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ISO 9806-3

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Test methods for solar collectors —

Part 3:
Thermal performance of unglazed liquid heating collectors (sensible heat transfer only) including pressure drop

Méthodes d'essai des capteurs solaires —

Partie 3: Performance thermique des capteurs non vitrés à liquide (transfert de chaleur appréciable seulement), chute de pression incluse

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

International Standard ISO 9806-3 was prepared by Technical Committee ISO/TC 180, *Solar energy*, Subcommittee SC 5, *Collectors and other components*.

ISO 9806 consists of the following parts, under the general title *Test methods for solar collectors*:

— *Part 1: Thermal performance of glazed liquid heating collectors including pressure drop*

— *Part 2: Qualification test procedures*

— *Part 3: Thermal performance of unglazed liquid heating collectors (sensible heat transfer only) including pressure drop*

— *Part 4: Thermal performance of air or gas heating collectors*

Annex A forms an integral part of this part of ISO 9806. Annexes B, C, D and E are for information only.

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Test methods for solar collectors —

Part 3:
Thermal performance of unglazed liquid heating collectors (sensible heat transfer only) including pressure drop

1 Scope

1.1 This part of ISO 9806 establishes methods for determining the thermal performance of unglazed liquid heating solar collectors.

1.2 This part of ISO 9806 contains methods for conducting tests outdoors under natural solar irradiance and simulated wind and for conducting tests indoors under simulated solar irradiance and wind.

1.3 This part of ISO 9806 is not applicable to those collectors in which a thermal storage unit is an integral part of the collector to such an extent that the collection process cannot be separated for the purpose of making measurements of these two processes.

1.4 This part of ISO 9806 is not applicable to collectors in which the heat transfer fluid can change phase, nor is it applicable to collectors affected by condensation of water vapour from the ambient air.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this part of ISO 9806. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this part of ISO 9806 are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

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

ISO 9806-1:1994, *Test methods for solar collectors — Part 1: Thermal performance of glazed liquid heating collectors including pressure drop.*

ISO 9845-1:1992, *Solar energy — Reference solar spectral irradiance at the ground at different receiving conditions — Part 1: Direct normal and hemispherical solar irradiance for air mass 1,5.*

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

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

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

WMO, *Guide to Meteorological Instruments and Methods of Observation,* 5th ed., WMO-8, Secretariat to the World Meteorological Organization, Geneva, 1983, Chapter 9.

3 Definitions

For the purposes of this part of ISO 9806, the definitions given in ISO 9806-1 and the following definitions apply.

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

NOTES

1 Irradiation is normally expressed in megajoules per square metre (MJ/m^2) over a specified time interval.

2 Solar irradiation is often termed "radiant exposure" or "insolation". The use of these terms is deprecated.

3.2 longwave radiation; thermal radiation: Radiation at wavelengths greater than 3 µm, typically originating from sources at terrestrial temperatures (e.g. ground and other terrestrial objects).

3.3 turbulence level: Root mean square velocity fluctuation divided by the mean velocity.

3.4 unglazed solar collector: Collector without a cover over the absorber.

4 Symbols and units

The symbols and their units used in this part of ISO 9806 are given in annex A.

5 Collector mounting and location

5.1 General

Collectors tested in accordance with this part of ISO 9806 shall be mounted in accordance with 5.2 to 5.9. The mounting arrangement shall be reported with the results in the format sheets.

Full-size collector modules or collector arrays typical of full-size installations shall be tested, because the edge losses of small collectors may significantly reduce their overall performance. A minimum collector gross area of 3 m^2 is recommended.

5.2 Collector mounting frame

The collector shall be mounted in the manner specified by the manufacturer. The collector mounting frame shall in no way obstruct the aperture of the collector, and shall not significantly affect the back or side insulation, unless otherwise specified (for example, when the collector is part of an integrated roof array). The collector shall be mounted such that the lower edge is not less than 0,5 m above the local ground surface.

If mounting instructions are not specified, the collector shall be mounted on an insulated backing of conductance $(2 \pm 0,5)$ W/(m^2 K) and the upper surface painted matt white and ventilated at the back. Collectors designed to be mounted directly on standard roofing material may be mounted over a simulated roof section.

Collector arrays constructed from pipe or strip components shall be mounted with the pipes (or strips) spaced 10 mm or one diameter (width of strip) apart, whichever is smaller. If a different pipe or strip spacing is specified in the manufacturer's installation instructions, then the recommended spacing shall be used. If the collector is delivered with mounting spacers or any device fixing the spacing of the pipes (or strips), then the collector shall be tested as delivered and its geometry shall be reported in the test report.

Currents of warm air, such as those which rise up the walls of a building, shall not be allowed to pass over the collector. Where collectors are tested on the roof of a building, they shall be located at least 2 m away from the roof edge.

5.3 Collector test module size

The performance of some forms of unglazed solar collectors is a function of module size. If the collector is supplied in fixed units of area greater than 1 m^2, then sufficient of the modules shall be linked together (in series or in parallel) to give a test system absorber surface of at least 3 m^2. If the collector is supplied in the form of strips, the minimum built-up module area shall be 3 m^2 (gross area).

5.4 Tilt angle

The collector shall be tested at tilt angles such that, during the test period, the angle of incidence with direct solar radiation, θ, is less than 30° or at angles of tilt such that the incident angle modifier for the collector varies by less than $\pm$ 2 % from its value at normal incidence. Before deciding on a tilt angle, it may be necessary to check the incident angle modifier at two angles prior to commencing the tests (see annex B).

NOTE 3 For most unglazed collectors the influence of tilt angle and radiation angle of incidence on collector efficiency is small, and unglazed collectors are commonly installed at low inclinations. However, care must be taken to avoid air locks. Absorbers made of separate parallel tubes may have an angle of incidence response that increases with angle of incidence.

5.5 Collector orientation outdoors

The collector may be mounted outdoors in a fixed position facing the equator, but this will result in the time available for testing being restricted by the acceptable range of incidence angles (see 8.6). A more versatile approach is to move the collector to follow the sun in azimuth, using manual or automatic tracking.

5.6 Shading from direct solar irradiance

The location of the test stand shall be such that no shadow is cast on the collector during the test.

5.7 Diffuse and reflected solar irradiance

5.7.1 Outdoors

For the purposes of analysis of outdoor test results, solar irradiance not coming directly from the sun's disc is assumed to come isotropically from the hemispherical field of view of the collector. In order to minimize the errors resulting from this approximation, the collector shall be located where there will be no significant solar radiation reflected onto it from surrounding buildings or surfaces during the tests, and where there will be no significant obstructions in the field of view. Not more than 5 % of the collector's field of view shall be obstructed, and it is particularly important to avoid buildings or large obstructions subtending an angle of greater than 15° with the horizontal in front of the collectors.

The reflectance of most rough surface such as grass, weathered concrete or chippings is not usually high enough to cause problems during collector testing. Surfaces to be avoided in the collector's field of view include large expanses of glass, metal or water.

5.7.2 Solar irradiance simulator

In most solar simulators the simulated beam approximates direct solar irradiance only. In order to simplify the measurement of simulated irradiance, it is necessary to minimize reflected irradiance. This can be achieved by painting all surfaces in the test chamber with a dark (low reflectance) paint.

5.8 Longwave irradiance

5.8.1 Outdoors

The temperature of surfaces adjacent to the collector shall be as close as possible to that of the ambient air in order to minimize the influence of longwave radiation from surrounding surfaces. For example, the outdoor field of view of the collector should not include chimneys, cooling towers, hot roof surfaces or hot exhausts.

5.8.2 Solar irradiance simulator

For indoor testing, the collector shall be shielded from hot surfaces such as radiators, air-conditioning ducts and machinery, and from cold surfaces such as windows and external walls. Shielding is important both in front of and behind the collector. For unglazed collectors the major difference between outdoor and indoor conditions is the longwave thermal irradiance. The longwave irradiance in a simulator shall not exceed the limits specified in 9.2.

5.9 Surrounding air speed

The performance of unglazed collectors is sensitive to air speed adjacent to the collector. In order to maximize the reproducibility of results, collectors shall be mounted such that air can freely pass over the aperture, exposed back and sides of the collector. Collectors designed for integration into a roof may have their backs protected from the wind; if so, this shall be reported with the test results.

The average surrounding air speed at a distance of 100 mm above and parallel to the collector aperture shall be within the range 1,5 m/s to 4 m/s, subject to the tolerance specified in table 2 (see 8.5). An artificial wind generator shall be used to provide a turbulence level in the range 20 % to 40 % to simulate natural wind conditions. The turbulence level shall be checked at the leading edge of the collector 100 mm above the collector surface. The turbulence level shall be monitored using a linearized hot wire anemometer with a frequency response of at least 100 Hz. If the absorber is not mounted directly on a roof or a sheet of backing material, the surrounding air speed must be controlled and monitored at the front and back of the absorber.

6 Instrumentation

6.1 Solar radiation measurement

6.1.1 Pyranometer

A class I (in accordance with ISO 9060) pyranometer shall be used to measure the global shortwave radiation from both the sun and the sky. The recommended practice for use given in ISO/TR 9901 shall be observed.

6.1.2 Precautions for effects of temperature gradient

The pyranometer used during the tests shall be placed in a typical test position and allowed to equilibrate for at least 30 min before measurements commence.

6.1.3 Precautions for effects of humidity and moisture

The pyranometer shall be provided with a means of preventing accumulation of moisture that may condense on surfaces within the instrument and affect its reading. An instrument with a desiccator that can be inspected is required. The condition of the desiccator shall be observed prior to and following each collector test.

6.1.4 Precautions for infrared radiation effects on pyranometer accuracy in simulator tests

Pyranometers used to measure the irradiance of a solar irradiance simulator shall be mounted in such a way as to minimize the effects on its readings of the infrared radiation of wavelength above 3 µm from the simulator light source.

6.1.5 Mounting of pyranometer

The pyranometer shall be mounted such that its sensor is coplanar, within a tolerance of ± 1°, with the plane of the collector aperture. It shall not cast a shadow onto the collector aperture at any time during the test period. The pyranometer shall be mounted so as to receive the same levels of direct, diffuse and reflected solar radiation as are received by the collector.

For outdoor testing, the pyranometer shall be mounted at the midheight of the collector. The body of the pyranometer and the emerging leads or the connector shall be shielded to minimize solar heating of the electrical connections. Care shall also be taken to minimize energy reflected and reradiated from the solar collector onto the pyranometer. Poles that can cast a shadow on the pyranometer shall be avoided.

For indoor testing, pyranometers may be used to measure the distribution of simulated solar irradiance over the collector aperture, using a grid of maximum spacing 150 mm. The pyranometers shall be mounted and protected as for outdoors testing. Alternatively, other types of radiation detector may be used, provided that they have been calibrated for simulated solar radiation.

6.1.6 Pyranometer calibration interval

Pyranometers shall be calibrated for solar response within 12 months preceding the collector tests. Any change of more than 1 % over a 12-month period shall warrant the use of more frequent calibration or replacement of the instrument. If the instrument is damaged in any significant manner, it shall be recalibrated or replaced.

6.2 Longwave radiation measurement

6.2.1 Pyrgeometer

A pyrgeometer mounted in the plane of the collector shall be used to measure longwave irradiance.

6.2.2 Precautions for effects of temperature gradient

The pyrgeometer used during the tests shall be placed in the same plane as the collector absorber and allowed to equilibrate for at least 30 min before measurements commence.

6.2.3 Precautions for effects of humidity and moisture

The pyrgeometer shall be provided with a means of preventing accumulation of moisture that may condense on surfaces within the instrument and affect its reading. An instrument with a desiccator that can be inspected is required. The condition of the desiccator shall be observed prior to and following each collector test.

6.2.4 Precautions for effects of solar heating

The dome of the pyrgeometer used to measure longwave irradiance shall be ventilated to minimize the influence of solar heating effects.

6.2.5 Pyrgeometer calibration interval

The pyrgeometer shall be calibrated within 12 months preceding the tests. Any change of more than 5 % over a 12-month period shall warrant the use of more frequent calibration or replacement of the instrument. If the instrument is damaged in any significant manner, it shall be recalibrated or replaced.

6.3 Temperature measurements

The temperature measurements required for solar collector testing are the fluid temperature at the collector inlet, the fluid temperature difference between the outlet and inlet of the collector, and the ambient air temperature. The required accuracy and the environment for these measurements differ, and hence the transducer and associated equipment may be different.

6.3.1 Measurement of heat transfer fluid inlet temperature (t_{in})

6.3.1.1 Required accuracy

The temperature (t_{in}) of the heat transfer fluid at the collector inlet shall be measured to an accuracy of ± 0,1 °C, but in order to verify that the temperature is not drifting with time, a very much better resolution of the temperature signal to ± 0,02 °C is required.

6.3.1.2 Mounting of sensors

The transducer for temperature measurement shall be mounted at no more than 200 mm from the collector inlet and insulation shall be placed both upstream and downstream of the transducer. If it is necessary to position the transducer more than 200 mm from the collector, then a test shall be made to verify that the measurement of fluid temperature is not affected.

To ensure mixing of the fluid at the position of temperature measurement, a bend in the pipework, an orifice or a fluid-mixing device shall be placed upstream of the transducer, and the transducer probe shall point upstream in a pipe where the flow is rising (to prevent air from being trapped near the sensor), as shown in figure 1.

6.3.2 Determination of heat transfer fluid temperature difference (ΔT)

6.3.2.1 Required accuracy

The difference between the collector outlet and inlet temperatures (ΔT) shall be determined to an accuracy of ± 0,1 K. Accuracies approaching ± 0,02 K can be achieved with modern well-matched and calibrated transducers, hence it is possible to measure temperature differences down to 1 K with a reasonable accuracy. However temperature differences less than 2 K should be avoided in order to minimize errors.

Dimensions in millimetres

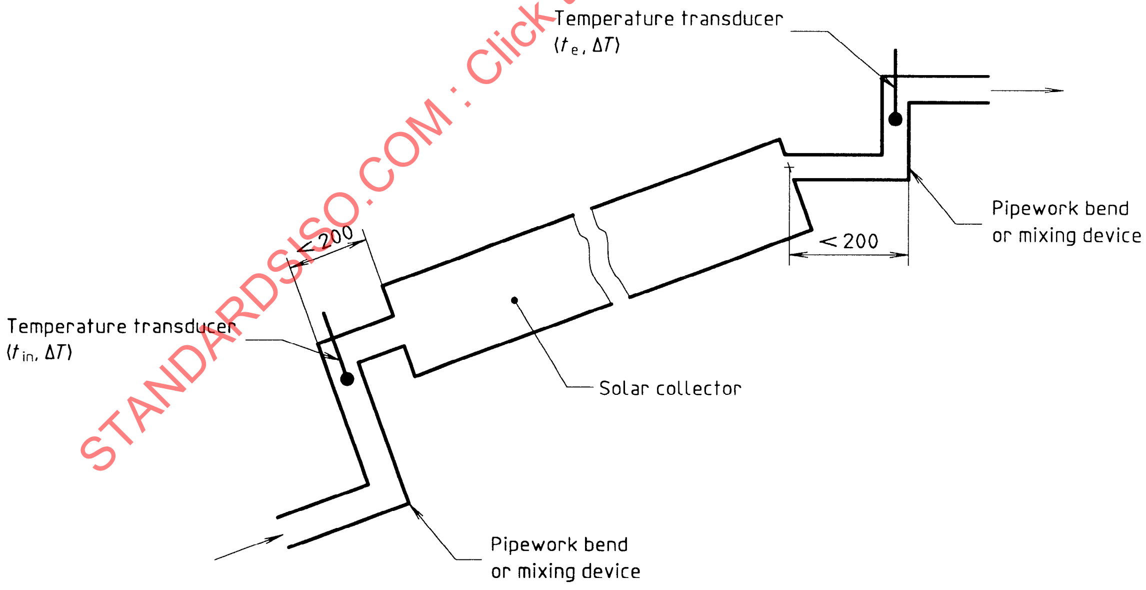


Figure 1 — Recommended transducer positions for measuring the heat transfer fluid inlet and outlet temperatures

6.3.3 Measurement of surrounding air temperature (t_a)

6.3.3.1 Required accuracy

The ambient air temperature (t_a) shall be measured to an accuracy of ± 0,1 °C. The dew point temperature t_{dp} shall be determined to an accuracy of ± 0,5 °C.

6.3.3.2 Mounting of sensors

The transducer for measuring the ambient air temperature shall be mounted in the outlet of the artificial wind generator. The transducer shall be shielded from direct and reflected solar radiation. One additional sensor should be used to measure the ambient air temperature in the back of the collector, in order to ensure that the ambient air temperature is uniform around the collector and to determine a representative average reading.

The temperature of the air flow out of the wind generator shall not deviate from the ambient air temperature more than ± 1 °C.

6.4 Collector fluid flowrate measurements

Mass flowrates may be measured directly or, alternatively, they may be determined from measurements of volumetric flowrate and temperature.

The accuracy of the liquid flowrate measurement shall be equal to or better than ± 1 % of the measured value, in mass units per unit time.

The flowmeter shall be calibrated over the range of fluid flowrates and temperatures to be used during collector testing.

NOTE 4 The temperature of the fluid in volumetric flowmeters must be known with sufficient accuracy to ensure that mass flowrates can be determined within the limits specified above.

The direction of flow through the meter should be horizontal or rising, in order to avoid air accumulation.

6.5 Surrounding air speed

The heat loss from a collector increases with increasing air speed (u) over the collector. By controlling the wind speed over the collector with an artificial wind generator as specified in 5.9, it is possible to define clearly the conditions under which the tests are performed.

6.5.1 Required accuracy

The speed of the surrounding air over the front surface of the collector shall be measured to an accuracy of ± 10 %.

Under outdoor conditions the surrounding air speed is seldom constant and gusting frequently occurs. The measurement of an average air speed is therefore required during the test period. This may be obtained either by an arithmetic average of sampled values or by a time integration over the test period.

6.5.2 Mounting of sensors

To account for air speed variations from one end of the collector to the other, a series of measurements shall be taken at a distance of 100 mm in front of the collector aperture, at nine positions equally spaced over the collector area. An average value shall then be determined. For a collector that does not have back insulation or is not mounted on a simulated roof surface, the air speed shall be measured over the front and back surfaces. The average air speed over the front and back surfaces shall be used in the data correlation.

During a test, the air speed shall be monitored at a convenient point that has been calibrated relative to the mean air speed over the collector. The anemometer shall not cast a shadow on the collector during the tests.

6.6 Pressure measurements

The heat transfer fluid pressure at the collector inlet and the pressure drop across the collector shall be measured with a device having an accuracy of ± 3,5 kPa. If the collector is supplied in modules, the pressure drop shall be specified per module. For strip absorbers, the pressure shall be specified per running metre of strip.

6.7 Elapsed time

Elapsed time shall be measured to an accuracy of ± 0,2 %.

6.8 Instrumentation/data recorders

In no case shall the smallest scale division of the instrument or instrument system exceed twice the specified accuracy. For example, if the specified accuracy is ± 0,1 °C, the smallest scale division shall not exceed ± 0,2 °C.

Analog and digital recorders shall have an accuracy equal to or better than ± 0,5 % of the full-scale reading and have a time constant of 1 s or less. The peak signal indication shall be between 50 % and 100 % of full scale.

Digital techniques and electronic integrators shall have an accuracy equal to or better than ± 1,0 % of the measured value.

The input impedance of recorders shall be greater than 1000 times the impedance of the sensors or 10 MΩ, whichever is higher.

The sampling interval shall be at most 30 s.

6.9 Collector area

The collector area (gross or absorber) shall be measured to an accuracy of ± 0,1%.

6.10 Collector fluid capacity

The fluid capacity of the collector, expressed as an equivalent mass of the heat transfer fluid used for the test, shall be measured to an accuracy of at least ± 10 %.

Measurements shall be made by weighing the collector when empty and again when filled with fluid.

7 Test installation

7.1 General consideration

Examples of test configurations for testing solar collectors employing liquid as the heat transfer fluid are shown in figures 2 and 3. These are schematic only, and are not drawn to scale.

7.2 Heat transfer fluid

The heat transfer fluid used for collector testing may be water or a fluid recommended by the collector manufacturer. The specific heat capacity and density of the fluid used shall be known to within ± 1 % over the range of fluid temperatures used during the tests. These values are given for water in annex D.

The mass flowrate of the heat transfer fluid shall be the same throughout the test sequence used to determine the thermal efficiency curve, time constant and, if any, incident angle modifiers.

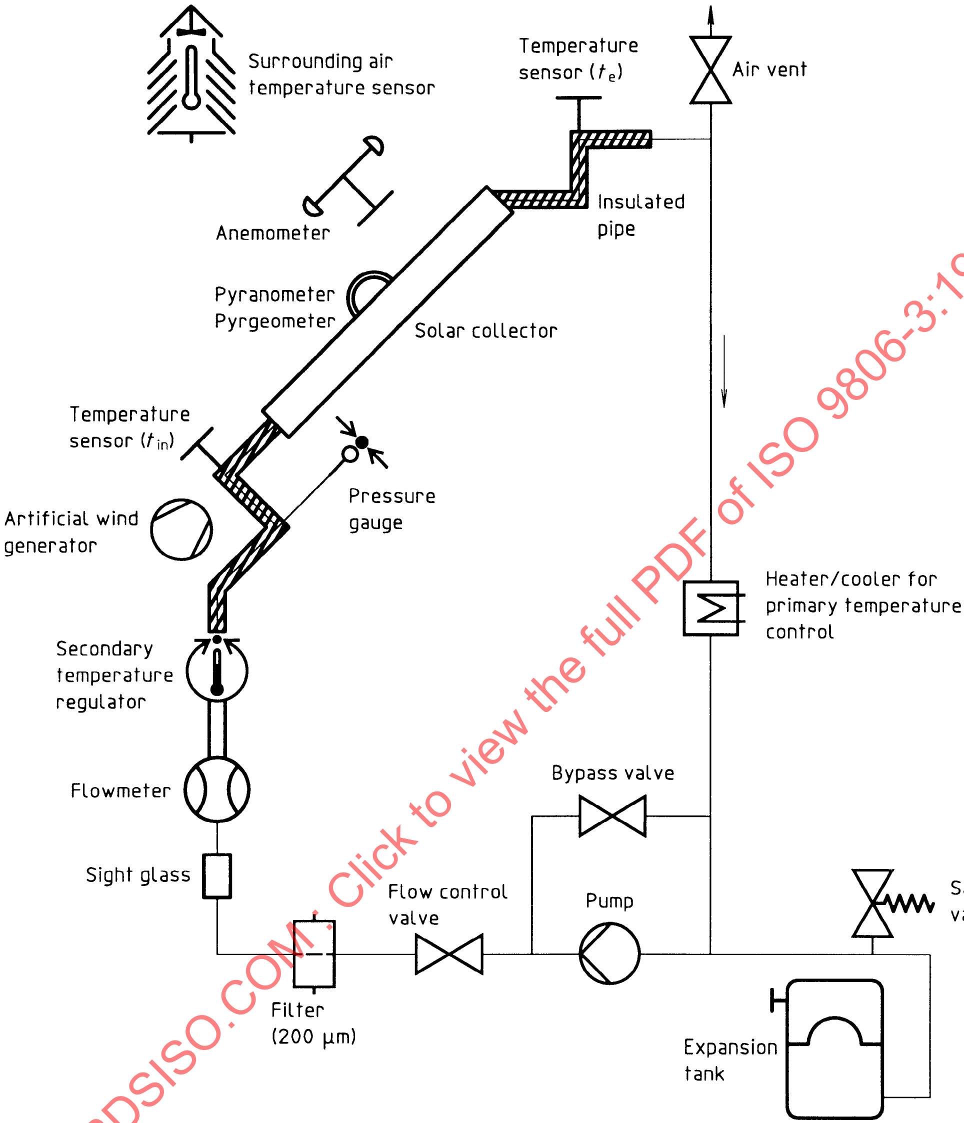


Figure 2 — Example of a closed test loop

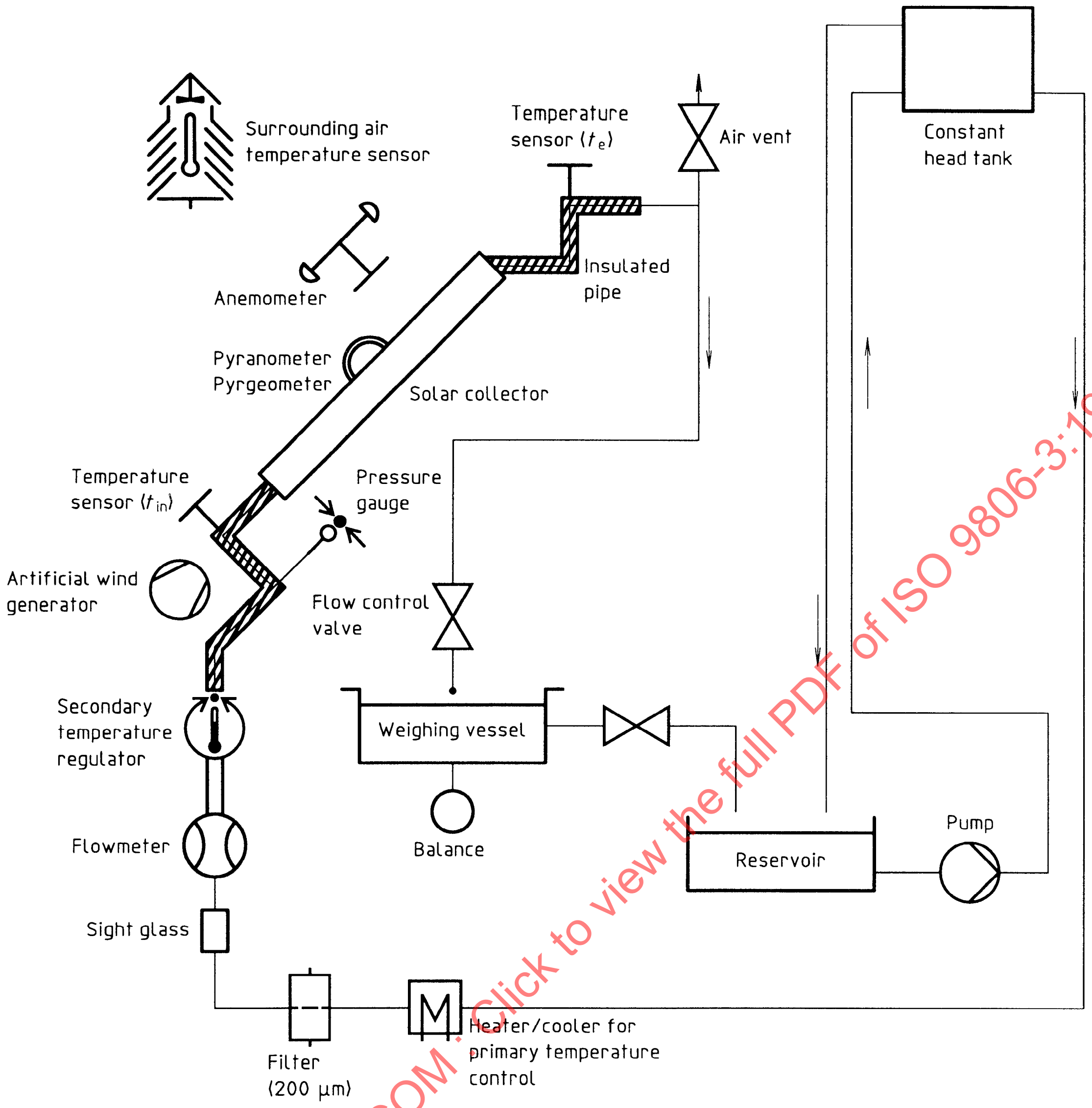


Figure 3 — Example of an open test loop

7.3 Pipework and fittings

The piping used in the loop shall be resistant to corrosion. If nonaqueous fluids are used, then compatibility with system materials shall be confirmed before the tests commence.

Pipe lengths shall generally be kept short. In particular, the length of piping between the outlet of the fluid temperature regulator and the inlet to the collector shall be minimized, to reduce the effects of the environment on the inlet temperature of the fluid. This section of pipe shall be insulated to ensure a rate of heat loss of less than 0,2 W/K and be protected by a reflective weatherproof cover.

Pipework between the temperature-sensing points and the collector (inlet and outlet) shall be protected with insulation and reflective weatherproof covers extending beyond the positions of the temperature sensors, such that the calculated temperature gain or loss along either pipe portion does not exceed 0,01 K under test conditions. Flow-mixing devices such as pipe bends are required immediately upstream of temperature sensors (see 6.3).

A short length of transparent tube shall be installed in the fluid loop so that air bubbles and any other contaminants will be observed if present. The transparent tube shall be placed close to the collector inlet but shall not influence the fluid inlet temperature control or temperature measurements. A variable area flowmeter is convenient for this purpose, as it simultaneously gives an independent visual indication of the flowrate.

An air separator and air vent shall be placed at the outlet of the collector, and at other points in the system where air can accumulate.

Filters shall be placed upstream of the flow-measuring device, the pump and elsewhere, in accordance with normal practice (a nominal filter size of 200 µm is usually adequate).

7.4 Pump and flow control devices

The pump shall be located in the collector test loop in such a position that the heat which is dissipated in the fluid does not impair either the control of the collector inlet temperature or the measurements of the fluid temperature rise through the collector.

With some types of pump, a simple bypass loop and manually controlled needle valve may provide adequate flow control. Where necessary an appropriate flow control device may be added to stabilize the mass flowrate.

The pump and flow controller shall be capable of maintaining the mass flowrate through the collector stable to within ± 1 % despite temperature variations, at any inlet temperature chosen within the operating range.

7.5 Temperature regulation of the heat transfer fluid

It is imperative that a collector test loop be capable of maintaining a constant collector inlet temperature at any temperature level chosen within the operating range. Since the rate of energy collection in the collector is deduced by measuring instantaneous values of the fluid inlet and outlet temperatures it follows that small variations in inlet temperature could lead to errors in the rates of energy collection deduced. It is particularly important to avoid any drift in the collector inlet temperature. A drift of less than 0,1 K over each test period is required.

Test loops shall therefore contain two stages of fluid inlet temperature control, as shown in figures 2 and 3. The primary temperature controller shall be placed upstream of the flowmeter and flow controller. A secondary temperature regulator shall be used to adjust the fluid temperature just before the collector inlet. This secondary regulator should normally not be used to adjust the fluid temperature by more than ± 2 K.

8 Outdoor steady-state efficiency test

8.1 Test installation

The collector shall be mounted in accordance with the recommendations given in clause 5, and coupled to a test loop as described in clause 7. The heat transfer fluid shall flow from the bottom to the top of the collector, or as recommended by the manufacturer.

8.2 Preconditioning of the collector

The collector shall be visually inspected and any damage recorded.

The collector absorber surface shall be thoroughly cleaned.

The collector pipework shall be vented of trapped air by means of an air valve or by circulating the fluid at a high flowrate and high temperature, as necessary.

The fluid shall be inspected for entrained air or particles by means of the transparent tube built into the fluid loop pipework. Any contaminants shall be removed.

8.3 Test conditions

The net irradiance (G'') at the plane of the collector absorber shall be greater than 650 W/m^2.

The angle of incidence (θ) of direct solar radiation at the collector aperture shall be in the range in which the incident angle modifier for the collector varies by no more than $\pm$ 2 % from its value at normal incidence. In order to characterize collector performance at other angles, an incident angle modifier shall be determined (see annex B).

Unless otherwise recommended, the fluid flowrate shall be set at approximately 0,04 kg/s per square metre of collector aperture area. It shall be held stable to within $\pm$ 1 % of the set value during each measurement period, and shall not vary by more than $\pm$ 10 % of the set value from one measurement period to another.

Measurements of fluid temperature difference of less than 1 K shall not be included with the test results because of the associated problems of instrument accuracy.

8.4 Test procedure

The collector shall be tested over its operating temperature range under clear sky conditions in order to determine its efficiency characteristic. If a collector is to be tested with inlet temperature less than ambient temperature, the surface of the absorber shall be inspected during the tests to ensure that condensation does not occur on the absorber (see 1.4).

The collector thermal performance shall be evaluated for the range of conditions specified in table 1.

At least four independent stable data points shall be obtained for each operating condition, to give a minimum of 32 data points. If a fixed collector installation is used, an equal number of data points shall be taken before and after solar noon for each operating condition.

During a test, measurements as specified in 8.5 shall be recorded. These may then be used to identify test periods from which satisfactory data points can be derived.

Table 1 — Minimum range of thermal performance test conditions

Test point	Net irradiance G'' W/m^2	Surrounding air speed, u m/s	$(T_{in} - T_a)/G''$ m^2 K/W	Efficiency
1	> 650	2 to 3	< 0,002	η_0
2	> 650	2 to 3		$0{,}8\eta_0$ to $0{,}6\eta_0$
3	> 650	2 to 3		$0{,}6\eta_0$ to $0{,}4\eta_0$
4	> 650	2 to 3		$< 0{,}4\eta_0$
5	> 650	< 1,5	< 0,002	
6	> 650	< 1,5		$< 0{,}5\eta_0$
7	> 650	3 to 4	< 0,002	
8	> 650	3 to 4		$< 0{,}5\eta_0$

8.5 Measurements

The following measurements shall be obtained:

a) gross area A_G and absorber area A_A;

b) mass flowrate of heat transfer fluid, $\dot{m}$;

c) global solar irradiance in the collector plane, G;

d) longwave irradiance in the collector plane E_L, or dew point temperature T_{dp};

e) surrounding air speed, u;

f) surrounding air temperature, t_a;

g) temperature of the heat transfer fluid at the collector inlet, t_{in};

h) temperature of the heat transfer fluid at the collector outlet, t_e.

8.6 Test period

The test period for a steady-state data point shall include a preconditioning period of at least 15 min with the desired fluid inlet temperature and mass flowrate, followed by a steady-state measurement period of at least 15 min.

In all cases the length of the steady-state measurement period shall be greater than four times the ratio of the thermal capacity C of the collector to the thermal capacity flowrate $\dot{m}c_f$ of the fluid through the collector (see clause 10).

A collector is considered to have been operating in steady-state conditions over a given measurement period if none of the experimental parameters deviate from their mean values over the measurement period by more than the limits given in table 2. To establish that a steady state exists, average values of each parameter taken over successive periods of 30 s shall be compared with the mean value over the measurement period.

Table 2 — Permitted deviation of measured parameters during a measurement period

Parameter	Symbol	Permitted deviation from the mean value
Global solar irradiance	G	$\pm$ 50 W/m^2
Longwave irradiance	E_L	$\pm$ 20 W/m^2
Surrounding air temperature	t_a	$\pm$ 1 K
Dew point temperature	t_{dp}	$\pm$ 1 K
Fluid mass flowrate	$\dot{m}$	$\pm$ 1 %
Fluid temperature at the collector inlet	t_{in}	$\pm$ 0,1 K
Surrounding air speed	u	$\pm$ 10 %

8.7 Presentation of results

The measurements shall be collated to produce a set of data points which meet the required test conditions, including those for steady-state operation. These shall be presented using the data format sheets given in annex A.

8.8 Calculation of collector efficiency

The test results shall be used to calculate collector efficiency η from the following equation:

$$\eta = \frac{\dot{Q}}{A_p G''} \quad \ldots (1)$$

where

A_p is either the gross collector area or the absorber area;

G'' is the net irradiance, determined by the equation

$$G'' = G + \frac{\varepsilon}{\alpha}\left(E_L - \sigma T_a^4\right) \quad \ldots (2)$$

in which E_L is the measured longwave irradiance in the collector plane, and $\varepsilon/\alpha = 1$ unless otherwise specified.

$\dot{Q}$ is the useful power output, calculated from:

$$\dot{Q} = \dot{m}c_f(t_e - t_{in}) \quad \ldots (3)$$

Provided that the angle of incidence θ less than 30°, the use of an incident angle modifier, as discussed in annex B, is not required.

A value of c_f appropriate to the mean fluid temperature shall be used.

If the fluid mass flowrate $\dot{m}$ is obtained from volumetric flowrate measurements, then the density shall be determined for the fluid at the temperature in the flowmeter.

The test data are correlated by curve-fitting using the least squares method to obtain an efficiency function of the form:

$$\eta = \eta_0 - (b_1 + b_2 u) \frac{t_{in} - t_a}{G''} \quad \ldots (4)$$

where η_0, b_1 and b_2 are coefficients to be determined by curve-fitting.

NOTE 5 In accordance with commercial practice for the most common applications of unglazed collectors, the correlating variable in the efficiency equation is $(t_{in} - t_a)/G''$. In ISO 9806-1, G replaces G'' and t_m may also be used (instead of t_{in}) for glazed collectors.

8.9 Evaluation of longwave irradiance outdoors

If instrumentation is not available for measuring longwave irradiance E_L, the following clear sky longwave model may be used to determine sky emittance from measured dew point temperature t_{dp}

$$\varepsilon_s = 0{,}711 + 0{,}56 \frac{t_{dp}}{100} + 0{,}73 \left(\frac{t_{dp}}{100} \right)^2 \quad \ldots (5)$$

where the dew point temperature t_{dp} shall be measured with an accuracy specified in 6.3.3.1.

The longwave sky irradiance in the horizontal plane is calculated by the expression:

$$E_S = \varepsilon_s \sigma T_a^4 \quad \ldots (6)$$

If the collector is inclined there will be thermal radiation exchange with both the sky and ground.

The longwave irradiance E_β outdoors on a collector inclined at an angle β is given by:

$$E_\beta = \varepsilon_s \sigma T_a^4 \frac{1 + \cos \beta}{2} + \varepsilon_g \sigma T_g^4 \frac{1 - \cos \beta}{2} \quad \ldots (7)$$

The ground temperature will have little influence on longwave radiation on a collector inclined at less than 45°, since the view factor between a collector and the ground is only 0,15 for $\beta = 45°$. In this case, equation (7) can be written as:

$$E_\beta = \varepsilon_s \sigma T_a^4 \frac{1 + \cos \beta}{2} \quad \ldots (8)$$

Thus, in equation (2) the longwave irradiance E_L in the collector plane is equal to E_β when the collector is located outdoors.

9 Steady-state efficiency test using a solar irradiance simulator

9.1 General

The performance of most collectors is better in direct solar radiation than in diffuse and at present there is little experience with diffuse solar simulation. This test method is therefore designed for use only in simulators where a near-normal incidence beam of simulated solar radiation can be directed at the collector. In practice it is difficult to produce a uniform beam of simulated solar radiation and a mean irradiance level has therefore to be measured over the collector aperture.

9.2 The solar irradiance simulator for steady-state efficiency testing

A simulator for steady-state efficiency testing shall have the following characteristics:

The lamps shall be capable of producing a mean irradiance over the collector aperture of at least 650 W/m^2.

The mean irradiance over the collector aperture shall not vary by more than $\pm$ 50 W/m^2 during a test period. 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 $\pm$ 15 %.

The spectral distribution of the simulated solar radiation shall be approximately equivalent to that of the solar spectrum at air mass 1,5 (see ISO 9845-1:1992 or ISO 9806-1:1994, annex C). For certain lamp types, i.e. metal halide designs, it is recommended that the initial spectral determination be performed after the lamps have completed their burn-in period.

The longwave irradiance at the collector shall not exceed that of a blackbody cavity at ambient air temperature by more than 50 W/m^2. This condition may require special precautions in some simulators.

9.3 Test installation

Clause 5 describes collector mounting and location requirements.

The collector tilt angle shall be such as to receive a near-normal incidence beam of simulated solar radiation. The tilt angle shall be at or corrected to 30°, or as recommended by the manufacturer.

A wind generator shall be used with a solar simulator to produce an air flow in accordance with 5.9.

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 of the collector varies by no more than $\pm$ 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 that point.

The irradiance shall be monitored during the test and shall not vary by more than 3 % during the test period. The method used for measuring the irradiance during the test period shall produce values of mean irradiance which agree with those determined by spatial integration to within $\pm$ 1 %.

9.4 Preconditioning of the collector

The procedure outlined in 8.2 shall be followed.

9.5 Test conditions

The test conditions described in 8.3 for outdoor testing shall be observed with the following addition. The longwave irradiance in the plane of the collector aperture shall not exceed the limit specified in 9.2.

9.6 Test period

The test period may be determined in the same way as for outdoor steady-state testing.

The more stable environment of an indoor test facility may allow steady-state conditions to be maintained more easily than outdoors, but adequate time shall still be allowed to ensure proper steady-state operation of the collector as discussed in 8.6.

9.7 Test procedure

The collector shall be tested over its operating temperature range in the same way as specified for outdoor testing in 8.4.

During a test, measurements shall be made as described in 9.8. These may then be used to identify test periods from which satisfactory data points can be derived.

9.8 Measurements during tests in solar irradiance simulators

Measurements shall be made as recommended in 8.5.

9.8.1 Measurement of simulated solar irradiance

NOTE 6 Simulated solar irradiance usually varies spatially over the collector as well as with time during a test. It is therefore necessary to employ a procedure for integrating the irradiance over the collector aperture. Time variations in irradiance are usually caused by fluctuations in the electricity supply and changes in lamp output with temperature and running time. Some lamps take more than 30 min to reach a stable working condition when warming up from cold.

Pyranometers may be used to measure the irradiance of simulated solar radiation in accordance with 6.1. Alternatively, other types of radiation detector may be used, provided they have been calibrated for simulated solar radiation. Details of the instruments and the methods used to calibrate them shall be reported with the test results.

The distribution of irradiance over the collector aperture shall be measured using a grid of maximum spacing 150 mm, and the spatial mean deduced by simple averaging.

9.8.2 Measurement of longwave irradiance in simulators

The longwave irradiance in a solar simulator is likely to be higher than that which typically occurs outdoors. It shall therefore be measured to ensure that it does not exceed the limit given in 9.2.

The mean longwave irradiance in the collector test plane shall be determined whenever changes are made in the simulator which could affect the longwave irradiance, and at least annually. The mean longwave irradiance in the collector test plane and the date when it was last measured shall be reported with collector test results.

9.8.3 Ambient air temperature in solar irradiance simulators

Careful consideration shall be given to the measurement of t_a in simulators. A mean of two measured values is necessary (6.3.3.2). Transducers shall be shielded in order to minimize radiation exchange. The air temperature in the outlet of the wind generator shall be used for the calculations of collector performance.

9.9 Computation and presentation of results

The analysis presented in 8.8 for outdoor testing is also applicable to solar simulator tests, and the results shall be presented on the data format sheets shown in annex A.

10 Determination of the effective thermal capacity and time constant of a collector

10.1 General

The effective thermal capacity and the time constant of a collector are important parameters which determine its transient performance.

A collector can usually be considered as a combination of masses, each at a different temperature. When a collector is operating, each collector component responds differently to a change in operating conditions, so it is useful to consider an effective thermal capacity for the whole collector.

Unfortunately, the effective thermal capacity depends on the operating conditions and is not a collector parameter with a unique value. Several different test methods have been used to measure the effective thermal capacity of collectors, and it has been shown that similar results can be obtained by using quite different methods. The method below is recommended because of its simplicity.

Just as there is no unique value of effective thermal capacity, there is no unique overall time constant for a collector. For most collectors, the dominant influence on the response is the fluid flow rate. Other collector components respond with different times to give an effective overall time constant which depends on the operating conditions.

10.2 Determination of thermal capacity

The thermal capacity of the collector C (expressed in joules per kelvin) is calculated as the sum, for each constituent element of the collector (absorber, heat transfer fluid), of the product of its mass per square metre of collector m_i (expressed in kilograms per square metre) and its specific heat c_i (expressed as joules per kilogram kelvin):

$$C = \sum_i m_i c_i$$

10.3 Test procedure for collector time constant

Testing shall be performed either under clear sky conditions outdoors or in a solar irradiance simulator. In either case the net irradiance G'' at the plane of the collector aperture shall be greater than 650 W/m^2.

The heat transfer fluid shall be circulated through the collector at the same flowrate as that used during collector thermal efficiency tests.

The collector shall be shielded from the solar radiation by means of a solar-reflecting cover, and the fluid temperature at the collector inlet set approximately equal to the ambient air temperature.

When a steady state has been reached, the cover shall be removed and measurements continued until steady-state conditions have been achieved again. For the purpose of this test, a steady-state condition is assumed to exist when the outlet temperature of the fluid varies by less than 0,05 K per minute.

The following quantities shall be measured in accordance with clause 6:

a) collector fluid inlet temperature (t_{in});

b) collector fluid outlet temperature [t_e (or ΔT)];

c) surrounding air temperature (t_a).

10.4 Calculation of collector time constant

The difference between the temperature of the fluid at the collector outlet and that of the surrounding air $(t_e - t_a)$ shall be plotted against time, beginning with the initial steady-state condition $(t_e - t_a)_0$ and continuing until the second steady state has been achieved at a higher temperature $(t_e - t_a)_2$.

The time constant τ_c of the collector is defined as the time taken for the collector outlet temperature to rise by 63,2 % of the total increase from $(t_e - t_a)_0$ to $(t_e - t_a)_2$, following the step increase in solar irradiance at time zero. If the response time of the temperature sensors is significant when compared with that measured for the collector, then it shall be taken into account in calculating the test results.

11 Determination of the pressure drop across a collector

11.1 General

The pressure drop across a collector may be of importance to designers of solar collector systems. The fluid normally used in the collector shall be employed for the tests.

In order that a representative range of pressure drops may be determined, a number of fluid flowrates shall be used.

11.2 Test installation

The collector shall be mounted in accordance with the recommendations of clause 5 and coupled to a test loop which conforms with the recommendations of clause 7 with only the instrumentation that is needed for this test. The heat transfer fluid shall flow from the bottom to the top of the collector unless recommended otherwise by the manufacturer. Particular attention shall be paid to the selection of appropriate pipe fittings at the collector entry and exit ports, as discussed in 7.3. The collector shall be shaded from solar irradiation during the pressure drop test.

11.3 Test procedure

The pressure drop between the collector inlet and outlet connections shall be determined with the collector and its fluid at close to ambient air temperature, and for flowrates which span the range likely to be used in the application for which the collector is intended.

In the absence of specific flowrate recommendations by the collector supplier, pressure drop measurements shall be made over the range of flowrates from 0,02 kg/s to 0,1 kg/s per square metre of collector area.

At least five measurements shall be made at values spaced equally over the flowrate range.

11.4 Test conditions

The fluid flowrate shall be held constant to within ± 1 % of the nominal value during test measurements.

The fluid inlet temperature shall be held constant to within ± 1 °C during test measurements. The test shall be carried out with the collector at a temperature which lies within ± 10 °C of that of the surrounding air. Pressure drop tests at other temperatures may be important for oil-based heat transfer fluids.

11.5 Measurements

The following measurements shall be obtained in accordance with the recommendations given in clause 6:

a) the fluid temperature at the collector inlet (t_{in});

b) the fluid flowrate ($\dot{m}$);

c) the heat transfer fluid pressure drop between the collector inlet and outlet connections (Δp).

11.6 Pressure drop caused by fittings

The fittings used to measure the fluid pressure may themselves cause a drop in pressure. A zero check on the pressure drop shall be made by removing the collector from the fluid loop and repeating the tests with the pressure-measuring fittings directly connected together.

11.7 Calculation and presentation of results

The pressure drop shall be presented graphically as a function of the fluid flowrate for each of the tests performed, using the format sheets given in annex A.

Annex A
(normative)

Format sheets for test data

A.1 Symbols and units

Symbol	Meaning	Units
A_a	aperture area of collector	m^2
A_A	absorber area of collector	m^2
A_G	gross area of collector	m^2
b_1	collector efficiency coefficient, equation (4), subclause 8.8	$W/(m^2\ K)$
b_2	collector efficiency coefficient, equation (4), subclause 8.8	$W\ s/(m^3\ K)$
c_f	specific heat capacity of heat transfer fluid	J/(kg K)
C	effective thermal capacity of collector	J/K
E_L	longwave irradiance ($\lambda > 3\ \mu m$)	W/m^2
E_β	longwave irradiance on an inclined surface outdoors	W/m^2
E_S	longwave sky irradiance in a horizontal plane	W/m^2
F_R	collector heat removal factor	dimensionless
G [1]	global solar irradiance	W/m^2
G''	net irradiance, equation (2), subclause 8.8	W/m^2
h_c	convective heat loss coefficient from the collector plate to ambient	$W/(m^2\ K)$
h_r	radiation heat loss coefficient from the collector plate to ambient	$W/(m^2\ K)$
LT	local time	h:min
K_v	incident angle modifier	dimensionless
$\dot{m}$	mass flowrate of heat transfer fluid	kg/s
$\dot{Q}$	useful power extracted from collector	W
t	time	s
t_a	ambient or surrounding air temperature	°C
t_{dp}	atmospheric dew-point temperature	°C
t_e	collector outlet (exit) temperature	°C
t_g	ground temperature	°C
t_{in}	collector inlet temperature	°C

1) In the field of solar energy the symbol G is used to denote solar irradiance, rather than the generic symbol E for irradiance.

Symbol	Meaning	Units
T_a	ambient or surrounding air temperature	K
T_g	ground temperature	K
T_s	atmospheric or equivalent sky radiation temperature	K
u	surrounding air speed	m/s
U_L	overall heat loss coefficient of a collector with uniform absorber temperature t_{in}	$W/(m^2\ K)$
Δp	pressure difference between fluid inlet and outlet	Pa
ΔT	Temperature difference between fluid outlet and inlet, $(t_e - t_{in})$	K
α	hemispherical (solar) absorptance, shortwave	dimensionless
β	inclination angle of a plane with respect to horizontal	°
ε	hemispherical emittance, longwave	dimensionless
ε_g	hemispherical emittance of ground, longwave	dimensionless
ε_s	hemispherical sky emittance, longwave	dimensionless
λ	wavelength	mm
η	collector thermal efficiency	dimensionless
η_0	collector thermal efficiency at $t_{in} = t_a$	dimensionless
θ	angle of incidence between collector normal and the solar beam	°
σ	Stefan-Boltzmann constant = $5{,}67 \times 10^{-8}$	$W/(K^4\ m^2)$
τ_c	collector time constant	s

Subscripts

A	reference to absorber area
G	reference to gross collector area

Test Report

Collector reference No.: ....

Test performed by ....
Address ....
Date .... Tel. .... Fax .... Telex ....

A.2 Unglazed solar collector description

A.2.1 Name of manufacturer ....

and collector model ....

A.2.2 Collector

Type: ☐ Unglazed flat plate ☐ Strip absorber

☐ Other (specify): ....

Gross area: .... m^2

Absorber area: .... m^2

Number of tubes or channels: ....

Tube diameter or channel dimensions: .... mm

Tube or channel pitch: .... mm

A.2.3 Heat transfer medium

Type: ☐ Water-glycol mixture, concentration of glycol: .... %

☐ Other (specify): ....

Specifications (additives etc.): ....

Alternative acceptable heat transfer fluids: ....

A.2.4 Absorber

Material: ....

Surface treatment: ....

Construction type: ....

Fluid content: .... litres

Weight empty: .... kg

Collector reference No.: ....

A.2.5 Thermal insulation and casing

Thermal insulation thickness: .... mm

Insulation material: ....

Casing material: ....

A.2.6 Limitations

Maximum temperature of operation: .... °C

Maximum pressure: .... Pa

Other limitations: ....

A.2.7 Schematic diagram of unglazed solar collector (attach separate page if necessary)

A.2.8 Photograph of the collector (attach separate page if necessary)

A.2.9 Comments on collector design (attach separate page if necessary)

Collector reference No.: ....

A.3 Instantaneous efficiency

A.3.1 Method

☐ Outdoor steady-state conditions ☐ Indoor steady-state conditions

A.3.2 Schematic diagram of the test loop (attach separate page if necessary)

A.3.3 Schematic diagram of collector mounting (attach separate page if necessary)

Collector reference No.: ....

A.3.4 Test results, measured and derived data

Gross area: .... m^2

Absorber area: .... m^2

Latitude: ....

Longitude: ....

Collector tilt: .... degrees

Collector azimuth: ....

Heat transfer fluid: ....

Local time at solar noon: ....

Table A.1 — Test results, measured data

Date YYMMDD	**LT** h:min	G W/m^2	E_L W/m^2	t_a °C	t_{dp} °C	u m/s	t_{in} °C	$t_e - t_{in}$ K	$\dot{m}$ kg/s

Collector reference No.: ....

Table A.2 — Test results, derived data

Date YYMMDD	**LT** h:min	G'' W/m^2	c_f J/(kg K)	$\dot{Q}$ W	$\frac{t_{in} - t_a}{G''}$ m^2 K/W	η_A	η_G

Collector reference No.: ....

A.3.5 Instantaneous efficiency curve based on gross collector area and temperature of heat transfer fluid at collector inlet

The instantaneous efficiency is defined by: $\eta_G = \frac{\dot{Q}}{A_G G''}$

where

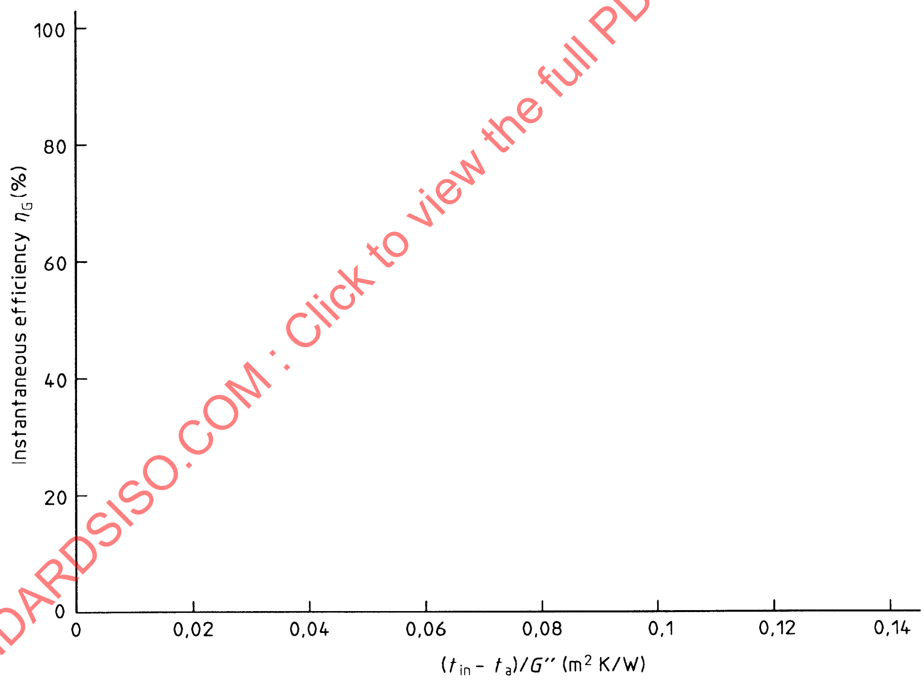
$G'' = G + \frac{\varepsilon}{\alpha}(E_L - \sigma T_a^4)$;

$\frac{\varepsilon}{\alpha}$ = ... (typically 1,0)

Gross collector area used for curve: .... m²

Fluid flowrate used for the tests: .... kg/s

Absorber area of the collector: .... m²



$$\eta_G = \eta_{0G} - (b_{1G} + b_{2G}u)\left(\frac{t_{in} - t_a}{G''}\right)$$

η_{0G} = ...

b_{1G} = ... W/(m² K)

b_{2G} = ... W s/(m³ K)

NOTE 7 Typical efficiency lines should be shown for surrounding air speed u = 1, 2, 4 m/s (only valid for operating temperatures above dew point temperature).

Collector reference No.: ....

A.3.6 Instantaneous efficiency curve based on absorber area and temperature of heat transfer fluid at collector inlet

The instantaneous efficiency is defined by: $\eta_A = \frac{\dot{Q}}{A_A G''}$

where

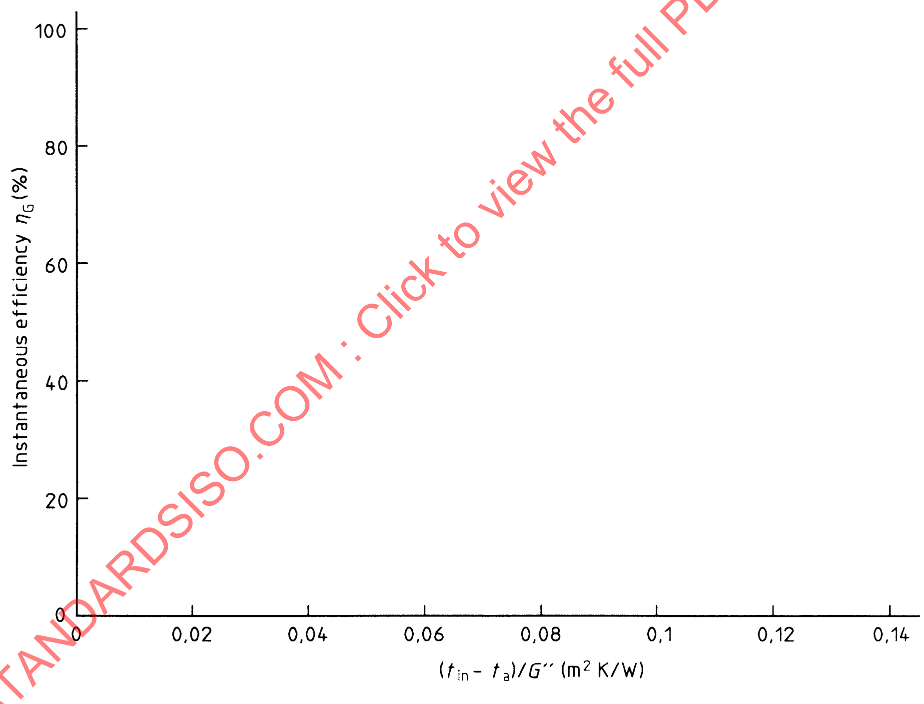
$$G'' = G + \frac{\varepsilon}{\alpha}(E_L - \sigma T_a^4);$$

$\frac{\varepsilon}{\alpha}$ = ... (typically 1,0)

Absorber area of the collector used for curve: .... m^2

Fluid flowrate used for the tests: .... kg/s

Gross collector area: .... m^2



$$\eta_A = \eta_{0A} - (b_{1A} + b_{2A}u)\left(\frac{t_{in} - t_a}{G''}\right)$$

η_{0A} = ...

b_{1A} = ... W/(m^2 K)

b_{2A} = ... W s/(m^3 K)

NOTE 8 Typical efficiency lines should be shown for surrounding air speed u = 1, 2, 4 m/s (only valid for operating temperatures above dew point temperature).

Collector reference No.: ....

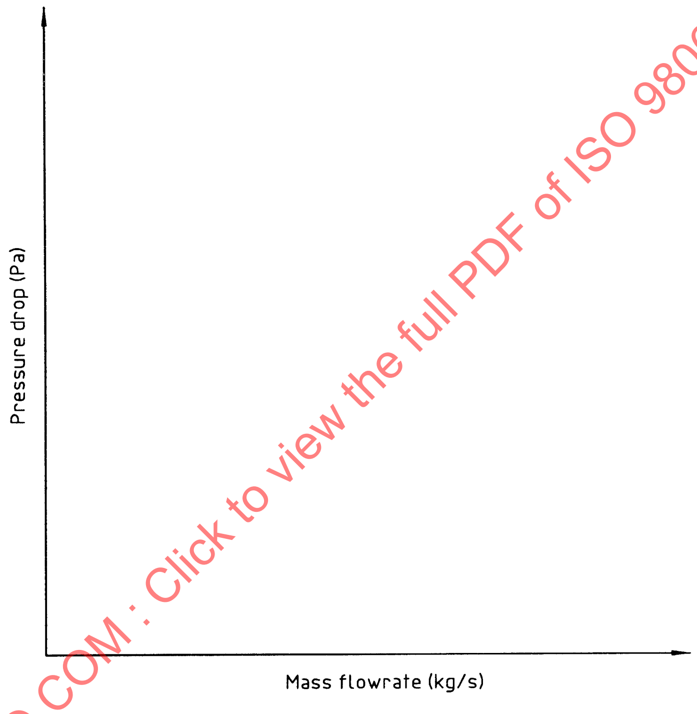
A.4 Pressure drop

Pressure drop is referred to: ☐ collector module

☐ per running metre of absorber

Fluid: ....

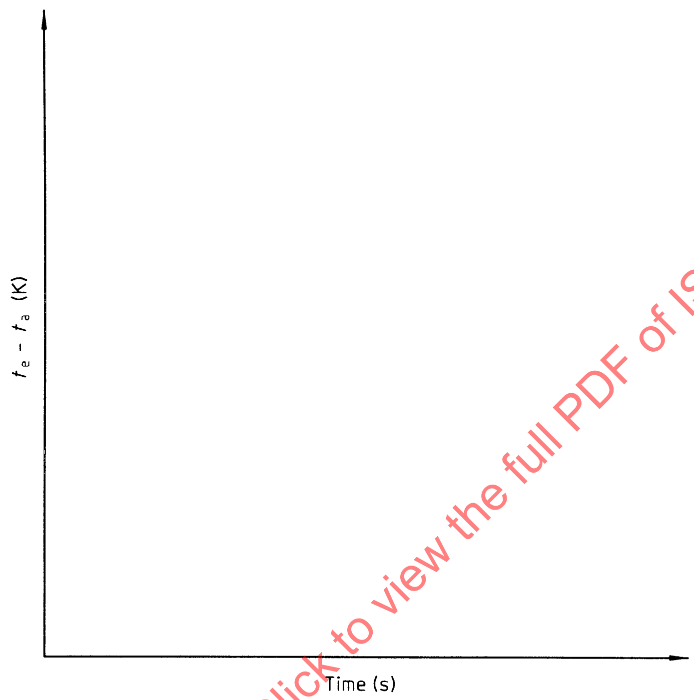
Temperature: .... °C



Collector reference No.: ....

A.5 Time constant

τ_c = ... s



A.6 Effective thermal capacity (calculated)

C = ... J/K

Annex B
(informative)

Collector incident angle modifier

B.1 Introduction

For solar beam incidence which is not near-normal, the efficiency η_0 in equation (5) can be replaced by $K_v\eta_0$, where K_v is the incident angle modifier.

$$\eta = K_v\eta_0 - U_L \frac{t_{in} - t_a}{G''} \qquad \text{... (B.1)}$$

Figure B.1 shows the typical variation in K_v with angle of incidence for an unglazed solar collector.

The significance of the incident angle modifier to the test procedures outlined herein is that the thermal efficiency values are determined for the collector at or near normal incidence conditions. Therefore, the y-axis intercept of the efficiency curve is equal to η_0. A separate measurement is conducted to determine the value of K_v so that the performance of the collector can be predicted under a wide range of conditions and/or time of day using equation (B.1).

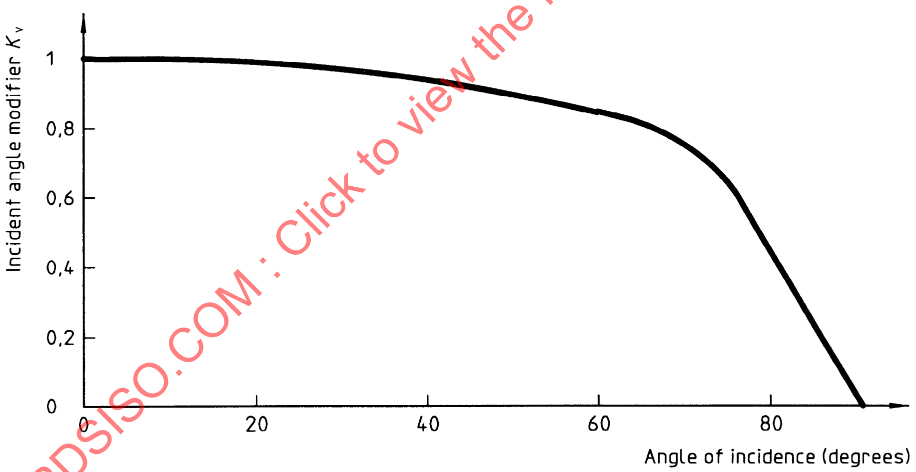


Figure B.1 — Typical incident angle modifiers

B.2 Experimental determination of collector incident angle modifier

Testing of a solar collector to determine its incident angle modifier can be done by one of two methods. During each test period, the orientation of the collector shall be such that the collector is maintained within ± 2,5° of the angle of incidence for which the test is being conducted.

B.2.1 Method 1

This method is applicable for testing indoors using a solar simulator, or outdoors using a movable test rack (alt-azimuth collector mount) so that the orientation of the collector can be adjusted with respect to the direction of the incident solar radiation.