purpose is to give a very light introduction to the standard and to explain how it is used for type testing as well as for innovation and development support. These target groups are mainly addressed in section 0 of this guide, where tests that can easily be carried out by e.g. manufacturers themselves are also briefly explained.

In addition to this guide a small informative brochure has also been developed and is available as a PDF as well as in a printed version.

During the writing of this guide, the EN 12975:2006 is currently under revision and some significant changes are expected in the new version planned for 2012/ 2013. As these changes cannot be predicted at present this guide is based on the 2006 version of the standard. However significant changes that are most likely to be part of the next version of the standard are indicated as far as possible.
Please note that the only official document in this context is the standard itself. For up to date detailed information always refer to the latest version of the full standard.

REFERENCED STANDARDS

The following list describes standards that are directly connected to the first two, for which this guide is written. A short comment is given *in italics* for each document. For further information on the scientific background to the EN 12975 standard, see the bibliography section in the standard.

i. EN 12975-1:2006, Thermal solar systems and components – Solar collectors – Part 1: General Requirements

ii. EN 12975-2:2006, Thermal solar systems and components – Solar collectors – Part 2: Test methods

iii. EN 12976-1:2000, Thermal solar systems and components – Factory made systems – Part 1: General Requirements. *Some of the requirements of the EN 12975 standard are also valid for systems covered by EN 12976.*

iv. EN 12976-2:2000, Thermal solar systems and components – Factory made systems – Part 2: Test methods. *For systems where the collector can be tested separately it is tested according to EN 12975. However in this case thermal performance, freeze resistance and internal pressure test of the collector is excluded.*

v. EN ISO 9488, Solar energy – Vocabulary (ISO 9488:1999). *Many essential definitions are explained in this document e.g. collector area definitions.*

vi. ISO 9060, Solar energy – Specification and classification of instruments for measuring hemispherical solar and direct solar radiation. *A normative reference to EN 12975-2. To learn about principles of radiation measurement, refer to instrument manufacturers' websites.*

2.1 A rough comparison with other solar thermal collector standards

There is a number of different standards available, describing testing of solar thermal collectors. Initial work for the design of Reliability and Durability tests was performed by Collector and System Testing Group [6]. Historically the US ASHRAE standard (93-77) was the first one to be widely used. Then the ISO 9806 series of standards was developed and from this one, the EN 12975. Several national standards are also available outside of Europe, most often based on the ISO 9806, but in Europe the EN 12975 has replaced all national standards. Currently the aim of CEN and ISO is to revise the ISO 9806 taking into account new knowledge gained during the development of the EN 12975 standard. The following table explains some of the main differences between EN 12975 and some other commonly used standards.

Table 1. Comparison between the EN 12975 and other collector test standards. Not mentioning e.g. the SRCC Standard 100 for the high temperature resistance test means that this particular test is not included in the standard.

Test	Standard	Test procedure
High temperature resistance	EN 12975	Collector A minimum 1 h with G > 1000 W/m² and ambient temperature 20 – 40 °C, wind < 1 m/s
	ISO 9806-2 [1]	Collector A minimum 1 h with G: A) 950 - 1049 ; B) 1050 - 1200 ; C) > 1200 (W/m²) and ambient temperature: A) 25 - 29,9 ; B) 30 - 40 ; C) > 40 °C, wind < 1 m/s
	CAN/CSA-F378-87 [3]	Collector A minimum 1,5 h with G = 950 + 5*(30-T_{amb}) W/m², wind < 5 m/s
	AS/NZS 2735.1	Collector A according to ISO 9806-2
	AS/NZS 2712 [4]	Collector A performance according to AS/NZS2535.1 G = 1050 W/m² with max 20 W/m² deviation at 6 points T_{amb} > 30 °C (Level 1) / >38 °C (Level 2), 12 h irradiation on / 12 h irradiation off for 10 days
Exposure	EN 12975	Collector A according to ISO 9806-2 Class A 30 days with H > 14 MJ/m² 30 h with G >850 W/m² and T_{amb} >10°C
	ISO 9806-2	Collector A, B, C 30 days with H: A) 14 ; B) 18 ; C) 20 MJ/m² 30 h with G: A) 850 ; B) 950 ; C) 1050 W/m² and T_{amb} >A) 10 ; B) 15 ; C) 20 °C
	SRCC Standard 100	Collector A 30 days with H > 17 MJ/m²
	CAN/CSA-F378-87	Collector A, first the collector will be filled, then drained and closed. Exposition phase started after closing of pipes 30 days with H > 17 MJ/m²
	AS/NZS 2735.1	Collector A according to ISO 9806-2
External thermal shock	EN 12975	Collector A 2 times according to ISO 9806-2 Class A minimum 1 h with G (W/m²) and T_{amb} (°C) as in 30 h exposure
	ISO 9806-2	Collector A 2 times minimum 1 h with G (W/m²) and T_{amb} (°C) as in 30 h exposure
	Standard 100-8	Collector A 2 times according to ISO 9806-2 Class B minimum 1 h with G >950 W/m² and T_{amb} > 15°C
	AS/NZS 2735.1	Collector A according to ISO 9806-2

Test	Standard	Test procedure
Internal thermal shock	EN 12975	Collector A 2 times according to ISO 9806-2 Class A minimum 1 h with G (W/m²) and T_{amb} (°C) as in 30 h exposure
	ISO 9806-2	Collector A 2 times minimum 1 h with G (W/m²) and T_{amb} (°C) as in 30 h exposure
	Standard 100-8	Collector A 1 time according to ISO 9806-2 Class B minimum 1 h with G >950 W/m² and T_{amb} >15 °C
	CAN/CSA-F378-87	Collector A 1 time minimum 1 h with G >900 W/m²
	AS/NZS 2735.1	Collector A according to ISO 9806-2
Rain penetration	EN 12975	Collector A, Test duration 4 h
	ISO 9806-2	Collector A, Test duration 4 h
	CAN/CSA-F378-87	Collector A, Test duration 30 min.
	AS/NZS 2735.1	Collector A according to ISO 9806-2
	AS/NZS 2712	Collector A 10 min. rain penetration, 4 h drying with shaded aperture
Impact resistance	EN 12975	Collector A according to ISO 9806-2 or with 7.5 g ice ball 10 times with 23 m/s ± 5%
	ISO 9806-2	Collector A or B max. 5 cm from the edge max. 10 cm from the corner. Steel ball 150 gram +/- 10 g each 10 times at 0,4 / 0,6 / 0,8 / 1,0 / 1,2 / 1,4 / 1,6 / 1,8 / 2,0 meter in height
	SRCC Standard 100	Collector A according to ISO 9806-2 for none tempered glass
	AS/NZS 2735.1	Collector A according to ISO 9806-2
	AS/NZS 2712	Collector A - no glass pieces > 50 mm with ice ball according to EN 12975 with steel ball 63 gram at 2,9 m height, 3 different positions, 150 mm from corner or edge
Mechanical Load	EN 12975	Collector A minimum + 1000 Pa, minimum - 1000 Pa
	CAN/CSA-F378-87	Collector A + 1500 Pa, - 2000 Pa
	AS/NZS 2712	Collector A positive and negative load

Test	Standard	Test procedure
Final Inspection	EN 12975	Collector A
	ISO 9806-2	Collector A, B, C
	Standard 100-8	Collector A
	CAN/CSA-F378-87	Collector A
	AS/NZS 2735.1	Collector A
Thermal performance	EN 12975	Collector B, pre-conditioning 5h with G > 700 W/m², diffuse fraction < 30 %. Steady State or Quasi-Dynamic Testing.
	ISO 9806-1	Collector A, tilt-angle latitude ± 5° but not less than 30°, diffuse fraction < 20 %. Collector area: 0,1 % accuracy, minimum global irradiation G >800 W/m². Wind speed 2 - 4 m/s. Volume flow 0,02 kg/(s*m²), max. drift +/- 10 %, deviation mass flow ± 1%, Deviation Irradiation ± 50 W/m². Deviation T_{amb} ± 1 K, deviation inlet temperature ± 0,1 K. T_{out}-T_{in} >1,5 K, T_m-T_{amb} at η_0 ± 3K. Conditioning phase minimum 15 min and measurement phase minimum 15 min.
	ISO 9806-2 [2]	Collector A according to ISO 9806-1
	SRCC Standard 100	Collector A, 5 minutes measurement points / 0,07 g/(s*m²) according to ISO 9806-1
	CAN/CSA-F378-87	Collector A according to ANSI/ASHRAE
	ANSI/ASHRAE standard 93	Minimum global irradiation G >790 W/m², deviation irradiation ± 32 W/m², diffuse fraction < 20 %. Max. T_{amb} 30 °C. Wind speed 2,2 – 4,5 m/s, volume flow 0,02 g/(s*m²). Deviation inlet temperature ± 2% or 1°C Deviation mass flow ± 2% or 0,000315 l/s. Deviation T_{amb} ± 1,5 K. Conditioning phase 2*times constant or minimum 10 minutes. Measurement phase minimum 0,5*times constant or minimum 5 minutes.
	AS/NZS 2735.1	Collector A, tilt-angle latitude ± 5° but not less than 30°, diffuse fraction < 20 %. Collector area: 0,1 % accuracy, minimum global irradiation G >800 W/m². Wind speed 2 - 4 m/s. Volume flow 0,02 kg/(s*m²), max. drift +/- 10 %, deviation mass flow ± 1%, Deviation Irradiation ± 50 W/m². Deviation T_{amb} ± 1 K, deviation inlet temperature ± 0,1 K. T_{out}-T_{in} >1,5 K, T_m-T_{amb} at η_0 ± 3K. Conditioning phase minimum 15 min and measurement phase minimum 15 min.

2.2 Certification according to Solar Keymark and SRCC

The procedures for certification according to Solar Keymark and SRCC are slightly different to each other. For Solar Keymark the certificates are issued by different certification bodies (CBs) and the tests are performed by labs which are sending the test results to the CB. The requirements on the labs are accreditation according to ISO/IEC 17025 (General requirements for the competence of testing and calibration laboratories) and accreditation to perform tests according to the EN 12975 standard. The CB´s must have accreditation according to ISO/IEC 17020 (General criteria for the operation of various types of bodies performing inspection). The test laboratories shall be recognized by one or more CB. The CB can put additional requirements on the test lab such as surveillance of the quality system and test equipment.

For the SRCC certification there is only the SRCC themselves that are issuing the certificates and different testing laboratories are recognized to perform the testing. The lab´s must be accredited according to ISO/IEC 17025 and accredited to perform tests according to the ISO 9806 and the standard 100 and/or the standard 600.

SELECTION OF SOLAR COLLECTORS FOR TESTING

The majority of requirements referred in this chapter are related to procedures anticipated by the Solar Keymark. In the case of single Standard implementation these requirements are not valid. This is also explained in conjunction to specific requirements below.

3.1 Random selection and pre-series

The solar thermal collectors being submitted for tests must be selected randomly by the designated representative of test laboratory or certification body (this is compulsory for certification according to the Solar Keymark Scheme rules but not a mandatory part of the standard). The manufacturer will make the test samples available from existing stock at the manufacturing facility or at the manufacturer's distribution location. In addition they can also be picked directly from the production line. Alternatively a remote sampling as described in Decision D13.M8 of the Solar Keymark Network can be carried out. The test laboratory representative will randomly tag on the test units for testing. The manufacturer will then have the tagged test units transported to the laboratory for testing. Also refer to document on procedures of solar thermal quality management (www.solarkeymark.org). See also 0 regarding how many collectors to pick out.

According to Keymark scheme rules, performance test shall be carried out for the smallest and for the largest collector in a family. Therefore at least 3 collectors (one smallest for the performance tests and two of the largest collector for parallel performance and reliability testing) shall be picked out at the factory/stock. It is not a bad idea to pick out some extra collectors and leave them in the factory in case the collectors are damaged during transportation or at the laboratory. It is also appropriate to make measurements of length, width and height of all other collector sizes in the collector family at place.

3.2 Receiving inspection

Upon receiving a test unit for testing, the test laboratory shall check that the unit is in normal conditions (no damages due to the transport) and inspect the document of the unit according to Solar Keymark scheme rules (www.solarkeymark.org)

3.3 Re-testing

Changes in design, components or materials used in a collector often occur as a result of product development. If the collector is certified e.g. with the Solar Keymark, the modification must be assessed by the certification body before it is implemented in a new product. Depending on which type of changes the manufacturer plans to do, the certification body can either approve the change without any requirements for re-testing or require that some or all tests are carried out again on the modified collector. The Solar Keymark network is continuously developing the certification scheme in order to further facilitate design changes.

As a result, a number of absorber coatings and glazings are exchangeable without any requirements for re-testing and the idea is to extend this concept to other materials and components. The certification body is therefore guided by three documents when assessing the need for re-testing:

i. The Solar Keymark scheme rules (www.solarkeymark.org)
ii. The Solar Keymark decision list (www.solarkeymark.org)
iii. Annex C of EN12975-1:2006

A recent add-on requirement connected to re-testing of rain penetration is that a pre-exposure must be performed before the new test. This is explained in the Solar Keymark Network decision list but has not yet been implemented in the scheme rules or in the standard (see D8.M10 of [18] alternatively [17]). In difficult cases, the Solar Keymark network should be consulted for guidance as it represents a significant experience in testing and certification.

TEST PROCEDURES FOR LIQUID HEATING SOLAR COLLECTORS AND SOME DEFINITIONS

This chapter gives an introduction to collector testing and an explanation of why some definitions are needed.

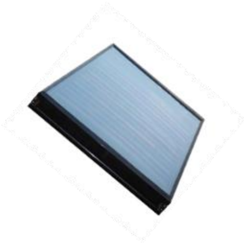
4.1 Solar collector types

The EN 12975:2006 standard covers performance, durability and reliability testing of almost all collector types available in the market. Tracking concentrating collectors were recently fully included in the scope. In the upcoming revision of the standard air collectors and PVT collectors will also be incorporated however in the latter case the standard will not be applicable to the electrical parts of the collector. In Table 2 the most common types of solar collectors are described, including their field of application and specific testing considerations.

At present, only collector types covered by the EN 12975 standard can obtain a Solar Keymark certificate. The most recent types added to the list of collector types are tracking concentrating collectors and the thermal part of PVT collectors. The former was included through amendment A1:2010 to 12975-1:2006 and the latter was included according to SKN decision list D7.M10.

Table 2. Most but not all collector types on the market are covered by the standard

Collector type (Common field of application)	Characteristics	Specific testing considerations	Picture
Unglazed collectors (Swimming pools, evaporators for heat pumps)	High performance at low temperatures (close to ambient temperature) and highly dependent of the wind speed Inexpensive Can often withstand freezing Sometimes designed for working under dew-point of ambient air (heat pumps)	• Requirements on test sample area and test flow rate differs from glazed collectors • Long wave irradiance and wind speed are important variables during performance testing and special considerations for measurements apply • Condensation effects on the performance are not yet taken into account in the thermal performance test • method	 

Collector type (Common field of application)	Characteristics	Specific testing considerations	Picture
Flat plate (Domestic hot water systems, combi systems and district heating)	Good performance at higher temperatures (typical temperatures for domestic hot water)	None	
Vacuum tubes (Domestic hot water systems, combi systems and district heating. Solar assisted cooling, process heat)	Normally good performance at higher temperatures (typical temperatures for domestic hot water and above). Low content of raw materials.	Biaxial incidence angle modifier (IAM) measurement required Heat pipes and heat transfer paste, if present, need special attention Check area definitions	
Stationary concentrating e.g. CPC:s (Domestic hot water systems, combi systems and district heating. Solar assisted cooling, process heat)	Good performance at high temperatures, however not as good as ETC:s. Low content of raw materials.	Bi- or multiaxial IAM measurement required Optical efficiency for diffuse and direct irradiance need to be determined	
Tracking concentrating (Solar assisted cooling, process heat, electricity production)	Can be of linear Fresnel, parabolic trough- or dish type	To be tested using the suppliers' tracking system Optical efficiency for diffuse and direct irradiance need to be determined Specific aspects related to durability testing, e.g. active protection, are not included in EN 12975:2006 but is included in the new draft prEN ISO 9806 as Annex P	 
Air-collectors (Drying of crops, pre-heating of air for building ventilation)	Can be of closed or open loop type, glazed or unglazed	Not in the scope of the EN 12975:2006 but is included in the new draft prEN ISO 9806	

Collector type (Common field of application)	Characteristics	Specific testing considerations	Picture
Hybrids	Can be of thermal air-liquid or thermal-electrical type (PVT)	Presently the EN12975 only covers the thermal liquid heating parts of these products. With the new prEN ISO 9806 the scope will be extended to air collectors and to some extent to PVTs however the PV parts will remain in the IEC standards.	

4.2 Gross area, aperture area and absorber area

The definitions for gross area, aperture area and absorber area are given in ISO 9488:1999.

The gross area is defined as the maximum projected area of a collector. Pipe connections and parts for mounting the collector are not included in gross area.

The maximum projected area where un-concentrated solar radiation enters the collector is called aperture area.

The absorber area is defined in two different categories, for collectors without and with reflector. For solar collectors without reflector it is the maximum projected area of the absorber, for collectors with reflector it is the area which is designed to absorb solar radiation.

Illustrated examples showing the definitions applied to different collector types are shown in Annex 1 to Guide to EN12975. Area definitions for different collector types".

4.3 Incidence angle modifiers

In general the (direct) radiation from the sun does not incident completely along the normal onto a solar collector, but arrives at a certain angle of incidence. This angle is measured between the radiation beam and the normal to the collector surface, see adjoining Figure 1.

The incidence direction is not only described by this single angle, but by two different ones, transversal and longitudinal. For flat-plate collectors this differentiation is not necessary, while e.g. for concentrating or evacuated tube collectors these angles have different influences. This influence is described via the so called IAM (incidence angle modifier).

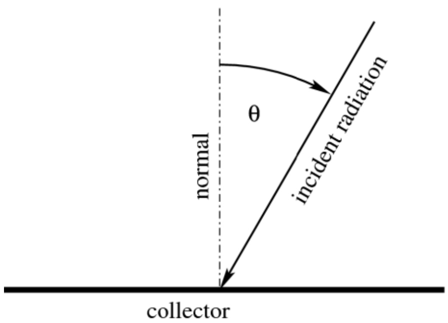


Figure 1. Definition of incidence angle

The IAM is defined as the efficiency at the given incidence angle divided by the efficiency at normal incidence and is thus equal to 1 for normal incidence of the direct radiation. It is well-known that for flat-plate collectors the IAM decreases with increasing incidence angle, i.e., the higher the incidence angle is, the lower the (relative) efficiency, as can be seen in the Figure 2. If the geometry of the collector is not flat, as is for example the case for a concentrating collector, the efficiency is not necessarily at its maximum at normal incidence. It may (and often does) happen, that the maximum appears at another angle, e.g. at 25° for the example in Figure 2. Then the IAM becomes larger than one near this maximum describing the higher collector efficiency for this condition.

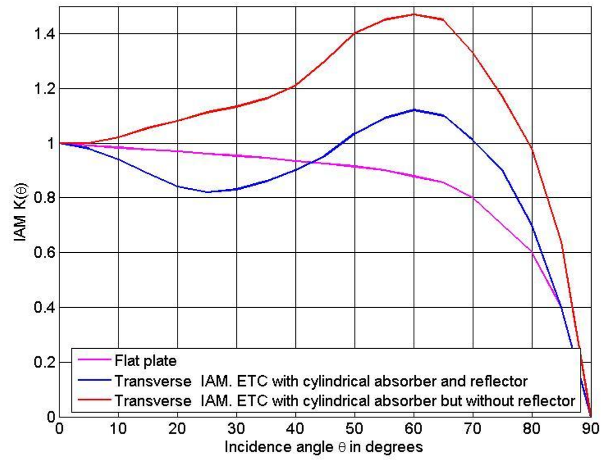


Figure 2. IAM for three different collectors types

With the information of the IAM, the mounting angle of the collector and the solar altitude the performance can be predicted for all incidence angles over the year. Different functions for a full description of IAM over the whole range of relevant incidence angles are used. However, as none of them is able to cover all cases, the use of a table with small enough angle intervals is often the most accurate way to model the IAM for complex collector geometries. For most geometries a ten degree resolution is appropriate but for some collectors a higher resolution may be needed for parts of the acceptance range.

Incidence angle modifier for glazed solar collectors under steady state conditions

In the following equation the influence of the incidence angle modifier, described by the symbol K_θ is described in the efficiency formula. If the incidence angle modifier is introduced in the equation, the effective transmittance – absorbance product $(\tau\alpha)_e$ can be replaced by the value at normal incidence $(\tau\alpha)_{en}$.

$$\eta = F' K_\theta (\tau\alpha)_{en} - a_1 \frac{t_m - t_a}{G} - a_2 G \left(\frac{t_m - t_a}{G}\right)^2 \quad \text{Eq. 1}$$

Hence:

$$(\tau\alpha)_e = K_\theta(\tau\alpha)_{en} \qquad \text{Eq. 2}$$

So the relationship between K_θ and the efficiency is:

$$\boldsymbol{K_\theta = \frac{\eta(\Theta)_{(at\, t_m - t_a = 0)}}{F'(\tau\alpha)_{en}}} \qquad \text{Eq. 3}$$

For conventional flat plate collectors, only one angle of incidence is needed which is 50°. For collectors with unusual optical performance characteristics (e.g. evacuated tube collectors and CPC collectors), it is necessary to measure the incidence angle effects from more than one direction (longitudinal and transversal) and at different angles (e.g. 20°, 40°, 60° and others) to fully characterize the incidence angle modifier.

The individual incidence angle modifier can be estimated by considering it to be the product of the longitudinal and transversal incident angle modifiers, $K_{\theta L}$ and $K_{\theta T}$.

$$K_\theta = K_{\theta L} \times K_{\theta T} \qquad \text{Eq. 4}$$

Incidence angle modifier for unglazed solar collectors under steady state conditions (optional)

In the following equation the influence of the incidence angle modifier K□□is described in the efficiency formula.

$$\eta = K_\theta \eta_0 (1 - b_u u) - (b_1 + b_2 u)\frac{t_m - t_a}{G''} \qquad \text{Eq. 5}$$

The relationship between K_θ and the efficiency is the same as in Eq. 3

For unglazed collectors that are symmetrical in the transverse and longitudinal directions, only one additional angle of incidence need to be measured, which is 50°. For collectors that are not, the same requirements as for glazed collectors apply.

Incidence angle modifier for glazed and unglazed solar collectors under quasi-dynamic conditions

The incidence angle modifiers, modeled as $K_{\theta b}(\theta)$ for direct radiation and as $K_{\theta d}$ for diffuse radiation, are mandatory parts of the collector model.

With the following equation, the basic modeling of IAM-dependence of flat plate collectors shall be done.

$$K_{\theta b}(\theta) = 1 - b_0\left(\left(\frac{1}{\cos\theta_i}\right) - 1\right) \qquad \text{Eq. 6}$$

For a standard flat plate collector the IAM is assumed to be the same in the transverse and the longitudinal direction. For collectors with an asymmetric IAM, either biaxial or multi axial, separate IAM's need to be determined in two or more of the quadrants from east to west and from north to south.

The east-west IAM is defined as the *transverse* IAM $K_{\Theta T}$ for the ETC collector in Figure 3 but as the *longitudinal* IAM $K_{\Theta L}$ for the CPC collector as these subscripts are referring to the optical axis of the collector. Vice versa, the north-south IAM equals $K_{\Theta L}$ for the ETC and $K_{\Theta T}$ for the CPC collector. A photo of the collector under test will help to avoid misinterpretations of these parameters.

Figure 3. ETC (left) and CPC (right)

4.4 Irradiance measurements

Accurate irradiance measurements are quite difficult to perform but for accurate determination of collector efficiency, they are indispensable. The following points should be considered:

- Measurement equipment always need to be well aligned with the collector tilt and azimuth and in the plane of the collector aperture
- Care should be taken to avoid shading and reflected irradiance on collector and measuring equipment
- The power output of some collector designs such as e.g. ETCs and CPCs will strongly depend on the diffuse fraction of the irradiance. For accurate results it is therefore necessary to measure not only the hemispherical radiation but also the direct or diffuse portion of it. This means that concentrating collectors should at present only be tested using the quasi dynamic test method
- The standard uncertainty of a calibrated first class pyranometer is in the range +/- 1,5-3%
- Much cheaper sensors based on semiconductor technology can be used for own development testing but these are not Class 1 as required by the standard and the accuracy is much lower: +/-5-10%

Dealing with solar collectors there are two different sources of radiation to distinguish between.

1. Solar radiation (short wave radiation) in the wavelength λ of approx. 250 nm to 3000 nm as energy source.
2. Sky radiation (long wave radiation) in the wavelength of approx. $\lambda > 3000$ nm as energy sink for the radiation losses of the solar collector.

With the exception of uncovered collectors the sky radiation can usually be neglected.

4.4.1 Solar radiation

The incoming hemispherical radiation consists of the direct radiation coming from the direction of the sun and the diffuse radiation, resulting from direct radiation scattered in the atmosphere and reflected from the ground or other surfaces. The diffuse radiation does not incident from a defined direction but has an anisotropic distribution over the field of view.

In terms of irradiance Eq. 7 is valid:

$$G_{hem} = G_{beam} + G_{dfu} \qquad \text{Eq. 7}$$

4.4.1.1 Measurement of hemispherical irradiance

For the measurement of the hemispherical irradiance G_{hem} pyranometers are used. The main components of a pyranometer are:

- A thermopile sensor with a black coating absorbing the solar radiation.
- A glass dome to limit the spectral response from 280 to 2800 nm while preserving the 180 degrees field of view. Another function of the dome is that it shields the thermopile sensor from convection.

The black coating on the thermopile sensor absorbs the solar radiation. This radiation is converted to heat. The thermopile sensor generates a voltage output signal that is proportional to the temperature difference between the black surface of the thermopile and the instrument body and thus proportional to the solar radiation.

Performance measurements according to EN 12975 require a pyranometer class 1or better as specified by ISO 9060:1990(E) Solar energy – Specification and classification of instruments for measuring hemispherical solar and direct radiation. The following table summarizes the requirements for class 1 pyranometers.

Table 3. Class 1 pyranometer requirements according to ISO 9060

Specification	Class 1
Response time: time for 95 % response	< 30 s
Zero off-set: a) response to 200 W m^{-2} net thermal radiation (ventilated) b) response to 5 K h^{-1} change in ambient temperature	+ 15 W m^{-2} ± 4 W m^{-2}
Non-stability: percentage change in responsivity per year	± 1.5 %
Non-linearity: percentage deviation from the responsivity at 500 W m^{-2} due to the change in irradiance within 100 W m^{-2} to 1000 W m^{-2}	± 1 %
Directional response (for beam radiation): the range of errors caused by assuming that the normal incidence responsivity is valid for all directions when measured from any direction a beam radiation whose normal incidence irradiance is 1000 W m^{-2}	± 20 W m^{-2}
Spectral selectivity: percentage deviation of the product of spectral absorptance and spectral transmittance from the corresponding mean within an 0,35 µm and 1.5 µm	± 5 %
Temperature response: Percentage deviation due to change in ambient temperature within an interval of 50 K	4 %
Tilt response: Percentage deviation from the responsivity at 0° tilt (horizontal) due to	± 2 %

Specification	Class 1
change in tilt from 0° to 90° at 1000 W m^{-2}	

Further information regarding pyranometer specification can be found in *ISO 9060:1990(E) Solar energy – Specification and classification of instruments for measuring hemispherical solar and direct radiation*.

4.4.1.2 Measurement of direct irradiance

For the measurement of the DNI (direct normal irradiance) a pyrheliometer is needed. The measurement principle is similar to the one of pyranometers (thermopile sensor absorbing the solar irradiance). However, to capture only direct irradiance (coming from the direction of the sun only) pyrheliometers have a very limited view angle of < 6°.Therefore, a part of the scattered radiation around the sun´s disk (circumsolar radiation) is included, as the solar disk itself has a field-of-view angle of about 0,5°.

To follow the apparent movement of the sun a two axis tracker is required for the use of a pyrheliometer.

The direct irradiance normal to the collector aperture is calculated using the angle of incidence θ by Eq. 8.

$$G_{beam} = DNI * \cos\theta \qquad \text{Eq. 8}$$

4.4.1.3 Measurement of diffuse irradiance

For the measurement of the diffuse irradiance (G_{dfu}) pyranometers are used. To block the direct radiation from the sensor a so called shadow band/ring is used. Since the shadow band/ring does not only block the direct radiation but also partly the diffuse radiation a correction of the pyranometer signal is necessary. The correction depends on the latitude, time of the year and the geometry of the shadow band/ring. The calculation should be done using the correlations given by the manufacturer. However the standard correction is only valid for a horizontal installation of the pyranometer.

For a tilted pyranometer correction factors can be derived using the standard corrections, taking into account that only part of the hemisphere is 'seen' by the pyranometer. Additionally the effect of ground-reflected radiation should then be taken into account. A more accurate way to determine the diffuse irradiance on a tilted plane is by measuring DNI and calculating it according to Eq. 7.

Most correction methods for shadow band pyranometers are strictly geometrical and based on the assumption of an isotropic distribution of the diffuse irradiation. Since – especially under (partly) clear-sky conditions – the distribution is not isotropic, this leads to an underestimation of diffuse irradiance of 10-30% according to different scientific publications. This effect can be reduced by using a tracked pyranometer with a shading ball which blocks a view-angle similar to that one of a pyrheliometer (< 6°) and thus a smaller fraction of the diffuse radiation.

4.4.1.4 Calculation of diffuse, direct and hemispherical irradiance

Usually either the diffuse irradiance or the direct irradiance is measured during performance testing. The other quantity is calculated by subtraction from the hemispherical irradiance using Eq. 8. For performance measurements under steady state conditions the calculation of the hemispherical irradiance is sufficient. When using the test method under quasi-dynamic conditions, however, the measurement of the direct irradiance is strongly recommended, especially when concentrating collectors are under test.

Some publications even promote the calculation of hemispherical irradiance by the measurement of direct irradiance with pyrheliometer and diffuse irradiance with shading ball as the most sophisticated method (Gueymard & Myers, 2008).

4.4.2 Sky radiation

The long wave irradiance coming from the sky is measured using a pyrgeometer which consists of the following major components:

- A thermopile sensor which is sensitive to radiation in a broad range from 200 nm to 100 µm
- A silicon dome or window with a solar blind filter coating. It has a transmittance between 4,5 µm and 50 µm that eliminates solar shortwave radiation.
- A temperature sensor to measure the body temperature of the instrument.

The measurement of the long wave radiation is only relevant when testing uncovered collectors, using a simulator without cold sky or applying the test method under quasi-dynamic conditions without using fans to create a constant wind speed on the collector surface.

4.4.3 Installation, measurement and maintenance

4.4.3.1 Installation

Sensors used for the measurement in the collector plane need to be installed parallel to the aperture area of the collector with a maximum deviation of 1° (better 0,5°). To ensure that the sensor receives the same irradiance as the collector under test, the position of the sensor must be chosen very carefully, avoiding reflection and partial shading of the sensor which does not reach the collector at the same time.

The sensor bodies have to be shielded from irradiance and have to be thermally decoupled from the mounting device as good as possible to avoid heating of the sensor body resulting in incorrect measurements. Ventilation devices may be used to further increase in accuracy.

Further recommendations for the use can be found in *ISO/TR 9901:1990(E). Solar energy – Field Pyranometers – Recommended practice for use.*

4.4.3.2 Measurement

Due to the thermopiles used in the radiation sensors the output voltage is in the range of 0 to 12 mV depending on the level of irradiance and the sensitivity of the instrument. These low voltages require special care during installation (e.g. shielded wires, usage of ground connection, etc.). To achieve a good accuracy also the following specifications of the digital voltmeter have to be taken into account: measuring range, resolution and integration time. Different time constants of instruments for measuring hemispherical and diffuse/direct irradiance have to be taken into account especially for measurements under partly clouded skies.

4.4.3.3 Maintenance

Cleaning of glass domes every day before collector tests with microfiber cloth is obligatory. If measurements last for several days also the collector covers must be cleaned regularly. Desiccants have to be checked periodically and changed/regenerated if exhausted. The shadow band/ring used for the measurement of the diffuse irradiances needs daily inspection and adjustment to ensure good results, as well as the tracking device of the pyrheliometer for the measurement of the direct irradiance. The maintenance requirements given by the manufacturer have to be followed very carefully.

4.4.3.4 Calibration and uncertainty

All radiation sensors need to undergo a yearly calibration. A two year interval can be accepted if the instrument can show a stable track record over several years. Usually these calibrations can be performed by the manufacturer of the instruments but in this case, the calibration may not be recognized through the European cooperation for accreditation. Any laboratory normal used for calibration shall be traceable to a reference at the World Radiation Centre (WRC) in Davos, Switzerland (www.pmodwrc.ch) who provides calibration services as well. The expanded measurement uncertainty for calibrating the reference pyranometer at Davos is about 1,3 % (for horizontal mounting as well as for a given irradiation, temperature and incidence angle range).

Because of additional uncertainty "portions" (like drift, tilted mounting, data acquisition system etc.) the overall uncertainty for the irradiation value within a thermal performance measurement will always be higher.

4.5 Safety precautions when testing solar collectors

The following risks for personal damage must be considered in testing of solar collectors:

i. Handling of heavy items and mounting on test stand (e.g. test stand, roof, tracker)

Use lifts and lifelines.

ii. Hot water and steam (i.e. at internal thermal shock tests)

The connections at the solar collector must be drained off to a secure place to avoid injuries from hot water or steam leaving the collector. Hot water can be "pumped" out of the collector by steam bubbles long time after the shock test if the collector again goes into stagnation.

iii. Pressure test (with air, water or oil)

Make sure that all connections are covered in case of some of them will come loose. Never stand in front of the collector connections when pressure testing! Pressure test with air should normally be avoided and needs special precautions.

iv. Poisonous gases from burning insulation materials during high temperature resistance tests.

Only perform high temperature tests with sufficient ventilation and avoid breathing in any gases coming from the collector.

v. Sharp glass and edges

Sharp edges shall be avoided at solar collectors. Broken pieces of glass, especially from ETC´s are very sharp.

vi. Precautions when using tracking devices (e.g. trackers)

Beware of moving test stands such as trackers, risk for getting squeezed

vii. Electrical safety of PV-modules

RELIABILITY TESTS

5.1 Purpose and “time” schedule for the different tests

During the collectors life time some severe climatic and working conditions will be met. It is required that the collectors do not suffer **major failures** when these conditions are met. The reliability and durability tests were designed to reproduce the most probable extreme conditions that a collector will be subjected to. For each test the standard describes in a very simple way the conditions that are intended to be simulated by each test.

Initial work for the design of Reliability and Durability tests was performed by Collector and System Testing Group [1]. According to this initial work and the first version of the EN 12975 (2000/2001) the tests should be performed in a certain order or sequence. At present there is no requirement on the full sequence of reliability tests. However this may change in the ongoing revision of the standard (see reference [19]).

In order to shorten the time necessary for tests it is possible, according to the present version of the standard to have three samples (collectors) tested according to the following justifications:

One collector for thermal performance

The standard indicates that the thermal performance test *shall be carried out on a collector that had not been used for the other tests*. This requirement is established in order that the results of the thermal performance test in different collectors are not influenced by the test conditions of reliability tests like Exposure test that may differ when tested in different locations with different climatic conditions. For this reason this test is performed on a collector that is only submitted to a short preconditioning with five hours exposure with irradiance above 700 Wm^{-2}.

One collector for high-temperature resistance, exposure, thermal shocks together with a final inspection

The standard does not impose a sequence on the durability tests but indicates that *high-temperature resistance and exposure test shall be carried out on the same collector*. This recommendation takes into consideration that high- temperature resistance test is a test with very extreme conditions but the consequences of this test can only be fully evaluated by an inspection. The same applies to the exposure test. For this reason it is most advisable that they are performed in the same sample. The standard also indicates that *thermal shocks may be combined with the high-temperature resistance and exposure test,* which is a good compromise between the number of samples to be tested and the time needed for testing.

One collector for mechanical loads and rain penetration

Although the present version of the standard [EN 12975-2:2006] allows the use of a third collector for the mechanical load and rain penetration test, this third sample shall be submitted to a pre-conditioning in the case of rain penetration taking into account D8.M10 of SK Network [18], alternatively [17].

Also it is expected that preconditioning of samples for these tests (rain penetration and mechanical load) is included in the future version of the standard [19]. It can also be noted that when testing for durability and reliability according to standards ISO 9806 and SRCC standard 100 the approach is different. The sequence is well defined in this case, all tests are carried out on the same collector and the performance test is performed as the final test in the sequence. During the reliability tests no Major Failure shall occur. The definition of Major Failure is given in section 5.3. of EN 12975-1.

Table 4 shows these definitions and tests where they are most likely to be identified.

Table 4 - Definition of Major Failure

Definition of major failure	Test where it is more likely to occur
Absorber leakage or such deformation that permanent contact between absorber and cover is established	Internal pressure Exposure test Internal thermal shock Impact resistance Mechanical load test
Breaking or permanent deformation of cover or cover fixings	High temperature resistance test Exposure test External thermal shock Internal thermal shock Impact resistance Mechanical load test
Breaking or permanent deformation of collector fixing points or collector box	Impact resistance Mechanical load test
Vacuum loss, such that vacuum or sub atmospheric collectors shall be classified according to the definition in EN ISO 9488 (only applicable for vacuum and sub atmospheric collectors.	High temperature resistance test Exposure test External thermal shock Impact resistance Mechanical load test
Accumulation of humidity in form of condensate on the inside of the transparent cover of the collector exceeding 10% of the aperture area.	External thermal shock Rain penetration

5.2 Internal pressure test

The objective of the test is to determine if *the absorber can withstand the pressures which it might meet in service.*The apparatus and procedures for internal pressure test are strongly dependent on the type of material of the absorber.

Note that by absorber it is meant both the absorber surface and the grid where the fluid circulates.

Table 5 shows essential differences considering the materials of the absorber.

Table 5 Summary of test conditions for internal pressure test

	Inorganic absorber	Organic absorber
Duration	15 min	1 hour
Temperature	Ambient (5 to 30ºC)	Stagnation Temperature
Pressure Source	Hydraulic	Hydraulic/Pneumatic
Pressure	1.5 maximum collector operating pressure	
Pre-conditioning	---	High temperature resistance test for determination of the stagnation temperature.

Since, for organic absorber, the test has to be performed at stagnation temperature, the test will be performed after the high temperature resistance and different procedures can be adopted to reach this temperature. Table 6 summarizes these procedures.

Table 6 Summary of heating procedures for internal pressure test using hydraulic pressure source.

Stagnation temperature /Test temperature	Pressure source	Fluid used	Heating procedure	Precautions during test
<90ºC (typical for unglazed collectors)	Hydraulic	Water	Submerge the absorber in a heated water bath	For safety reasons, the collector shall be encased in a transparent box to protect personnel in the event of explosive failure during this test
>90ºC	Hydraulic	oil	Connect the collector to a hot oil circuit	For safety reasons, the collector shall be encased in a transparent box to protect personnel in the event of explosive failure during this test
			Connect the collector to a oil circuit / heat the collector using a solar simulator	Take safety measures to protect personnel from hot oil in the event of explosive failure during test
			Connect the collector to a oil circuit / heat the collector using natural solar irradiance	
	Pneumatic	air	Heat the collector using a solar simulator	For safety reasons, the collector shall be encased in a transparent box to protect personnel in the event of explosive failure during this test
			Heat the collector using natural solar irradiance	

Evaluation of test results shall take into account the identification of major failures as explained in section 5.1.

New proposal for revision of the standard does not introduce major changes in this test for collector using liquid as heat transfer fluid. However, the introduction of a new normative Annex on tracking collectors opens up for the concept of active or passive overheat protection. As this concept can also be used to protect organic materials from high temperatures it will most probably be introduced in a future version of the standard, see reference [18]. In practice active or passive protection means that such measures are allowed to keep the absorber temperature down, below the actual stagnation temperature, during high temperature resistance and exposure tests. Note that a new test is now proposed for air collectors, allowing the identification of leakage problems.

5.3 High-temperature resistance test

The objective of the high-temperature resistance test is to determine *if the collector can withstand high irradiance levels without failures*; Examples of failures are glass breakage, collapse of plastic cover, melting of plastic absorber or seals, degradation of insulation materials and wooden parts or significant deposits on the collector cover from outgassing or fogging.

The test is also very useful for determination of the collector stagnation temperature by measuring the absorber temperature. The stagnation temperature is needed for the internal pressure test of collectors with organic absorber. Another main objective of the stagnation temperature measurement is to provide information for the installer which will be further clarified in the next version of the standard. The standard clearly defines a way to measure the absorber temperature in a flat plate collector but it is not very clear on how to do it in other collector types. Table 7 lists different collector types and different forms for measurement of the stagnation temperature.

Table 7 Measurement procedure for stagnation temperature

Collector type	Procedure	Precautions
Flat plate collector	Drill of small hole in the back of the collector at two-thirds of height and half of the absorber width.	It is necessary that the temperature sensor is in contact with the absorber fin and that the area of contact is not shield in the front of the collector by another absorber fin or any structural element used in the front part of the collector.
Evacuated tubular collector /double glazed	Take out one tube and insert the temperature sensor between the inner glass and the fins thermally connected to the tubes where water circulates or to the heat pipe. The standard also describes an option where the absorber is partially filled with a liquid and sealed. Thereafter the temperature or the pressure of the fluid is measured.	It is necessary that the temperature sensor is in contact with the absorber tube.
Evacuated tubular collector /single glazed (not possible to put the temperature sensor in contact with absorber)	Select a place in the collector grid where the temperature is close to the absorber temperature and place the temperature sensor in good thermal contact in that place. Again, the alternative method mentioned above is an option.	

Evaluation of test results should take into account the identification of major failures as explained in section 5.1.

For concentrating and tracking collectors, special recommendations are included in a normative annex of the standard under revision [18].

5.4 Exposure test

The test was conceived [1] as a short term ageing test with the objective to give an indication of the ageing effects which are likely to occur during a longer period of natural ageing. Especially adverse situations including cycles of high and low temperature, high and low irradiance (between solar noon and night) and humidity variation are taken into account. Table 8 shows the conditions for testing according to the present version of the standard. These conditions will probably be aligned with those of ISO 9806 in the next edition.

Table 8 Summary of test conditions for Exposure Test

	Test completely performed outdoors	**Test performed outdoors and indoors**
Number of outdoor exposure days	30 valid days	30 valid days
Outdoor valid day	H>14 MJ m^{-2}	H>14 MJ m^{-2}
Number of hour with irradiance above 850Wm^{-2} and an ambient air temperature of above 10°C	30 hours (outdoors) , only sequences of 0,5h or more are counted	30 hours (indoors) , only sequences of 0,5h or more are counted (between 11th and 15th valid day)
Ambient temperature	>10ºC (Only required for the 30 h with more than 850 W/m²)	

The exposure test as defined in EN 12975-2:2006 can have different impact on the collector, considering different test locations and different periods of the year.

In the best case in summer, only 30 consecutive days will be needed to perform the test but the total dose of radiation incident on the collector will be different when tested in a northern or southern climate.

In the same test location, the 30 valid days will be obtained with much higher number of total test days in winter than in summer but probably with a higher dose of radiation in summer than in winter.

It is important that the test Laboratory registers climatic data during the test, i.e., irradiance on collector plane, ambient temperature and rain. A register of daily observations of the collector is also recommended.

The evaluation of the exposure test and classifying of potential problem as minor or severe problem shall be done based on visual observation of the collector at the end of the test (see section 5.11, Table 17 or Annex B 5.5. of EN 12975-2:2006). The classification as “severe problem” can be defined as a problem that may have a strong impact either on the thermal performance of the collector or on the durability of the collector. This classification is dependent on the judgment of the test laboratory. Table 9 gives guidance on the criterion for classification of “severe problem” after exposure test.

The classification of a problem as severe has consequences for the certification of the collector (see 5.3.4 of EN 12975-1:2006).

Table 9 Recommendations for classification of a potential problem as severe after exposure test.

Collector component	Potential problem	Evaluation Consider severe if:
Collector box/fasteners	Cracking	Large areas are affected resulting in future rain penetration problem
	Warping	
	Corrosion	
	Rain penetration	If exceeding the limits of rain penetration test.
Seals/gaskets	Cracking	Large areas are (potentially) affected resulting in future rain penetration problem i.e. also smaller failures that can be expected to progress during longer exposure
	Adhesion	
	Elasticity	
Cover/Reflector	Cracking	Areas affected will result in decrease of thermal performance. Fast increase of the problem during the test period. (*)
	Crazing	
	Buckling	
	Delamination	
Absorber coating	Cracking	Areas affected will result in decrease of thermal performance. More than 10%. Fast increase of the problem during the test period. (*)
	Crazing	
	Blistering	
Insulation	Outgassing	Will result in decrease of thermal performance

(*) This criterion will only be possible to evaluate if the Laboratory makes a daily register of observations of the collector.

Evaluation of test results should also take into account the identification of major failures as explained in section 5.1.

In order to have a more uniform treatment of collectors for different periods of the year and different test locations, the proposal for the future version of the standard uses the concept of irradiation dose to define the conditions of the Exposure test. This proposal also includes the definition of conditions for the pre-conditioning of other tests such as Mechanical Load Test and Rain Penetration Test, see reference [19]. For concentrating and tracking collectors, special recommendations are included in a normative annex.

5.5 External thermal shock test

The objective of the test is to provide a test procedure *to assess the capability of a collector to withstand a severe thermal shock that can result from a sudden rainstorm on a hot sunny day*.

The test can be associated with exposure test. The test has to be performed twice, the first time during the first 10 hours of irradiance higher than 850 Wm^{-2} and the second during the last 10h of the 30 hours with irradiance higher than 850 Wm^{-2}.

Table 10 Summary of test conditions for External thermal shock

Parameter	Requirement
Collector fittings	Collector empty; all openings of the fluid pipes sealed except one.
Pre-conditioning	1h
Irradiance level during pre-conditioning	G > 850Wm^{-2}
Ambient temperature	> 10ºC
Water temperature (spray)	< 25ºC
Spray flow rate	0,03 to 0,05 kg/s per square meter of collector aperture area
Duration of spaying	15 min

Evaluation of test results should take into account the identification of major failures as explained in section 0.

New proposal for revision of the standard does not introduce major changes in this test, however it is suggested that the two shocks can be done anywhere in the 30 h cycle. See reference [19].

5.6 Internal thermal shock test

The objective of the test is to provide a test procedure *to assess the capability of a collector to withstand a severe thermal shock that can result from an intake of cold heat transfer fluid a hot sunny day*. This is likely to occur during system installation when the collector loop is filled or after a period of shutdown, when the installation is brought back into operation.

The test can be associated with exposure test. The test is performed twice, the first time during the first 10 hours of irradiance higher than 850 Wm^{-2} and the second during the last 10h of the 30 hours with irradiance higher than 850 Wm^{-2}.

Table 11 Summary of test conditions for internal thermal shock.

	Test performed outdoors	Test performed indoors
Collector tilt	Adapted to time of year to guaranty that the irradiance values required for the test are achievable in a sunny day	According to the solar simulator
Collector fittings	Collector empty; all openings of the fluid pipes sealed except one inlet and one outlet.	
Pre-conditioning	1h	
Irradiance level during pre-conditioning	G > 850 W m^{-2}	
Ambient temperature	> 10ºC	
Water temperature	<25ºC	
Flow rate	0,02 kg/s per square meter of collector aperture area (unless otherwise specified by the manufacturer.	
Duration of flow	5 min or until the absorber temperature drops below 50ºC (*)	

(*) see Table 7 for suggestions on how to measure absorber temperature in different collectors.

Evaluation of test results should take into account the identification of major failures as explained in section 0.

New proposal for revision of the standard does not introduce major changes in this test, however it is suggested that the two shocks can be done anywhere in the 30 h cycle. For concentrating and tracking collectors, special recommendations are included in an informative annex. See reference [19].

5.7 Rain penetration test

The objective of the test is to provide a test procedure *to assess if glazed collectors are substantially resistant to rain penetration*.

Examples of problems that are likely to occur if water penetrates and stays in the collector are e.g. corrosion of the collector casing and absorber surface, reduced thermal performance due to persistent condensation on the inner side of the glass or reduced insulation properties when the insulation is wet.

Problems are more likely to occur if the collector is mounted with a low tilt angle.

The manufacturer can recommend the shallowest angle at which the collector can be used in order to avoid rain penetration problems. If this angle is not indicated the test is performed with a 30º tilt. Table 12 presents a summary of test conditions.

Table 12 Summary of test conditions for rain penetration test.

Parameter	Nominal value	Remark
Collector tilt	Shallowest angle to the horizontal recommended by the manufacturer.	30º if no angle is recommended
Collector mounting	Open frame or simulated roof	Or simulated roof and protected underside, if the collector is to be integrated into a roof structure.
Method to keep the absorber warm	Exposure of collector to solar radiation; Collector empty; all openings of the fluid pipes sealed except one. Alternatively, hot water circulation at a minimum temperature of 50ºC.	---
Duration of test	> 4 hours	---
Water temperature	< 30ºC	---
Flow rate	0,05 kg/s per square meter of collector aperture area	---

Three different methods for evaluation of test results are applicable. Table 13 summarizes these methods.

Table 13 Methods for evaluation of rain penetration test.

Method	Pass/Fail criterion	Advantages	Disadvantages
Weighing: Before and after the test	Difference in weights < 30 g/m^2	Easy and fast. Applicable to FP and ET collectors.	Scale must have uncertainty better than 5 g/m^2. Not applicable to large collectors. Remains of water on outside of collector affect result
Humidity measurement	Absolute humidity < 20g/kg or double of the humidity value before spraying	Application to FP collectors is clear.	Pre-conditioning period of 5 hours necessary Installation of an absolute humidity sensor in the air gap of the collector between glass and absorber needs a bore hole. application only to FP collectors
Condensation level + measurement of water leaking from collector when tilted	Condensation on Max. 10% of aperture are AND leakage of max. 30g/m² (Only leakage from ETC should be sufficient)	Easy and fast.	Requires drilling of hole or opening of collector → can only be done at end of test sequence. Some water remains in collector / insulation → imprecise.

Evaluation of test results should take into account the identification of major failures as explained in section 5.1.

New proposal for revision of the standard contains several changes of the rain penetration test. It excludes the humidity measurement and condensation methods and gives a more detailed indication on the spaying areas in the collector taking into consideration critical points for rain penetration. Furthermore rain penetration test is to be carried out just before the final inspection so that it is actually evaluated by examining the dismounted collector. See reference [19]].

5.8 Freeze resistance test (only collectors which are claimed to be freeze resistant)

The objective of the test, according to the standard, is to provide a test procedure *to assess if a collector which is claimed to be freeze resistant can withstand freezing and freeze/thaw cycling.*

If in the installation manual is clearly stated that the collector may only be used with antifreeze fluid the test is not applicable.

A climatic chamber big enough to accommodate the collector and to simulate temperatures between 10ºC and -20ºC is necessary.

Table 14 Summary of conditions for freeze resistance test.

	Collectors claimed to be freeze-resistant when filled with water	**Collectors claimed to resist freezing after being drained**
Collector tilt – Glazed collectors	Shallowest angle to the horizontal recommended by the manufacturer or 30º if no such recommendation exists.	
Collector tilt – Uncovered collectors	Shallowest angle to the horizontal recommended by the manufacturer or **0º** if no such recommendation exists.	
Beginning of freeze/thaw cycle	Filled collector at operating pressure	Fill collector at operating pressure and keep at this pressure during 10 minutes
During freezing	---	Drain collector using the drain-down device; Evaluate if after 5 min of initiating the process, 95% of the water was drained , if yes, no freeze test has to be performed
End of freeze/thaw cycle	Drain the collector	**In the last cycle** fill collector at operating pressure and keep at this pressure during 10 minutes
Number of Freeze/Thaw cycles	3	
Point for measurement of temperature of water	Inside the absorber	Inside the absorber close to inlet
Temperature of water in the collector / time during which temperature is maintained	Freezing: -20ºC/30 min	
Temperature of water / Time for thawing	10ºC/30 min	

Evaluation of test results should take into account the identification of major failures as explained in section 5.1.

New proposal for revision of the standard does not introduce major changes in this test. See reference [19]. A closely related test is however being developed in which the freeze resistance of heat pipes for ETCs is being tested. In this test heat pipes are temperature cycled when placed inside the vacuum tubes as cycling only the heat pipes is assumed to give an unrealistically high stress. The test has been developed as a response to frequent reports about frozen heat pipes from European installations in recent years and is expected to be part of an international (ISO) standard within 2-3 years.

5.9 Mechanical load test

The objective of the test, according to the standard, is to provide a test procedure *to assess:*

The extent to which the transparent cover and the collector box are able to resist the positive pressure load due to the effect of wind and snow;

The extent to which the fixings between the collector cover and collector box are able to resist uplift forces caused by wind.

Test conditions are summarized in Table 15.

Table 15 Summary of test conditions for mechanical load test.

	Positive pressure load	**Negative pressure load**
Methods	Use of gravel; Use of water; Suction cups Positive air pressure with test bench according EN12211	Suction cups; Negative air pressure with test bench according EN12211
Mounting	Collector placed horizontally <u>using the manufacturers' original equipment for mounting</u>	
Maximum test pressure ($F_{max+/-}$)	Until failure occurs or up to the value specified by the manufacturer.	
Minimum test pressure	1000 Pa	
Steps for pressure application	250 Pa	
Permissible Pressure (to be reported)	$F_{perm+} = F_{max+}/1,5$	$F_{perm-} = F_{max-}/2$

Evaluation of test results should take into account the identification of major failures as explained in section 0.

New proposal for revision of the standard does not introduce any major changes in the method of this test. However the minimum load is suggested to be increased to 2400 Pa. For concentrating and tracking collectors, special recommendations are included in a normative annex of the new proposal of revision of the standard. See reference [19].

Figure 4. Positive mechanical load on collector cover. Beware that un-even distribution of load, as in this example, *may* cause unrealistically high stress

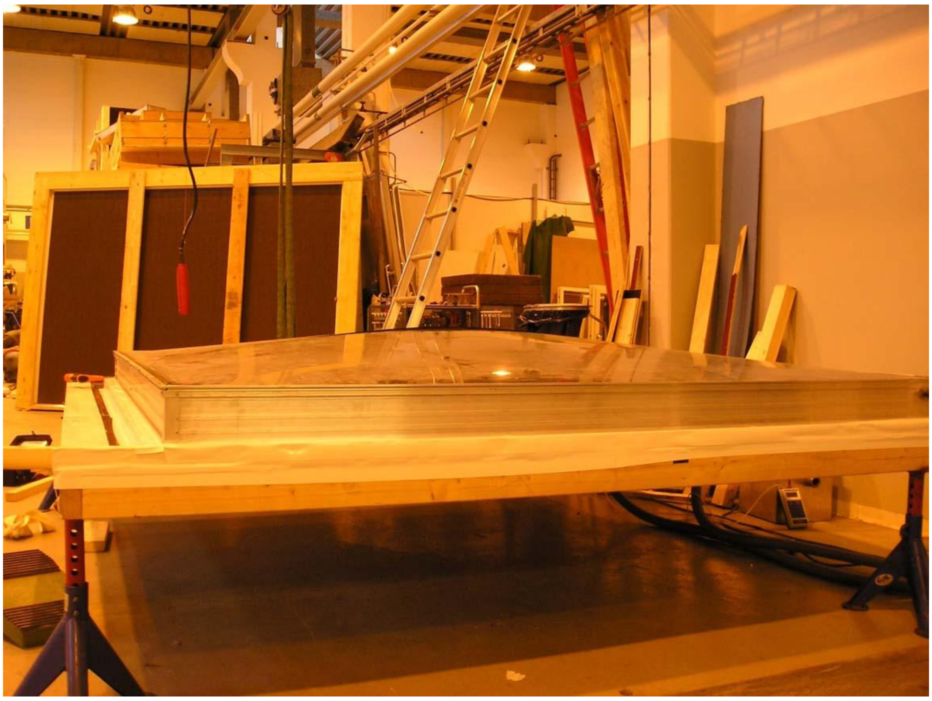


Figure 5. Negative mechanical load test (700 Pa) on collector cover by applying internal air pressure to the collector box

Figure 6. Simple setup for positive load test on evacuated tube collectors (using an adjustable wooden frame, a tarpaulin and water)

Figure 7. Mechanical load test at TUV using the manufacturers' original mounting equipment

5.10 Impact resistance test (optional)

The objective of the test is to provide a test procedure *to assess the extent to which a collector can withstand the effects of heavy impacts caused by hailstones*.

In the present version of the standard EN 12975-1:2006+A1:2010 the test is considered optional.

Two methods are considered in the standard to perform the test: Using a steel ball or using ice balls. Figure 8 shows an ice ball launcher for vertical shots on collectors using a loading device for single ice balls, adjustable pressured air and photo sensors. **Table 16** gives a summary of test conditions for both methods.

Table 16 Summary of test conditions for impact resistance test.

	Steel ball	**Ice ball**
Mounting	Vertical or horizontal on stiff support	Collector impact surface normal to the path of projected ice ball; Collector on stiff support
Ball	Steel – Mass of 150g±10g	Diameter: 25mm±5% Mass: 7,53g±5% Velocity: 23 m/s±5%
Drop height	0,4m; 0,6m; 0,8m; 1,0m; 1,2m; 1,4m; 1,6m; 1,8m; 2,0m	----
Maximum test height	2,0m or value specified by the manufacturer	----
Number of	Drops; 10 times for each height (down-up) until collector sustains some damage or maximum test height is reached.	Launches: 10 times
Point of impact	Within 5 cm from edge of the collector cover and 10 cm from the corner of the collector cover.	
	---	See section 5.10.2.3 for characteristic of apparatus to be used

Evaluation of test results should take into account the identification of major failures as explained in section 5.1.

New proposal for revision of the standard suggests impact resistance to become normative and better aligned with the IEC test procedures for PV modules, however the steel ball test is suggested to remain. See reference [19].

Figure 8. Ice ball launcher for vertical shots on collectors (using a loading device for single ice balls, adjustable pressured air and photo sensors

5.11 Final inspections

The final inspection corresponds to the dismantling of the collector. Most of the results of reliability testing are found at the final inspection. The results are reported according to Annex B5.5 of EN 12975-2:2006, which is reproduced in Table 17.

Table 17 Annex B5.5 of EN 12975-2:2006

Collector component	Potential problem	Evaluation
Collector box /fastener	Cracking / warping / corrosion / rain penetration	0/1/2
Mountings / structure	Strength / Safety	0/1/2
Seals / gaskets	Cracking / adhesion / elasticity	0/1/2
Cover / reflector	Cracking / crazing / buckling / delaminating / warping / outgassing	0/1/2
Absorber coating	Cracking / crazing / blistering	0/1/2
Absorber tubes and manifold boxes	Deformation / corrosion / leakage / loss of bonding	0/1/2
Absorber mountings	Deformation / corrosion	0/1/2
Insulation	Water retention / outgassing / degradation	0/1/2

0: No problem, 1: Minor problem, 2: Severe problem, x: Inspection to establish the condition was not possible

The classification of Severe Problem was already discussed in section 5.4. See Table 9. Table 18 to

Table 25 presents recommendations for classification of a potential problem as severe. In this table reference to example figures is given.

Table 18 Collector box/fasteners: Recommendations for classification of a potential problem as severe after exposure test

Potential problem	Evaluation. Consider severe if:
Cracking	Large areas are affected resulting in future rain penetration problem.
Warping	
Corrosion	
Rain penetration	If exceeding the limits of rain penetration test.

Figure 9 Corroded collector box. Manifold casing after exposure test

Figure 10 Cracked collector box

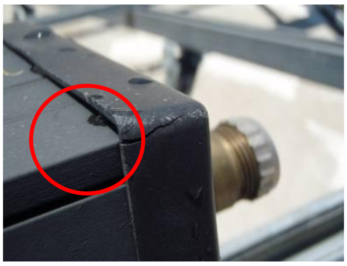


Figure 11 Cracking of polymeric parts of manifold

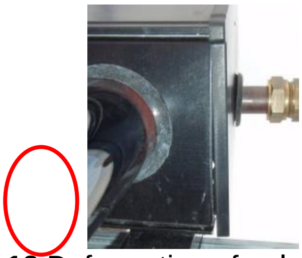


Figure 12 Deformation of polymeric parts of manifold

Table 19 Mountings/ structure: Recommendations for classification of a potential problem as severe after exposure test

Potential problem	Evaluation. Consider severe if:
Strength Safety	Risk of collector damaging the roof or falling from the roof. Warped fasteners after mechanical load tests, see below.

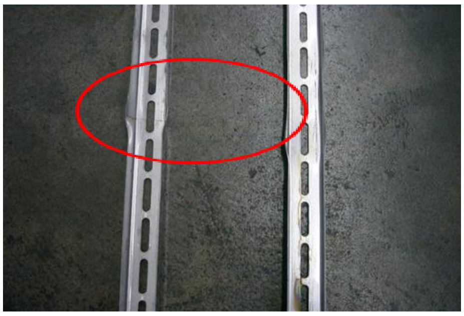


Figure 13 Warped fasteners after mechanical load tests.

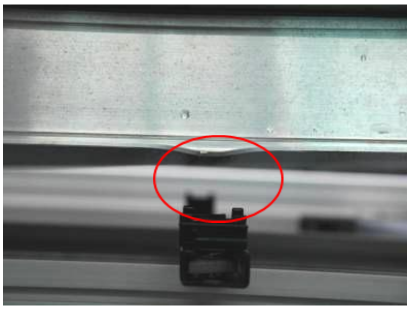


Figure 14 Warped fasteners after mechanical load tests.

Table 20 Seals/gaskets: Recommendations for classification of a potential problem as severe after exposure test

Potential problem	Evaluation. Consider severe if:
Cracking	Large areas are affected resulting in future rain penetration problem.
Adhesion	
Elasticity	

Table 21 Cover/Reflector: Recommendations for classification of a potential problem as severe after exposure test

Potential problem	Evaluation. Consider severe if:
Cracking, crazing	Areas affected will result in decrease of thermal performance.
Buckling, delamination	

Figure 15 Cracked glass after external thermal shock test

Table 22 Absorber coating: Recommendations for classification of a potential problem as severe after exposure test

Potential problem	Evaluation. Consider severe if:
Cracking	Areas affected will result in decrease of thermal performance. More than 10%.
Crazing	
Blistering	

Figure 16 Cracking on absorber coating

Figure 17 Cracking on absorber coating

Table 23 Absorber tubes and headers: Recommendations for classification of a potential problem as severe after exposure test

Potential problem	Evaluation. Consider severe if:
Deformation	Deformation imposes limitation on fluid circulation.
Corrosion	Areas affected will result in future leakage.
Leakage	Always severe
Loss of Bonding	Will result in decrease of thermal performance.

Figure 18 Deformation of absorbers tubes and headers

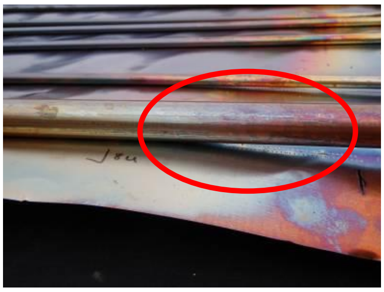


Figure 19 Loss of bonding absorber tubes

Table 24 Absorber mounts: Recommendations for classification of a potential problem as severe after exposure test

Potential problem	Evaluation. Consider severe if:
Deformation	Strong risk of contact between absorber and cover
Corrosion	

Table 25 Insulation: Recommendations for classification of a potential problem as severe after exposure test

Potential problem	Evaluation. Consider severe if:
Water retention	If exceeding the limits of the rain penetration test.
Outgassing	Material has optically or tangibly changed its structure in a way that is deemed to result in decrease of thermal performance.
Degradation	
 **Figure 20** Outgassing	 **Figure 21** Outgassing
 **Figure 22** Degradation of PU foam insulation in manifold casing after exposure test	 **Figure 23** Degradation of PU foam insulation in manifold casing after exposure test
 **Figure 24** Outgassing within Vacuum Tubes	 **Figure 25** Degradation of insulation

THERMAL PERFORMANCE

Two generically different methods/ approaches are available in the standard to determine the thermal performance of solar collectors: The Steady state method and the Quasi dynamic method, hereafter generally abbreviated SS and QDT. Both methods are accepted when testing for Solar Keymark certification whereas the SRCC certification of non-concentrating collectors only relies on the Steady state method. Steady state testing has been used since decades whereas the QDT was introduced in the mid-1990s and was included in the first edition of EN 12975 which was published in 2001. Both methods have their advantages and drawbacks, which are further explained in the following. However in terms of results, the two methods are considered to give reliable results for most collectors available in the market.

There is no software package generally available for measurement and evaluation of test data for either of the two methods but each laboratory has developed its own tools.

In order to give accurate results on the collector performance (actually on the heat loss coefficients), the collector should, if possible be tested at its "highest normal operating temperatures". For standard applications this is normally not a problem and 80-90°C inlet temperature can easily be handled. For medium to high temperature applications however, this may be a problem. If the collector is dedicated mainly to such applications, it should be tested at a laboratory with relevant resources i.e. a high temperature test rig.

Every collector submitted to a performance test shall be exposed for 5 hours at minimum 700 W/m^2 before the performance test.

6.1 Glazed solar collectors under steady state conditions

The steady state method is well defined and there is significant experience gained from the long time this method has been used. It is thus more known by the users, namely the manufacturers and the consumers, compared to the QDT method. In sunny climates, the steady state method is also easier to apply.

On the other hand, the steady state method does not account for influence of air speed and diffuse irradiance, while the test conditions can be considered as restrictive, referring to the requirements for clear sky, limitations in diffuse radiation, normal incidence of solar radiation and the stability of test conditions.

6.1.1 Collectors mounting and location

Dependency of tilt angle

6.1.1.3. *Tilt angle*

- For “unusual” types of collector, the IAM could be determined first in order to ensure the “2%” requirement.
- During testing, the tilt angle cannot be fixed due to the requirement for the value of the IAM. The tilt angle range during measurements provides useful and practical information and can be reported in the test report.
- Collectors based on heat pipes can have a strong tilt dependency and this must be considered when testing such collectors. Normally slopes below 20-

30 degrees should be avoided but this cannot be taken as a general rule. Complimentary measurements can quite easily give an indication of the tilt dependency.

- The heat loss coefficient of flat plate collectors also has a dependency on tilt. For this reason measurements at high temperatures (for determining the heat losses) should only be performed at the nominal tilt (2% IAM requirement) unless of course the purpose of the measurement is to determine the tilt dependency.

6.1.1.6 Diffuse and reflected solar irradiance

- According to the standard, “The reflectance of most rough surfaces such as grass, weathered concrete or chippings is usually low enough so no problem is caused during collector testing”. Thus, in the case these materials are used, the requirements of 5% regarding the unobstructed field of view and the avoidance of obstructions subtending an angle greater than 15° to the horizontal in front of the collector can be flexibly interpreted.
- The requirements of “5%” and “15°” do not have the same importance for low or high tilt angles of the collector.
- With regard to the above mentioned points, the best solution would be to validate that there is no noticeable influence (e.g. through the use of a pyranometer and the implementation of measurements in various positions in the field of view of the collector).

6.1.2 Instrumentation

Zero settings (short circuit the fluid, both sensors in counter flow and well insulated, to test $t_{in} – t_e$. Shall not exceed 0,05 K)

6.1.2.1.1.4. *Precautions for infrared radiation effects on pyranometer accuracy*

In the case of simulated light source, the testing Laboratories have to provide evidence for the prevention of infrared radiation effect on the pyranometer indication.

6.1.2.1.1.5 *Mounting of pyranometers outdoors*

The pyranometer for global irradiance shall not differ more the 1% from the irradiance measured by the pyranometer for diffuse irradiance (without shadowing the beam irradiance).

6.1.2.1.1.6 *Use of pyranometers in solar irradiance simulators*

The satisfaction of requirements regarding the spatial / temporal variation of simulated solar irradiance has to be clearly documented and available to the accreditation body.

6.1.2.2.2 *Determination of thermal irradiance indoors and in solar simulators*

The satisfaction of requirements regarding the determination of thermal irradiance indoors has to be clearly documented and available to the accreditation body.

6.1.2.3.2.2 *Mounting of sensors (Measurement of heat transfer fluid inlet temperature)*

As depicted in fig. 1 of the standard, it is not clear that the distance of 200 mm between the temperature sensors and the collector should be measured from the collector edge (and not the piping edge).

6.1.2.3.3 *Determination of heat transfer fluid temperature difference (ΔT)*

- An alternative solution to the use of ΔT sensor is the use of two independent sensors, t_{in} and t_{out} respectively. In this case the uncertainty on the ΔT values should be estimated on the basis of the individual sensors uncertainty.
- In the case of a ΔT sensor, an appropriate calibration of this sensor should be implemented over the complete range of t_{in}, as well as over the temperature difference range.
- The zero value of ΔT sensor should be checked using a short-circuit of the fluid. An easy method would anticipate the use of a short insulated tube in the place of the collector. The measured temperature difference shall not exceed 0.05 K

6.1.2.3.4.2 *Mounting of sensors (Measurement of surrounding air temperature t_a)*

The shielding surface used for the shading of the sensor could be of a reflective material (e.g. polished aluminum) and not necessarily white painted. Ventilation of the shield will further increase the accuracy of the measurement.

6.1.2.4 *Measurement of collector fluid flow rate*

The requirement for calibration of the flow meter all over the temperature range can be neglected if the thermal drift of the sensor, as resulting from the specification of the measuring instrument, is less than half of the standard uncertainty at the desired flow rate.

6.1.2.5.2, 6.1.2.5.3 *Measurement of air speed*

For outdoor testing, the requirements of these paragraphs are not quite clear.

Since it is difficult to perform continuous measurement near the collector surface (without influencing the performance measurement), an alternative solution would be the adjustment of the wind generator in order to ensure that the air-speed over the collector surface lies within the required range. The checking of this condition can be preliminarily performed through a series of air-speed measurements at a distance of 10 to 50 mm in front of the collector aperture at equally spaced positions over the collector area (as in the case of the indoor measurements).

For the case of windy locations, collector performance measurements should not be considered valid if the surrounding air velocity measurements, provided by an anemometer placed on a board next to the collector, indicate values beyond the maximum limit imposed by the standard.

6.1.2.6 *Elapsed time*

In the case of computerized data logging system, the satisfaction of the required uncertainty can be performed through the checking of the computer clock.

6.1.2.7 *Instrumentation / data recorders*

For modern acquisition devices, the requirement for the signal indication lying between 50 and 100% of full scale is not applicable in the case of computerized data logging devices.

6.1.2.8 *Collector area*

Definitions of collector area are given in section 0.

6.1.3 Test installation

6.1.3.5 *Temperature regulation of the heat transfer fluid*

The notes of this paragraph should be interpreted taking into account the technological evolution of the respective devices.

6.1.4 Outdoor steady-state performance test

6.1.4.2 *Preconditioning of the collector*

By the beginning of the test sequence, it is recommended to raise the collector inlet temperature to a level of 80°C approximately, in order to avoid the presence of dilute air in the water circuit.

6.1.5 Steady-state efficiency test using a solar irradiance simulator

The thermal efficiency test at indoor steady state requires a solar simulator. The main technical characteristics to meet are:

- *The lamps shall be capable of producing a mean irradiance over the collector aperture of at least 700 Wm^{-2}. Values in the range 300 Wm^{-2} to 1000 Wm^{-2} may also be used for specialized tests, provided that the accuracy requirements given in Table 26 can be achieved and the irradiance values are noted in the test report.*

It is recommended to use lamps with levels of radiation that can reach up to 1100 Wm^{-2}, so that the simulator can also be used for other standard tests such as the high temperature test. It is important to take into consideration the distance between the collector and the solar simulator to assure the desired levels and distribution of radiation. It is also desirable that the lamps' intensity settings can be individually controlled from a computer. In this way it is continuously possible to see the radiation map on the collector and it is possible to adjust the uniformity of the lamps in a visual and easy way.

Figure 26. Performance testing in solar simulator

- *At any time the irradiance at a point on the collector aperture shall not differ from the mean irradiance over the aperture by more than ± 15 %.*

The uniformity of the solar simulator must be checked before each efficiency test. The irradiation map is usually measured with an automated X-Y system that moves the reference pyranometer every 150 mm in both directions. The pyranometer is maintained about 20-30 seconds in each position and gets the irradiation map of the area covered by the solar collector. The difference between the irradiance value of each position and the mean irradiation map shall be less than 15%.

It is important to age lamps at the beginning of their life to stabilize the different components of the lamp. It is also recommended to stabilize lamps of the simulator before any test, the period required being dependent on the type of lamps used.

- *The spectral distribution of the simulated solar radiation shall be approximately equivalent to that of the solar spectrum at optical air mass 1,5.*

The spectral distribution of the lamps must be measured by a spectroradiometer or outsourcing the characterization of the lamp to an accredited laboratory. It is difficult to find equipment or laboratories that can measure the spectrum from 0,3 μm to 3 μm, especially from 2,5 μm. It is recommended to do these measurements for each replacement of lamps. Although the standard does not indicate an acceptance criterion, it is possible to use Table 26 as reference:

Table 26. Guiding figures for the spectral distribution in a solar simulator

Wavelength range [nm]	Acceptance criteria [%]
0 – 400	0 - 8
400 – 700	30 - 60
700 – 1000	15 - 40
1000 - 2500	15 - 45

Where collectors contain spectrally selective absorbers or covers, a check shall be made to establish the effect of the difference in spectrum on the ($\tau\alpha$) product for the collector. If the effective values of ($\tau\alpha$) under the simulator and under the optical air mass 1,5 solar radiation spectrum differ by more than ± 1 %, then a correction shall be applied to the test results . Measurement of the solar simulator's spectral qualities shall be in the plane of the collector over the wavelength range of 0,3 µm to 3 µm and shall be determined in bandwidths of 0,1 µm or smaller.

$$\text{Effective}(\tau\alpha) = \frac{\int_{0,3\mu m}^{3\mu m} \tau(\lambda)\alpha(\lambda)G(\lambda)d\lambda}{\int_{0,3\mu m}^{3\mu m} G(\lambda)d\lambda} \qquad \text{Eq. 9}$$

In some cases when the collector is manufactured with selective absorbers or covers, the value of the optical performance measured in the solar simulator can differ from the optical performance value of the same collector measured in outdoor conditions. This difference depends on the type of lamps used by the simulator and selective materials used in the collector. It is recommended to check this difference to evaluate if it is necessary to apply a correction factor.

- *The amount of infrared thermal energy at the collector plane shall be suitably measured (measurements in the wavelength range above about 2,5 μm if possible, but starting not beyond 4 μm) and reported. The thermal irradiance at the collector shall not exceed that of a blackbody cavity at ambient air temperature by more than 5 % of global irradiance.*

To verify this requirement a pyrgeometer can be used to measure the thermal radiation. Several measurements are performed in the same plane of the collector and values have to fulfill the standard requirements by calculation. This measurement is enough to perform for each change of lamps or whenever changes are made in the simulator or its environment.

To minimize the effect of thermal radiation it is very common to have a cold sky with a double glass through which cold air is circulating to get the glass temperature near the room temperature.

Figure 27. IAM measurement in solar simulators requires more parallel light than the standard efficiency tests.

The collimation of the simulator shall be such that the angles of incidence of at least 80 % of the simulated solar irradiance lie in the range in which the incident angle modifier (the requirement of homogeneity as described in 6.1.5 need to be fulfilled for IAM measurements as well)of the collector varies by no more than ± 2 % from its value at normal incidence. For typical flat plate collectors, this condition usually will be satisfied if at least 80 % of the simulated solar radiation received at any point on the collector under test shall have emanated from a region of the solar irradiance simulator contained within a subtended angle of 60° or less when viewed from any point

One way to check this requirement is to use a cylinder that geometrically fulfills the requirements specified in the standard. This cylinder which must be painted black inside to minimize the reflectance is placed over the pyranometer and irradiance measurements are made at the same point of the collector plane with and without cylinder. The measurement obtained with the tube must be above 80% for efficiency tests and 90% for incidence angle modifier tests compared to the irradiance measured without tube in the same point.

If the collimation of the simulator does not meet the requirements of the standard, results of the determination of the optical performance value will be seriously influenced. Especially when measuring vacuum tubes collectors or other collectors with odd IAM behaviors or in incidence angle modifier measurements in general. Concentrating collectors should not be measured at all in solar simulators.

6.1.6 Determination of the thermal capacity and the time constant of a collector

It has been widely experienced that the thermal capacity of double glazed ETCs, in particular with heatpipes, is difficult to determine with high accuracy and the different methods described in the standard tends to give different results. Further work is required in order to improve this situation.

6.1.6.2 *Determination of effective thermal capacity*

It is practically impossible for the labs to know the required values of the specific collector elements (mass and thermal capacity). Thus, most often these values have to be provided by the manufacturers and this has to be mentioned in the test report.

This method has been reported to underestimate the thermal capacitance of double glazed ETCs.

Annex G (Measurement of effective thermal capacity)

Special caution should be paid by the laboratories for the accurate determination of the time point denoting the removal of the solar radiation shield from the collector (e.g. by recording the signal at the output of a photo-detector being placed next to the collector).

6.1.7 Collector incidence angle modifier (IAM)

6.1.7.1 *General*

See paragraph 4.3 for a detailed description on IAM:s.

It is assumed that the Eq. 6 describes the incidence angle modifier K_θ for the flat plate collector. It is not clear in the standard whether the same equation is valid for the longitudinal K_{θ_L} in the case of the ETC collectors, however this is generally accepted. Moreover, the standard does not propose any equation for the transversal K_{θ_T} in the case of ETC collectors. A general recommendation is to use a table of incidence angles and corresponding K_θ-values to report the IAMs of ETCs and other optically asymmetric collectors.

6.1.7.3 *Test procedures*

Thus, for the case of flat plate collectors, the IAM for an incidence angle of 50° should be measured. If it is required by the simulation (e.g. the software requests the specific values of incidence angle modifier in different angles), measurement in other angles can be performed. Normally equation 33 in the standard can however be used to calculate K_θ for any incidence angle once the value at 50° has been measured.

6.2 Unglazed solar collectors under steady state conditions

The most important dependencies that occur for an unglazed collector in addition to those of a glazed are the wind speed dependency of the zero loss coefficient (b_u), of the heat loss coefficient (b_2) and the dependency on long wave (IR) radiation exchange (taken care of by defining the net irradiance G´´). Thus:

- The efficiency of unglazed collectors is highly dependent on wind speed.
    - Performance tests need to be performed at different fluid temperatures and different wind speeds
    - Efficiency function is different to that for glazed collectors (factors for wind dependency)
- In addition to the dependency on hemispherical radiation there is a significant effect due to exchange in long wave radiation
    - Efficiency function is related to net irradiance, taking absorber emittance into account. (In glazed collectors the transparent cover is opaque to long wave radiation (if made of glass) and the exchange in long wave radiation only takes place between absorber and glazing)

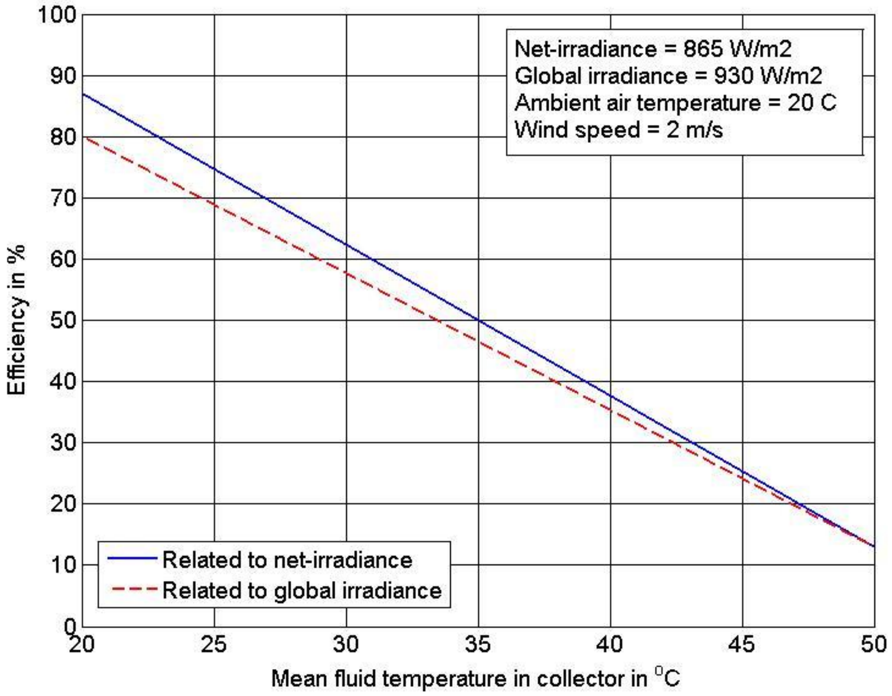


Figure 28. Efficiency of a typical unglazed collector related to net-irradiance in comparison to the relation to hemispherical irradiance

Due to the requirements on measurements to be carried out at three different wind speeds for each of three different operating temperatures, it may be very difficult to achieve the appropriate test conditions. In particular in locations where steady state conditions in general are difficult to achieve. A more time saving test can be achieved by applying the Quasi dynamic test method according to chapter 6.3 of the standard. On the other hand due to the correlation/interaction of coefficients in Quasi dynamic test method the physical meaning of single collector parameters and their plausibility get lost.

Recent research furthermore shows that using artificial wind in a way that resembles natural wind is very difficult and that results tend to over/under estimate the performance when artificial wind is used.

Please note!

- As unglazed collectors are usually combined to large areas (generally custom built) the requirements on test sample area differ from those for glazed collectors

Requirements on test flow rate are different from those for glazed collectors!

- The measured quantity E_L is the incoming long wave irradiance i.e. resulting from the sky temperature relative to 0 K
- Inlet temperatures must not be below the dew point temperature
- (Condensation effects are currently being investigated but are not yet implemented in the standard)

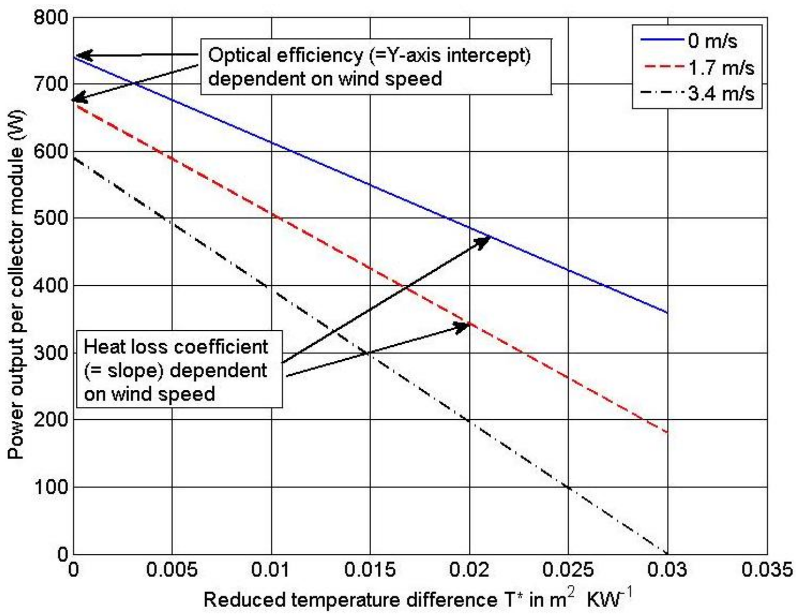


Figure 29. Power curves of an unglazed collector as function of wind speed and T^*

6.2.1 Collectors mounting and location

For performance test unglazed collectors have to be mounted on a matt white surface to minimize thermal yield from the test installation staying in contact with the collector.

Long wave radiation: Due to the specific characteristics of unglazed collectors it is particularly important that surfaces in the field of view of the collector (including back side) are kept at temperatures close to the ambient.

As the performance of unglazed collectors is sensitive to the wind conditions the use of artificial wind generators is problematic. Besides the wind speed there has to be an exact view on the turbulence level. The turbulence level of artificial generated wind is often higher compared to that of natural wind adjacent to the collector surface (esp. at the required collector area of at least 3 m²) that leads to an overestimation of heat loss and the wind depending coefficients.

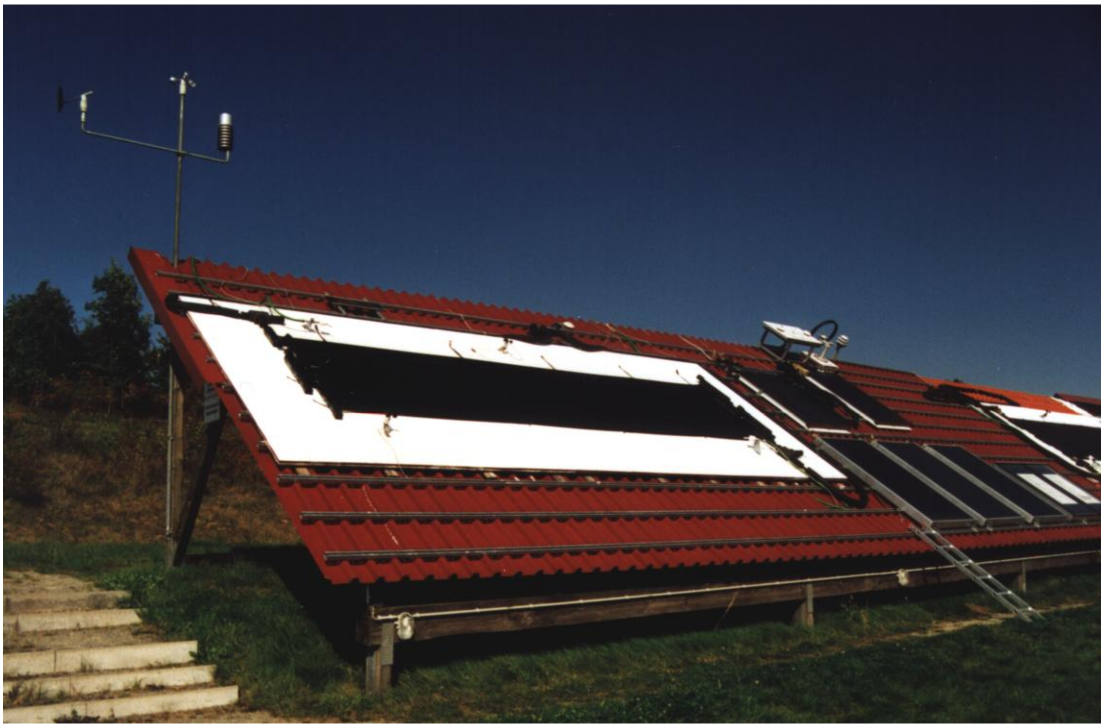


Figure 30. An unglazed collector with instrumentation mounted for performance test

6.2.2 Instrumentation

Long wave radiation: The preferred method is the use of a pyrgeometer. The output E_L from the pyrgeometer should be in the order of 300 W/m^2 in a dark room with surfaces at ambient temperature of 20 °C and between 300 and 400 W/m^2 during clear sky conditions

Zero settings (short circuit the fluid to test $t_{in} – t_e$. Shall not exceed 0,05 K)

Air speed: Use of ultrasonic anemometers is encouraged as they can normally detect lower wind speeds than e.g. vane/ three cup anemometers. This will result in more accurate determination of the wind speed dependencies. In the next revision of the standard the use of two wind speed sensors and two ambient temperature sensors will be prescribed, to be placed diagonal on opposite sides of the collector.

6.2.3 Test installation

The test installation is very similar to that of glazed collector but with the additional need of a device for determining the long wave radiation.

To get the right data for the exchange in long wave radiation the optical properties of the absorber (solar absorptance and hemispherical emittance) should be determined or given by the manufacturer. There is also an empirical value for the emittance/absorptance ration of the absorber of ε/α = 0,85 to be used for collectors with unknown optical properties.

6.2.4 Outdoor steady-state performance test

The temperature range for the performance test is dependent on the expected maximum temperature difference between ambient air and medium fluid temperature in real operation conditions. For swimming pool absorbers this is assumed to be about 10 K, so maximum temperature for testing is 10 K above ambient air. For collectors used for pre-heating this maximum operation temperature might be higher.

Please note:

- An extrapolation of efficiency data above the highest temperature difference (t_m-t_a) from the performance test leads to a rising inaccuracy and is not correct!

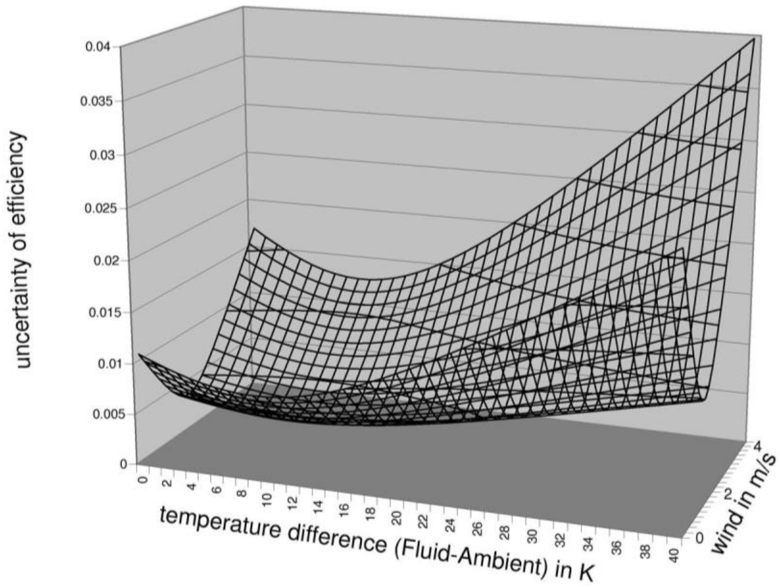


Figure 31. Typical uncertainties of efficiency data as function of wind speed and temperature difference (steady state, net irradiance 800 W/m²K, confidence level 68,3%)

6.2.5 Steady-state efficiency test using a solar irradiance simulator

There is just a cross references to the description for glazed collectors and the outdoor measurement for unglazed.

The required size of a collector and the requirement concerning wind speed conditions make it difficult to use a solar irradiance simulator for testing unglazed collectors norm-conform. For comparative tests (for instance prototype tests) indoor tests are an appropriate and quick way to get results.

6.2.6 Determination of the thermal capacity and the time constant of a collector

The procedure is similar to the one for glazed collectors, but especially the determination of thermal capacity using the calculation method is much easier as most unglazed collectors are made of one or a few simple materials with known thermal capacity so furthermore just the fluid contents has to be determined.

6.2.7 Collector incidence angle modifier (IAM)

This is an optional test for unglazed collectors, as the influence of incidence angle of most unglazed collectors is nearly negligible.

However, depending on optical and physical appearance of the absorber surface (typical swimming pool collector tubes or flat plates) the IAM may play a significant role for the energy performance.

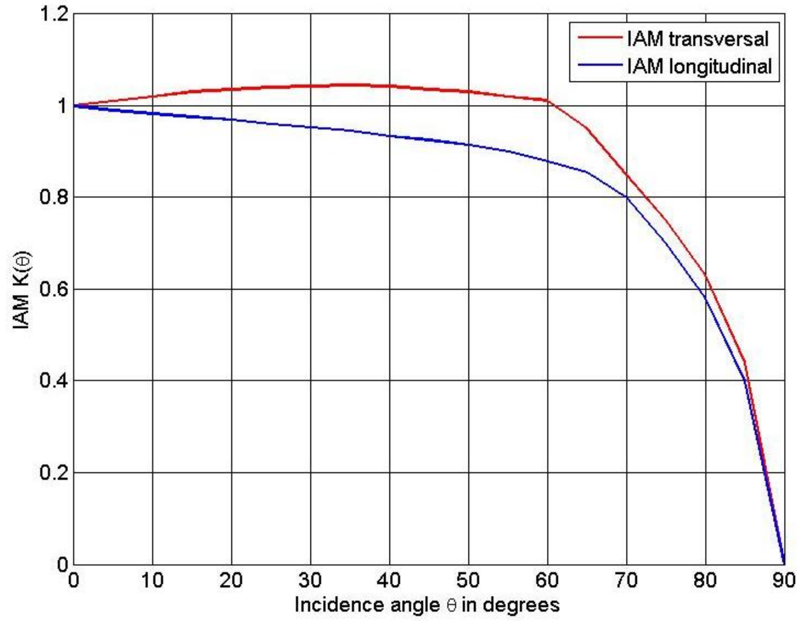


Figure 32. Typical incidence angle modifiers for an unglazed collector with tubular channel

6.2.8 Determination of the pressure drop across a collector

The determination of pressure drop is an optional test but the manufacturers documents have to show data for pressure drop across the collector.

Most unglazed collector types are custom built with a great variety in lengths of tubes and manifolds. So in EN 12975 for those collectors the testing of different configurations is described to get data related to manifold and related to tube. Modular types of unglazed collectors can be tested as glazed collectors with a set of pressure drop data related to the collector module.

6.3 Glazed and unglazed solar collectors under quasi-dynamic conditions

The Quasi dynamic test method (QDT) was first introduced in the original (2001) version of EN 12975 and is nowadays used by approximately one third of the laboratories in Europe. The method is based on a mathematical collector model where the original steady state equation has been modified and extended with some additional terms, see equation Eq. 10 below. The major improvement compared with the steady-state method is the distinction between direct and diffuse irradiation with an incidence angle modifier $K_{\theta b}(\theta)$ for direct and $K_{\theta d}(\theta)$ for diffuse irradiance. This distinction allows for testing of concentrating collectors with different degree of concentration using a wide range of irradiance conditions and diffuse fractions. In addition the thermal capacitance term (c_5) is integrated in the equation which describes the transient behavior of the collector. Furthermore, terms for the heat loss dependence on long wave irradiance (c_4) and wind speed (c_3) and wind speed dependence of the zero loss coefficients (c_6) have been added.

$$\dot{Q}/A = F'(\tau\alpha)_{en} K_{\theta b}(\theta) G_b + F'(\tau\alpha)_{en} K_{\theta d} G_d - c_6 u G^* - c_1 (t_m - t_a) - c_2 (t_m - t_a)^2 - c_3 u (t_m - t_a) + c_4 (E_L - \sigma T_a^4) - c_5 dt_m/dt \quad \text{Eq. 10}$$

These generalizations make it possible to test a wide range of collectors under the most varying weather conditions and in fact, a certain variation in the weather during testing is desirable in order to have all relevant parameters properly identified. This feature is a great advantage in some European locations where steady state testing can be very time consuming. In particular outdoor testing of unglazed collectors is greatly facilitated as the wind speed is allowed to vary over the whole range during testing. On the contrary, applying QDT can be difficult in other locations where the weather is very stable or where diffuse fractions are constantly very low. Main advantages and drawbacks of this method are given in Table 27.

The QDT and the Steady State test methods are considered to give comparable results for most collector designs but for collector types having large differences in efficiency with respect to direct and diffuse irradiance, the QDT method is considered to give more reliable results. However in some cases e.g. for vacuum tubes with cylindrical absorbers or semi concentrating collectors, in particular the separation between direct and diffuse efficiency provided by the former will give a more accurate characterization of the collector. Furthermore in order to reach a high accuracy in any performance prediction the same collector model should be used in the simulation as in the evaluation of test data.

Table 27 Advantages and drawbacks of the Quasi dynamic test method

Advantages	Drawbacks
Applicable under dynamic operating- and ambient conditions	A higher threshold to get started with the evaluation than in Steady state testing
Applicable to a wide range of collector designs that can be accurately modeled using the same base model	Can have limited applicability in locations with small variations in weather conditions
Gives a more complete characterization of the collector compared to Steady state testing as test conditions reflect normal operating conditions	Effort for measuring biaxial IAM is bigger
Potential for further reduction of test duration due to the dynamic features of the method	
The same complete collector model is available for parameter identification as well as for performance prediction i.e. in principal an extended test data set can be used for direct model validation	

NOTE: Definition of parameter c_4 is incorrectly described in the EN 12975-2:2006 nomenclature section. This parameter is dimensionless and reflects the long wave irradiance dependence of the collectors' heat loss coefficient.

6.3.1 Collector mounting and location

A big advantage of the QDT method is that the IAM is determined separately for beam and diffuse irradiance and that it is a built in feature of the method. Thus, whole day measurements are used with the collector oriented due south and there is no need for a tracking device. Still, for collectors having an asymmetric IAM a tracker is useful as it will facilitate changing the (fixed) slope of the collector. Apart from this the same requirements as for outdoor steady state measurements on glazed and unglazed collectors apply for mounting and location.

Collectors based on heat pipes can have a strong tilt dependency and this must be considered when testing such collectors. Normally slopes below 20-30 degrees should be avoided but this cannot be taken as a general rule. Complimentary measurements can quite easily give an indication of the tilt dependency.

The heat loss coefficient of flat plate collectors also has a dependency on tilt. For this reason measurements at high temperatures (for determining the heat losses) should only be performed at the nominal tilt (2% IAM requirement) unless of course the purpose of the measurement is to determine the tilt dependency.

6.3.2 Instrumentation

The same requirements as for outdoor steady state measurements on glazed and unglazed collectors apply for instrumentation. However, as QDT measurements comprise whole day measurements additional caution is needed with respect to:

- Shading of sensors and collector in early mornings and late evenings
- Condensation, moisture and frost on collectors and sensors, in particular in early mornings. Ventilation of the pyranometer domes can improve the accuracy
- Adjustment of shading ring. Please note that the whole dome shall be covered by the shadow band during the whole day
- Use of a pyrheliometer is recommended
- Alignment between collectors and irradiance sensors and accurate determination of tilt and azimuth

6.3.3 Test installation

The same requirements as for outdoor steady state measurements on glazed and unglazed collectors apply for the test installation, however requirements on wind speed are easier to fulfill without using artificial wind when applying QDT. This is particularly true for unglazed collectors where a general wind speed dependency is determined from the continuous whole day measurements, provided there is enough variation in the natural wind.

6.3.4 Outdoor efficiency test

The test procedure and the description of test sequences are well explained in the standard. In annex H the collector model is compared to the steady state model and further explained. The basic difference compared to steady state testing is that instead of managing steady state conditions, the challenge in QDT is to ensure enough variability in the test data. This is mainly achieved through the variations in irradiance where clear sky as well as partly cloudy conditions is needed for accurate determination of parameters. Furthermore there are no restrictions on the diffuse fraction of the irradiance during testing. A wide range in inlet temperatures is furthermore essential in order to decouple thermal and optical parameters.

The presently described test conditions are partly designed in order to achieve compatibility with the Steady state method. In order to further improve the efficiency of the QDT they will probably be further refined in the next version of the standard. E.g. Step changes in inlet temperature could be included in the data for parameter identification in order to determine the thermal capacitance.

The only variables additionally needed to calculate during tests when performing QDT compared to Steady state testing is the time derivative of the collector mean temperature and the power output of the collector. These must be calculated on line in real time for each sampled value and averaged as the other variables. They cannot be calculated afterwards from average values of the other variables. An accurate time stamp (preferably corresponding to the middle of the averaging interval) for each data record is also required for the subsequent calculation of incidence angles for direct irradiance. For this purpose the collector tilt and azimuth also have to be accurately determined.

Due to the dynamics of the irradiance during testing, the requirements on sampling interval are quite strict as compared to Steady state testing (1 to 6 seconds). On the other hand this enables relaxing the requirements on e.g. inlet temperature stability.

Determining which parameters to include in the identification is rather straight forward with the significance of a parameter determined by its T-ratio (parameter value / standard deviation of parameter value). The mandatory parameters are described in the standard. If e.g. the wind speed dependency parameter c_3 turns out to have a T-ratio smaller than 2 the variable u*(Tm-Ta) is simply omitted from the measured data. Parameters c_4 and c_6 are normally only used to model unglazed collectors

6.3.5 Determination of the effective thermal capacity

The thermal capacitance of the collector, parameter c_5, is determined together with the other parameters and from the same measured data i.e. no separate measurement is needed. The capacitance of some ETC collectors using Sydney tubes and heat pipes have turned out to be particularly difficult to model due to a complex coupling of two main capacities. The currently used model therefore tends to give quite different results for the capacitance of these collectors compared to values determined during steady state testing.

6.3.6 Collector incidence angle modifier

See section 4.3 for definitions on incidence angle modifiers (IAM). When using QDT to determine the IAM for direct irradiance a half day measurement from early morning until solar noon or from noon until late evening will provide enough information for flat plate collectors and collectors having a biaxial behavior regarding the IAM for direct irradiance (for east-west direction). Depending on the time of the year the (fixed) collector tilt may have to be adjusted in order to satisfy the requirement that the IAM in the north-south direction should not vary more than 2% from the value at normal incidence. During the month before and after summer solstice this requirement is difficult to satisfy with a fixed slope for incidence angles $\theta_{E\text{-}W}$>50. Some bias from the complimentary IAM must then be accepted unless a tracker is used. Optimum conditions for this measurement at fixed tilt are achieved around the equinoxes.

When determining the IAM for direct irradiance in the north-south direction the fixed tilt of the collector must be changed in order to achieve high enough incidence angles. For a regular symmetric geometry, e.g. an ETC with the optical axis in the north-south direction, one measurement at $\theta_{N\text{-}S}$=50 degrees incidence angle is enough. For more complex geometries the whole range of angles from 0 to at least 70 degrees or to the end of the acceptance range must be covered. Three alternative procedures can be used for this measurement:

- The collector can be rotated 90 degrees and the measurement can then proceed as when determining the $K_{\Theta E\text{-}W}$
- A tracker can be used to track the sun using different collector tilts during the day
- The collector can be mounted in a fixed position in such a way that an angle of incidence of $\theta_{N\text{-}S}$=50° is reached during the measurement.

The special capacitance of some ETCs mentioned in the previous paragraph should be taken into consideration when determining the IAM of these collectors. This is best done by using symmetric data before and after solar noon as recommended for Steady state testing. Furthermore the tilt dependency of collectors using heat pipes must be considered when determining the IAM.

UNDERSTANDING THE TEST RESULTS

7.1 Comparison between parameters from steady-state and quasi-dynamic testing

When testing a solar collector according to the Steady State (SS) method (EN 12975:2006-2, 6.1 or 6.2) there are a couple of parameters that are not determined if you compare to the Quasi Dynamic Testing (QDT) (EN 12975:2006-2, 6.3). This is a short description of how to convert these parameters from QDT to SS and vice versa. Using these conversions should give a higher accuracy in the end results when the parameters are used in different simulation models.

In the SS collector model for near normal incidence, see equation below, only a few parameters are used to describe the power output from a collector.

$$Q/A = G^* *(\eta_0 - a_1 *(t_m - t_a)/G^* - a_2 *(t_m - t_a)^2/G^*) \qquad \text{Eq. 11}$$

The incidence angle modifier for the global hemispherical irradiance K_θ (diffuse fraction <30%) and the thermal capacitance C are determined from separate measurements. When added to the equation the model can be used to predict the collector performance in all day operation.

In the QDT collector model (Perers 1993, Perers 1995, Perers 1997, Fischer 2004), see equation below, the original steady state equation has been modified and extended with some correction terms. A single incidence angle modifier for hemispherical irradiance has thereby been divided into incidence angle modifiers for direct $K_{\theta b}(\theta)$ and diffuse $K_{\theta d}(\theta)$ irradiance and the thermal capacitance term (c_5) is integrated in the equation. Furthermore, terms for the heat loss dependence on long wave irradiance (c_4) and wind speed (c_3) and wind speed dependence of the zero loss coefficients (c_6) have been added. All parameters are determined together based on whole day measurements.

$$\dot{Q}/A = F'(\tau\alpha)_{en} K_{\theta b}(\theta) Gb + F'(\tau\alpha)_{en} K_{\theta d} Gd - c_6 u G^* - c_1 (t_m - t_a) - c_2 (t_m - t_a)^2$$
$$- c_3 u (t_m - t_a) + c_4 (E_L - \sigma T_a^{\ 4}) - c_5 dt_m/dt \qquad \textit{Eq. 12}$$

7.1.1 Zero-loss efficiency (SS) and collector efficiency factor times effective transmittance-absorptance product (QDT)

The SS parameter for zero-loss efficiency, η_0, is a grouping of the collector efficiency for both direct and diffuse irradiance (with the restriction that the diffuse fraction during testing is <30%). The corresponding parameter in QDT is the collector efficiency factor times effective transmittance-absorptance product, $F'(\tau\alpha)_{en}$. It can also be seen as the zero loss efficiency for direct irradiance. The standard equation for conversion of QDT parameters into an equivalent SS zero-loss efficiency was developed in order to be able to present a comparable efficiency- or power curve irrespectively of the test method used.

$\eta_0 = 0{,}85 * F'(\tau\alpha)_{en} * K_{\theta b}(\theta=15°) + 0{,}15 * F'(\tau\alpha)_{en} * K_{\theta d}$ Eq. 13

It is assumed that the direct irradiance is 85 % and the diffuse irradiance is 15 % of the global irradiance. This distribution is equivalent to quite a clear sky on a summer day used in SS testing. To be able to convert η_0 into an $F'(\tau\alpha)_{en}$, the parameters for direct and diffuse incidence angle modifier are needed, see 7.1.3. In the other way:

$F'(\tau\alpha)_{en} = \eta_0 / [K_{\theta b}(\theta=15°) * 0{,}85 + K_{\theta d} * 0{,}15]$ Eq. 14

7.1.2 Incidence angle modifier (IAM) for direct irradiation

The IAM at SS testing and the corresponding $K_{\theta b}$ from QDT testing are practically equivalent as long as the SS testing has been performed at a low diffuse irradiation (less than 15 % of global). See also section 7.3.

7.1.3 Incidence angle modifier for diffuse irradiation

The incidence angle modifier for diffuse irradiation, $K_{\theta d}$, cannot be determined directly from an SS test but it can be calculated as in (Perers 1995). The $K_{\theta d}$ is determined from the measured values of $K_{\theta bL}$* $K_{\theta bT}$, by integrating them over a hemisphere, assuming isotropic sky conditions. Thereafter, $F'(\tau\alpha)_{en}$ can be calculated according to Eq. 14. The calculation is available in the calculation tool for annual energy gain used within the Solar Keymark certification for solar collectors.

7.1.4 The heat loss coefficients

The heat loss coefficients determined with the steady state method, a_1 and a_2 are relatively directly translatable to the dynamic coefficients c_1 and c_2. The only major difference is that c_1 in general does not include wind. The conversion therefore becomes:

$a_1 = c_1 + u * c_3$ Eq. 15

In the Steady State measurements the wind (u) shall be between 2 and 4 m/s and therefore 3 m/s is normally used for the conversion. Please note that parameter c1 from QDT testing *may* include wind, if parameter c3 for some reason was not identified. In that case a1=c1.

7.1.5 Wind dependencies

In the dynamic testing there are two coefficients for wind dependence of the heat losses, c_3 and c_6. The c_3 term can be used together with the heat losses above (provided it can be significantly identified in the regression). Parameter c_6 is the wind dependency in the zero loss efficiency for direct irradiance and in practice only significant when measuring unglazed collectors.

7.1.6 Effective thermal capacity

The thermal capacity for SS testing is C [JK^{-1}] and for QDT c_5 [$J\ m^{-2}K^{-1}$]. Note the differences in units. In the SS test the thermal capacity can be either calculated or measured and these two methods can end up in different result, especially for evacuated tubular collectors. The c_5 in QDT testing is measured but not really reliable when it comes to ETC. Some researchers [Fisher, Perers] have proposed other terms for the equation to have a better agreement in the model.

7.1.7 Sky temperature dependency

There is no parameter to account for sky temperature dependency in the Steady State measurements. Instead an equivalent net irradiance G'' is calculated. The parameter is only significant for unglazed collectors in QDT.

7.2 The power curve

The power curve shows the power of a solar collector in dependence of the temperature difference. The temperature difference between the mean temperature of heat transfer fluid t_m and the ambient temperature is plotted on the abscissa (x-axis) and the power of the collector on the ordinate (y-axis) of the graph.

The power curve is calculated out of the efficiency parameters at normal incidence and based on the collector module and not on a certain area. The power values are normalized to an irradiation of 1000W/m².

Equation for calculating the power per collector unit:

$$\dot{Q} = AG^*(\eta_0 - \frac{a_1(t_m - t_a)}{G^*} - \frac{a_2(t_m - t_a)^2}{G^*}) \qquad \text{Eq. 16}$$

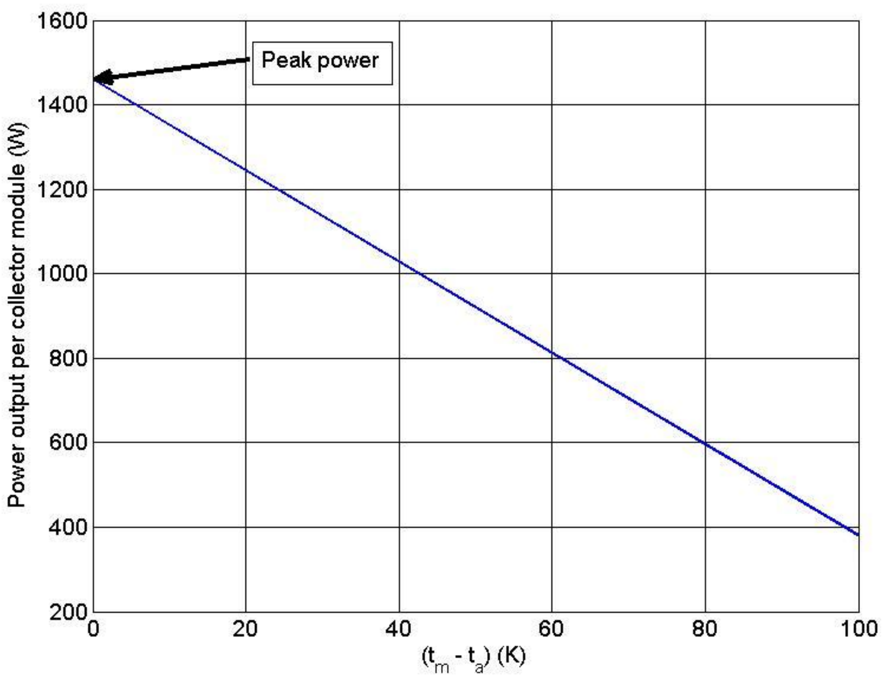


Figure 33 The power curve

The highest power is delivered to the point where no temperature difference between the mean temperature of the heat transfer fluid and the ambient temperature exist (t_m-t_a=0).

The EN 12975 also requires a table showing the performance of a solar collector with different irradiation mapped for different temperature difference, see **Table 28**. *The reported values are for normal incidence!*

performance of collector (W)		irradiance (W/m²)		
		400	700	1000
T_m-T_a (K)	10	509	953	1397
	30	331	769	1213
	50	117	561	1005
Peak performance (G=1000 W/m²) per collector module (Wpeak)			**1480**	

Table 28 Power output per collector unit

7.3 Annual energy output

Another way of illustrating the collector performance is by calculating the annual energy output from the collector using collector model parameters derived from performance tests together with well-defined climate data and operating conditions. From 2012, all new Solar Keymark collector datasheets include annual energy output figures for four locations and three operating temperatures.

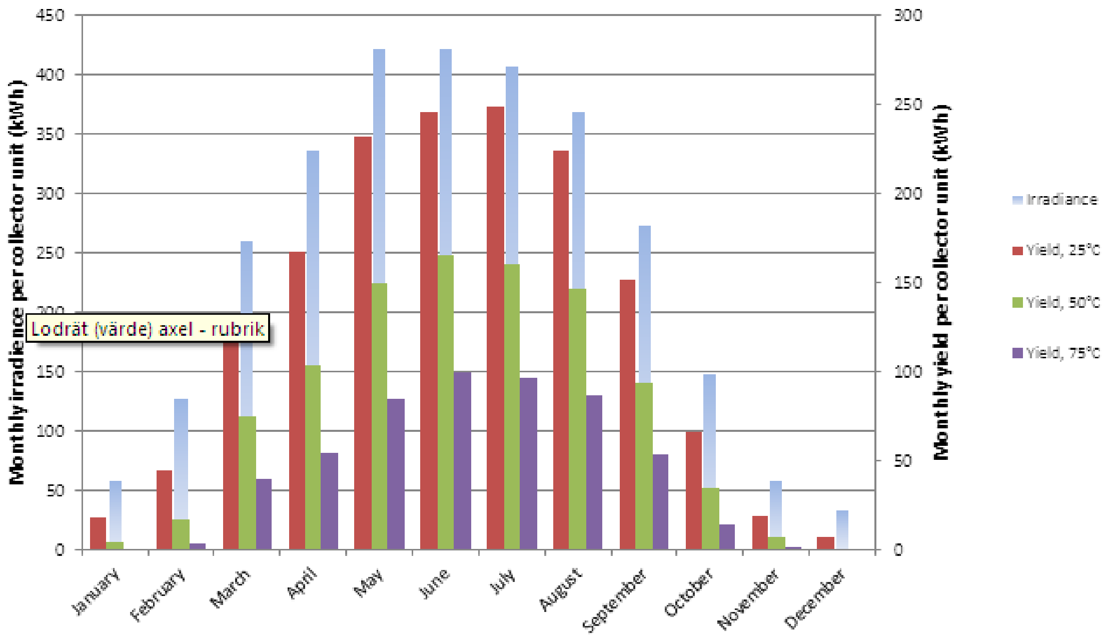


Figure 34. The annual energy yield per collector module is presented for four locations and three mean temperatures in the Solar Keymark collector data sheet.

7.4 IAM

The incident angle modifier for the tested collector is shown in the test report.

For conventional flat plate collectors the IAM can be given either as a constant value for 50° or as a b_0-value according to Eq. 6. It can also be given as constant values at e.g. 10°, 20°, 30°, 40°, 50°, 60°, 70°, 80° without distinguishing between longitudinal and transversal, see Table 29. For collectors with non-symmetric optical characteristics it is necessary to distinguish between longitudinal and transversal for these angles (i.e. bi-axial IAM) and it can also be necessary to determine individual IAMs for each of the four quarter spheres (i.e. multi axial IAM) .

IAMs at high incidence angles have a higher uncertainty but on the other hand they normally have a low influence on the annual energy output.

Table 29 IAMS for a set of incidence angles, not taking transverse or longitudinal into account

θ	10	20	30	40	50	60	70	80
$K_{\theta b}(\theta)$								

7.5 Thermal capacity

The effective thermal capacity describes the amount of heat to put into a solar thermal collector to raise the fluid temperature by 1 K. Since only the fluid temperature can be easily measured, a simplified 1-node model is used to characterize the thermal performance of the solar thermal collector, assuming that all main parts of the collector have the same temperature as the fluid. The standard gives in principle two methods to determine the effective thermal capacity:

1. The calculation method according to 6.1.6.2, taking into accounts the thermal masses and specific heat of the single components of the collector. Factors in the range of 0 to 1 are used to weight the heat transfer mechanisms between the collector components.
2. The determination by measurement according to 6.3 or Annex G. Here the effective thermal capacity is calculated out of measured data. This method directly takes into account the heat transfer between the different collector components.

For collectors having a high temperature difference between absorber and fluid (e.g. Sydney tubes with heat pipes) the two different methods often give different results, the experimental method showing up to 5 times higher effective thermal capacities.

As shown above the effective thermal capacity is not taken into account when the power curve is presented. Nevertheless it is an important parameter when it comes to dynamic system simulation. Assuming an effective thermal capacity of 10 kJ/(m²K) the yearly energy gain of a solar thermal collector decreases by approximately 1 % per 10 kJ/(m²K) added to the initial effective solar capacity.

7.6 Optional pressure drop

For designers of solar collector systems, the pressure drop across a collector may be of importance (e.g. for sizing of pumps).

The pressure drop between the collector-inlet and the collector-outlet is shown in the pressure drop curve at different flow rates. The pressure drop curve is normally a quadratic function of the fluid flow rate, which means, that the pressure drop increases with the square of the flow rate. I the collector also operate at low flow rates, when the flow is laminar, another relation must be used.

Pressure drop curve

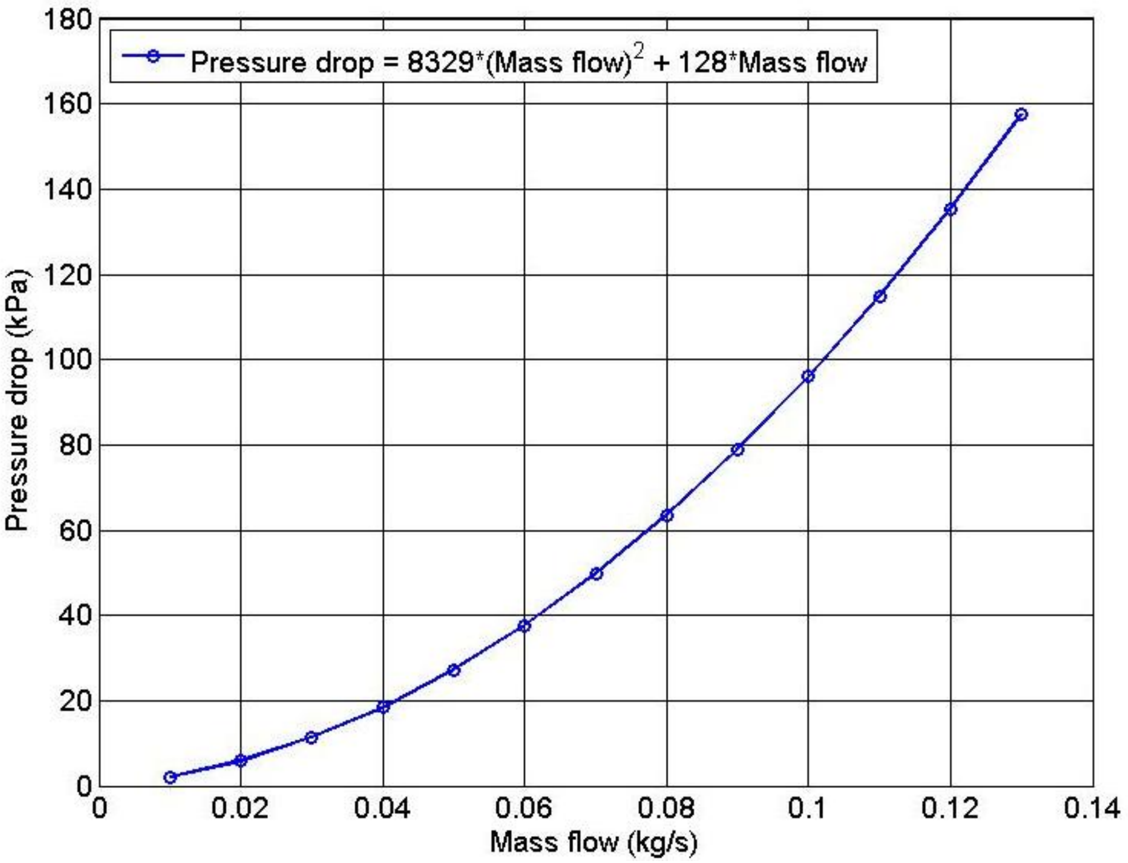


Figure 35**.** Pressure drop is an optional test in the standard. Different heat transfer fluids give different curves.

As different heat transfer fluids result in different pressure drop characteristics and thus give different curves the pressure drop should preferably be measured using a fluid with similar properties as the one to be used in practical applications. In particular if the results are to be used by system designers and not only for relative comparisons.

7.7 Durability and reliability test results

According to the EN 12975_2:2006 standard, the test reports will include a Table similar to Table 30.

Table 30 Record of test sequence and summary of main results.

Test		Date		Summary of main test results
		Start	End	
Internal pressure				
High-temperature resistance				
Exposure				
External thermal shock	First			
	Second			
Internal thermal shock	First			
	Second			
Rain penetration				
Freeze resistance				
Mechanical load				
Thermal performance				
Impact resistance (optional)				
Final inspection				

In the column ”Summary of main test results”, the test laboratory will indicate one of the following options:

- No failure or pass
- No major failure or pass
- Major failure or fail

In the case of no major failure or major failure reference to the section of the test report related to that test will be given. In this section description of the occurrence during the test is given. In case of major failure the manufacturer will determine what corrections are needed in the product or in the manufacturing process and new tests will be necessary for final certification of the product (if this was the aim of the tests).

In the case of no major failure, a minor problem has occurred (see sections 0 to 5.10). The manufacturer should analyze carefully the description of the problem given by the laboratory and see if he should introduce corrections in the product or in the manufacturing process. If this is done, the certification body has to be informed in order to evaluate with the laboratory the need to repeat tests (provided that the purpose of the test was to get a certificate).

7.8 Estimation of uncertainty

The overall standard uncertainty in solar collector efficiency values determined by an accredited test laboratory is about 3 %. The uncertainty in calculated energy gain can be even higher and could exceed 10 % depending on the operating temperature and test method applied. The higher uncertainty in calculated energy gain is due to the climatic data used for this calculation and interannual climate variability. One should also keep in mind that the uncertainty of final results contains many components: Measurement uncertainty during testing, model uncertainties, manufacturing/ material property uncertainties, etc.

In an inter-laboratory comparison on uncertainty calculations carried out in the Solar Keymark II project [13] uncertainty was thoroughly discussed and a common understanding on achievable measurand uncertainties was reached, see Table 31. Based on these a common procedure for calculating the uncertainty in collector model parameters was developed according to the procedure described in Annex K of the standard.

Table 31 Measurand uncertainties in collector testing achievable at a professional test lab.

Measurand	Standard uncertainty
A_a [m²]	0,1%
G [W/m²]	2%
$\dot{m}$ [kg/s]	0,4%
t_{in} [°C]	0,04
t_e [°C]	0,04
(t_e-t_{in}) [K]	0,02
t_a [°C]	0,2

There are many publications dealing with the complicated topic of uncertainty assessment and calculation. Most commonly referenced are the GUM [11] EA 4/02 [12] and the ENV 13005 [10].

REPORTING RESULTS

Some pitfalls to be avoided in order to get comparable parameters from testing and harmonized test reports.

8.1 Comparison between different types of collectors

It is not appropriate to compare different collectors by comparing single parameters from testing. The parameters are first of all useful in a complete collector model for calculation of energy gained and for power output from the collector in different kinds of installations. The best way to compare collectors to each other is therefore to calculate the useful energy from a square meter of collector or a whole module under equivalent circumstances. The Solar Keymark data sheet is now including the calculated energy for certified collectors using four different standardized climates and three different operating temperatures.

8.2 Comparison of parameters from QDT and SS testing

In chapter 7, Understanding the test results, there is explanations of how to compare the different parameters from QDT and SS testing to each other. The awareness of the differences of the parameters is crucial when using them as input to different kind of simulation programs and calculation tools. Again it should be stressed that parameter c1 (QDT) is directly comparable to parameter a1 (SS) only if c1 was determined without c3 being determined simultaneously. In this case the wind dependency is included in the c1 parameter. If c3 was determined simultaneously then a1=c1+c3*v, where v should be set to an appropriate wind speed, normally 3 m/s.

8.3 Measuring uncertainty and significant figures

A laboratory accredited to EN ISO/IEC 17025 shall always present an uncertainty estimate in their test reports. The lab can choose to present measurement uncertainty as a figure related to each of the measurands or it can calculate an aggregated uncertainty for the final result. For further information on calculation of uncertainties, see section 7.8.

When reporting parameters and other figures such as energy or power output the test lab should not use more figures then the significant ones. Table 32 gives guidance to this issue.

Table 32. Recommended number of significant figures in the main performance parameters and key numbers

Parameter	η_0	$K_{\theta b}$	$K_{\theta d}$	a_1/c_1	a_2/c_2	c_3	C/c_5	*Power output*	*Annual energy yield*
No. of significant figures	0,xxx	0,xx	0,xx	x.xx	0,xxx	0,xxx	xxx0	xxx0	xxx0

MANUFACTURERS' INTRODUCTION TO EN 12975 AND TO IN-HOUSE TESTING

This chapter gives a brief introduction to the European test standard for solar thermal collectors EN 12975, hereafter referred to as "the standard". The purpose is to explain how it is used for type testing as well as for innovation and development support. Tests that can easily be carried out by e.g. manufacturers themselves (in house testing) are briefly explained. When it comes to collector performance testing, experienced laboratory staff and first class measuring equipment with traceable calibration for irradiance, fluid flow rate and temperature difference across the collector is required in order to achieve accurate, high quality results. Development testing can be carried out with lower requirements on staff and less advanced equipment compared to what is required by the standard but then of course instrument accuracy as well as accuracy in final results will be much lower.

Please note that the only official document in this context is the standard itself. For up to date detailed information always refer to the latest version of the full standard. A revised version of the standard is expected during 2012/13.

Table 33 Summary of test and in house testing possibilities

Test	Purpose	In house testing recommended?
Internal pressure	Can the absorber withstand the pressures which it might meet in service?	**Yes**, see section 0 and 9.2.1
High-temperature resistance	Can the collector withstand high irradiance levels without failures?	**Yes**, see section 5.3 and 9.2.2
Exposure	A short term ageing test	**Yes**, see section 5.4 and 0
External thermal shock	To assess the capability of a collector to withstand a severe thermal shock that can result from a sudden rainstorm on a hot sunny day.	**Yes**, see section 5.5 and 9.2.4
Internal thermal shock	To assess the capability of a collector to withstand a severe thermal shock that can result from an intake of cold heat transfer fluid a hot sunny day	**Yes**, see section 5.6 and 9.2.5
Rain penetration	To assess if glazed collectors are substantially resistant to rain penetration.	**Yes**, see section 5.7 and 9.2.6
Freeze resistance	To assess if a collector which is claimed to be freeze resistant can withstand freezing and freeze/thaw cycling.	**No**, see section 5.8 and 9.2.7
Mechanical load	To assess the extent to which the transparent cover and the collector box are able to resist the positive and negative pressure load due to the effect of wind and snow	**Yes**, see section 5.9 and 9.2.8

Test	Purpose	In house testing recommended?
Impact resistance (optional)	To assess the extent to which a collector can withstand the effects of heavy impacts caused by hailstones	**Yes**, see section 5.10 and 9.2.9
Final inspection	Is there any permanent deformation from the tests above?	**Yes**, see section, 5.11and 9.2.10
Thermal performance	How much energy can be gained from the collector at different temperatures, irradiances and more	**No**, not recommended, see section 0 and 9.3

Note! Several safety precautions should be considered when testing solar collectors, se guide section 4.5.

9.1 Referenced standards and scientific background

A set of standards are directly connected to the EN 12975. It is referred in the EN 12976 dealing with factory made “compact” systems as well as in the EN 12977 series dealing with custom built “site assembled” systems. Furthermore the EN ISO 9488 defines the solar thermal technical vocabulary and the ISO 9060 defines criteria for radiation measurement equipment. For further information on the scientific background to the EN 12975 standard, see the bibliography section in the standard. *To learn about principles of radiation measurement, refer to instrument manufacturers' websites.*

9.2 Reliability tests

9.2.1 Internal pressure

The objective of the test, according to EN 12975, is to determine if *the absorber can withstand the pressures which it might meet in service.*

Collectors can have inorganic or organic (plastic or elastomeric) absorbers. Resistance to pressure is different since in the latter case it may be dependent on the temperature of the absorber. For inorganic absorbers the internal pressure test is a most valuable tool for quality control on the production line when the collector grid is assembled and depending on soldering processes.

It is recommended that the test is performed to a pressure of 1,5 times the maximum working pressure of the collector.

In the case of organic absorbers the test should be considered, especially in the phase of prototype development. Means for heating the fluid to the stagnation temperature of the collector are necessary and the time to perform it is longer than for inorganic absorbers. For further information see section 0.

9.2.2 High-temperature resistance

The objective of the test, according to the standard, is to determine if *the collector can withstand high irradiance levels without failures*. Examples of failures are glass breakage, collapse of plastic cover, melting of plastic absorber or significant deposits on the collector cover from outgassing or fogging.

The test can be performed in a simple way just by exposing the collector to natural irradiance during a day with clear sky and ambient temperature above 20ºC. No additional equipment will be necessary. A summary of simplified test conditions is shown in Table 34.

This test is highly recommended when changes of insulation material are considered.

Table 34 Test conditions in simplified high temperature resistance test

Variable	Recommended test condition
Collector tilt	Summer: latitude – 15º Autumn/spring: latitude
Solar irradiance	Clear sky conditions
Ambient Temperature	>20ºC "the higher the better/ tougher"

For further info on high temperature resistance test, see section 5.3.

9.2.3 Exposure

The test was conceived [1] as a short term ageing test with the objective to give an indication of the ageing effects which are likely to occur during a longer period of natural ageing, especially in adverse situations of strong cycles of high and low temperature, high and low irradiance (between solar noon and night) and humidity variation.

Degradation of collector cover, especially when organic materials are used and degradation of the absorber material can be observed with this test. Change in color either on the cover or on the absorber will have impact on the properties relevant to the collector thermal performance – transmission of cover and absorption of the absorber.

Possible occurrence of outgassing/ fogging is possible to detect after a few days of exposure in high irradiance.

The test can be performed just by exposing the collector to natural radiation without any fluid circulating through the collector. The test should be at least 30 sunny days (not necessarily all clear sky days). It is advisable to put any new product on a continuous outdoor exposure for one or two years as failures can occur even if the standards' 30 day exposure were managed without any problems. For details on the exposure test, see section 5.4.

9.2.4 External thermal shock

The objective of the test, according to the standard, is to provide a test procedure *to assess the capability of a collector to withstand a severe thermal shock that can result from a sudden rainstorm on a hot sunny day*.

The test is usually performed in association with the exposure test. To perform the test, keep the collector in dry stagnation during a sunny day and after solar noon spray the collector with cold water (mains water). Make sure that the spray covers the whole collector front or if it's a very large collector, at least two complete glass panes.

Cracking or breakage of collector cover and rain penetration can be problems detected with this test but they rarely occur on tempered glass. Fogging i.e. condensation of gases on the inside of the cover often occur when it is cooled by water. However this often looks much worse directly after the shock than after some time and the result therefore may need to be reevaluated after the collector cover temperature is back a close to ambient temperature. For details on the external thermal shock test, see section 5.5.

9.2.5 Internal thermal shock

The objective of the test, according to the standard, is to provide a test procedure *to assess the capability of a collector to withstand a severe thermal shock that can result from an intake of cold heat transfer fluid a hot sunny day*. This is likely to occur during system installation when the collector loop is filled or after a period of shutdown, when the installation is brought back into operation.

The test is usually performed in association with the exposure test. To perform the test, keep the collector in dry stagnation on a sunny day and, after solar noon, flush cold water (mains water) in the collector during 5 min. The flow of water should be similar to the flow recommended for the collector in normal operation.

Loss of vacuum or breakage of the tubes in evacuated tubular collectors, loss of bonding between tubes and absorber plate or permanent deformation of the absorber plate in flat plate collectors are the most common problems that can be detected with this test. For details on the internal thermal shock test, see section 5.6.

9.2.6 Rain penetration

The objective of the test, according to the standard, is to provide a test procedure *to assess if glazed collectors are substantially resistant to rain penetration*.

Examples of problems that are likely to occur if water penetrates and stays in the collector are e.g. corrosion of the collector casing and absorber surface, reduced thermal performance due to persistent condensation on the inner side of the glass or reduced insulation properties when the insulation is wet.

Problems are more likely to occur if the collector is mounted with a low tilt angle.

To perform the test, the collector can be installed outdoors and sprayed with cold water during at least four hours, on all exposed sides. The collector will be heated by the sun and water penetration can be visualized by the level of condensation on the inner glass.

If tested indoors the collector can be heated by circulation of hot water inside (a minimum temperature of 50º is necessary).

It is recommended that the collector is opened (dismantled) to evaluate if there was penetration of water resulting in a wet insulation but no condensation on the collector glass. For more info on the rain penetration test, see section 5.7.

9.2.7 Freeze resistance (only collectors which are claimed to be freeze resistant)

The objective of the test, according to the standard, is to provide a test procedure *to assess if a collector which is claimed to be freeze resistant can withstand freezing and freeze/thaw cycling*.

If in the installation manual it is clearly stated that the collector may only be used with antifreeze fluid the test is not applicable. For further information on this test, see section 5.8.

9.2.8 Mechanical load

The objective of the test, according to the standard, is to provide a test procedure *to assess:*

the extent to which the transparent cover and the collector box are able to resist the positive pressure load due to the effect of wind and snow and the extent to which the fixings between the collector cover and collector box are able to resist uplift forces caused by wind.

The nominal test pressure F_{max} is the pressure at which a failure occurs but a lower pressure can be given by the manufacturer. The minimum test pressure is 1000 Pa. No major failure shall occur to the collector when tested with this pressure.

The permissible pressure for use of the collector is:

for positive pressure test: $F_{perm+} = F_{max+}/1.5$

for negative pressure test: $F_{perm-} = F_{max-}/2$

The manufacturer should take this into account since the collector should not be used in locations where values higher then F_{perm} are expected to occur.

These values can be related to Snow and Wind load. In each country there is specific legislation on these loads since building envelopes have to withstand these loads. Simple methods for these calculations can also be seen in reference [1].

Remember that the mounting structure is also part of the complete structure! Maximum loads given in the installer documentation should also be valid for the mounting structure but the latter is NOT taken care of in the current tests.

See also EN 1991-1-3:2003 and EN 1991-1-4:2005.

This information should be considered already in collector design phase for selection of components e.g. collector cover, it's sealing's, type of frame etc. New proposal for revision of the standard does not introduce any major changes in the method of this test. However the minimum load is suggested to be increased to 2400 Pa. See also section 5.9.

9.2.9 Impact resistance (optional test)

The objective of the test, according to EN 12975, is to provide a test procedure *to assess the extent to which a collector can withstand the effects of heavy impacts caused by hailstones*.

In the present version of the standard the test is considered optional.

Two methods are considered in the standard to perform the test: Using a steel ball or using ice balls. The first method, see 5.10, is not considered to correspond to the physical effect of hailstones as the deformation energy absorbed by the ice particles is not being considered, but it is a method easy to apply and therefore preferred by industry. New proposal for revision of the standard suggests impact resistance to become normative.

9.2.10 Final inspection

The final inspection corresponds to the dismantling of the collector. The results are reported according to Annex B 5.5. of the standard. The classification of Severe Problem is discussed in section 5.4.

9.3 Thermal performance

Two generically different methods/ approaches are available in the standard to determine the thermal performance of solar collectors: The Steady state method and the Quasi dynamic method, hereafter generally abbreviated SS and QDT. Both methods are principally ok to use when testing for Solar Keymark certification whereas the SRCC certification of non-concentrating collectors only relies on the Steady state method. Steady state testing has been used since decades whereas the QDT was introduced when the first edition of EN 12975 was published in 2001. Both methods have their advantages and drawbacks. However in terms of results, the two methods are considered to give comparable results for most collectors available in the market. Please see the introduction to section 0 for a discussion about requirements and accuracies in performance testing. For further detailed information about performance testing, see section 6.

9.4 Understanding the test results

9.4.1 Comparing different collectors

It is not appropriate to compare different collectors by comparing single parameters from testing. The parameters are first of all useful in a complete collector model for calculation of energy gained and for power output from the collector in different kinds of installations. The best way to compare collectors to each other is therefore to calculate the useful energy output from the whole collector module under equivalent circumstances. The Solar Keymark collector data sheet shows the calculated energy yield for certified collectors using four different standardized climates and three different operating temperatures.

9.4.2 The power curve

The power curve is an alternative way of showing the collector efficiency and it shows how the power output of a solar collector varies with the temperature difference between the mean temperature of heat transfer fluid t_m and the ambient air temperature t_a. The power curve is calculated out of the efficiency parameters at normal incidence and based on the collector module and not on a certain area. The power values are normalized to an irradiation of 1000W/m². See also section 7.2.

9.4.3 Annual energy output

Another way of illustrating the collector performance is by calculating the annual energy output from the collector using collector model parameters derived from performance tests together with well-defined climate data and operating conditions. From 2012, all new Solar Keymark collector datasheets include annual energy output figures for four locations and three operating temperatures. See also section 7.3.

9.4.4 Optional pressure drop

For designers of solar collector systems, the pressure drop across a collector may be of importance (e.g. for sizing of pumps). As different heat transfer fluids result in different pressure drop characteristics and thus give different curves it’s essential that the pressure drop is measured using a fluid with similar properties as the one to be used in practical applications. Several practical issues must be considered when measuring pressure drop. These issues are thoroughly described in Annex L of the standard. See also 7.6.

9.4.5 Durability and reliability test results

According to the standard, the test reports will include a table containing the performed tests, date performed and a summary of the main results. In the ”Summary of main test results”, the test laboratory will indicate one of the following options:

- No failure or Pass
- No Major Failure or Pass
- Major Failure or Fail

For further information, see section 7.7.

9.4.6 Measurement and calculation uncertainties

The overall standard uncertainty in solar collector efficiency values determined by an accredited test laboratory is about 3 %. The uncertainty in calculated energy gain is even higher and could exceed 10 % depending on the operating temperature and test method applied. This must always be taken into consideration when reading test reports and designing solar thermal installations. One should also keep in mind that the uncertainty of final results contains many components: Measurement uncertainty during testing, model uncertainties, manufacturing/ material property uncertainties, etc. For further information, see section 7.8.

REFERENCES AND FURTHER READING

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[2] ISO 9806-1:1994. Test methods for solar collectors -- Part 1: Thermal performance of glazed liquid heating collectors including pressure drop

[3] CAN/CSA-F378-87 (R2004) Solar Collectors

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[18] Solar Keymark Network - Experience exchange circle of test labs and certifiers working according to the Solar Keymark scheme rules - List of Decisions Revision 5 Date: May 12th, 2011

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Annexes

Annex 1 to Guide to EN12975. Area definitions for different collector types

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