

# Thermal solar systems and components — Solar collectors —

## Part 2: Test methods

The European Standard EN 12975-2:2006 has the status of a  
British Standard

ICS 27.160

# National foreword

This British Standard is the official English language version of EN 12975-2:2006. It supersedes BS EN 12975-2:2001 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee RHE/25, Solar heating, which has the responsibility to:

- aid enquirers to understand the text;
- present to the responsible international/European committee any enquiries on the interpretation, or proposals for change, and keep UK interests informed;
- monitor related international and European developments and promulgate them in the UK.

BSI committee RHE/25, Solar heating, would like to draw users attention to the fact that for solar collectors using absorbers that contain silicone rubber to enclose the fluid, the absorber should be tested in accordance with the requirements for organic materials.

A list of organizations represented on this committee can be obtained on request to its secretary.

## Cross-references

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## Summary of pages

This document comprises a front cover, an inside front cover, the EN title page, pages 2 to 140, an inside back cover and a back cover.

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This British Standard was published under the authority of the Standards Policy and Strategy Committee on 28 April 2006

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ISBN 0 580 48131 X

## Amendments issued since publication

| Amd. No. | Date     | Comments                        |
|----------|----------|---------------------------------|
| 16424    | May 2006 | Correction to national foreword |
|          |          |                                 |
|          |          |                                 |
|          |          |                                 |

English Version

## Thermal solar systems and components - Solar collectors - Part 2: Test methods

Installations solaires thermiques et leurs composants -  
Capteurs solaires - Partie 2 : Méthode d'essai

Thermische Solaranlagen und ihre Bauteile - Kollektoren -  
Teil 2: Prüfverfahren

This European Standard was approved by CEN on 6 February 2006.

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## Foreword

This European Standard (EN 12975-2:2006) has been prepared by Technical Committee CEN/TC 312 “Thermal solar systems and components”, the secretariat of which is held by ELOT.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by September 2006, and conflicting national standards shall be withdrawn at the latest by September 2006.

This European Standard supersedes EN 12975-2:2001.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and United Kingdom.

## Introduction

This standard specifies test methods for determining the ability of a liquid heating solar collector to resist the influence of degrading agents. It defines procedures for testing collectors under well-defined and repeatable conditions.

This standard also provides test methods and calculation procedures for determining the steady-state and quasi-dynamic thermal performance of glazed liquid heating solar collectors. It contains methods for conducting tests outdoors under natural solar irradiance and natural and simulated wind and for conducting tests indoors under simulated solar irradiance and wind.

This standard also provides methods for determining the thermal performance of unglazed liquid heating solar collectors. Unglazed collectors are in most cases used for heating swimming pools or other low temperature consumers. In general the collectors are put together on-site, connecting absorber strips with manifolds. Real absorber areas are mostly between ten to one hundred square meters. For unglazed absorbers, readily fabricated modules with a specific size are seldom used. Therefore, during the test, it should be checked that a realistic flow pattern and flow velocity is used.

This standard also provides test methods and calculation procedures for determining the steady-state as well as the all-day thermal performance parameters for liquid heating solar collectors, under changing weather conditions. It contains methods for conducting tests outdoors during whole days and under stationary inlet temperature conditions and natural solar irradiance and natural and/or simulated wind conditions. Important effects for the all-day performance of the collector, as the dependence on incident angle, wind speed, diffuse fraction of solar irradiance, thermal sky radiation and thermal capacity are taken into account. Dependence on flowrate is not included in this standard.

Some of the advantages of the proposed extension of the present steady-state test methods of all-day testing are:

- shorter and less expensive outdoor test, suitable for European climate conditions.
- much wider range of collectors can be tested with the same method.
- at the same time, a much more complete characterisation of the collector is achieved.
- collector model is still directly compatible with that of the present basic test standards, and only correction terms are applied in this extended approach.
- all additions are based on long agreed collector theory.
- at any time, full backwards comparability to steady-state can be established by evaluating only periods of the test days that correspond to steady-state test requirements.
- same test equipment can be used as for stationary testing with only minor changes, which will also improve the accuracy of steady-state testing.
- commonly available standard PC software can be used for the parameter identification, such as spreadsheets or more advanced statistical packages that have Multiple Linear Regression (MLR) as an option.

## 1 Scope

This European Standard specifies test methods for validating the durability, reliability and safety requirements for liquid heating collectors as specified in EN 12975-1. This standard also includes three test methods for the thermal performance characterisation for liquid heating collectors.

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

It is basically applicable to tracking concentrating collectors, thermal performance testing as given in 6.3 (quasi dynamic testing) is also applicable to most concentrating collector designs, from stationary non-imaging concentrators as CPCs to high concentrating tracking designs. Parts of the solar radiation measurement should be adjusted in case of a tracking collector and in case a pyrheliometer is used to measure beam radiation.

Collectors that are custom built (built in; e.g. roof integrated collectors that do not compose of factory made modules and are assembled directly on the place of installation) cannot be tested in their actual form for durability, reliability and thermal performance according to this standard. Instead, a module with the same structure as the ready collector may be tested. The module gross area should be at least 2 m<sup>2</sup>. The test is valid only for larger collectors than the tested module.

## 2 Normative references

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

EN 1991 (all parts), *Eurocode 1: Actions on structures*

EN 12975-1:2006, *Thermal solar systems and components – Solar collectors – Part 1: General requirements*

EN ISO 9488, *Solar energy – Vocabulary (ISO 9488:1999)*

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

## 3 Terms and definitions

For the purposes of this European Standard, the terms and definitions given in EN ISO 9488 apply.

## 4 Symbols and units

|           |                                                             |                  |
|-----------|-------------------------------------------------------------|------------------|
| $a_1$     | heat loss coefficient at $(T_m - T_a)=0$                    | $Wm^{-2}K^{-1}$  |
| $a_2$     | temperature dependence of the heat loss coefficient         | $Wm^{-2}K^{-2}$  |
| $A_A$     | absorber area of collector                                  | $m^2$            |
| $A_a$     | aperture area of collector                                  | $m^2$            |
| $A_G$     | gross area of collector                                     | $m^2$            |
| $AM$      | optical air mass                                            |                  |
| $b_u$     | collector efficiency coefficient (wind dependence)          | $m^{-1} s$       |
| $b_o$     | constant for the calculation of the incident angle modifier |                  |
| $b_1$     | heat loss coefficient at $(T_m - T_a)=0$                    | $Wm^{-2}K^{-1}$  |
| $b_2$     | collector efficiency coefficient                            | $Wsm^{-3}K^{-1}$ |
| $c_1$     | heat loss coefficient at $(T_m - T_a)=0$                    | $Wm^{-2}K^{-1}$  |
| $c_2$     | temperature dependence of the heat loss coefficient         | $Wm^{-2}K^{-2}$  |
| $c_3$     | wind speed dependence of the heat loss coefficient          | $Jm^{-3}K^{-1}$  |
| $c_4$     | sky temperature dependence of the heat loss coefficient     | $Wm^{-2}K^{-1}$  |
| $c_5$     | effective thermal capacity                                  | $J m^{-2}K^{-1}$ |
| $c_6$     | wind dependence in the zero loss efficiency                 | $sm^{-1}$        |
| $c_f$     | specific heat capacity of heat transfer fluid               | $Jkg^{-1}K^{-1}$ |
| $C$       | effective thermal capacity of collector                     | $JK^{-1}$        |
| $D$       | date                                                        | YYMMDD           |
| $E_L$     | longwave irradiance ( $\lambda > 3\mu m$ )                  | $Wm^{-2}$        |
| $E_\beta$ | longwave irradiance on an inclined surface outdoors         | $Wm^{-2}$        |
| $E_s$     | longwave irradiance                                         | $Wm^{-2}$        |
| $F$       | radiation view factor                                       |                  |
| $F'$      | collector efficiency factor                                 |                  |
| $G$       | hemispherical solar irradiance                              | $Wm^{-2}$        |
| $G^*$     | global hemispherical solar irradiance                       | $Wm^{-2}$        |
| $G''$     | net irradiance                                              | $Wm^{-2}$        |
| $G_b$     | direct solar irradiance (beam irradiance)                   | $Wm^{-2}$        |

|                |                                                                                           |                               |
|----------------|-------------------------------------------------------------------------------------------|-------------------------------|
| $G_d$          | diffuse solar irradiance                                                                  | $\text{Wm}^{-2}$              |
| $LT$           | local time                                                                                | h                             |
| $K_\theta$     | incidence angle modifier                                                                  |                               |
| $K_{\theta b}$ | incidence angle modifier for direct radiation                                             |                               |
| $K_{\theta d}$ | incidence angle modifier for diffuse radiation                                            |                               |
| $m$            | thermally active mass of the collector                                                    | kg                            |
| $\dot{m}$      | mass flowrate of heat transfer fluid                                                      | $\text{kg s}^{-1}$            |
| $\dot{Q}$      | useful power extracted from collector                                                     | W                             |
| $\dot{Q}_L$    | power loss of collector                                                                   | W                             |
| SF             | safety factor                                                                             |                               |
| $t$            | time                                                                                      | s                             |
| $t_a$          | ambient or surrounding air temperature                                                    | $^{\circ}\text{C}$            |
| $t_{dp}$       | atmospheric dew point temperature                                                         | $^{\circ}\text{C}$            |
| $t_e$          | collector outlet (exit) temperature                                                       | $^{\circ}\text{C}$            |
| $t_{in}$       | collector inlet temperature                                                               | $^{\circ}\text{C}$            |
| $t_m$          | mean temperature of heat transfer fluid                                                   | $^{\circ}\text{C}$            |
| $t_s$          | atmospheric or sky temperature                                                            | $^{\circ}\text{C}$            |
| $t_{stg}$      | stagnation temperature                                                                    | $^{\circ}\text{C}$            |
| $T$            | absolute temperature                                                                      | K                             |
| $T_a$          | ambient or surrounding air temperature                                                    | $^{\circ}\text{C}$            |
| $T_m^*$        | reduced temperature difference ( = $(t_m - t_a)/G^*$ )                                    | $\text{m}^2\text{KW}^{-1}$    |
| $T_s$          | atmospheric or equivalent sky radiation temperature                                       | K                             |
| $U$            | measured overall heat loss coefficient of collector,<br>with reference to $T_m^*$         | $\text{Wm}^{-2}\text{K}^{-1}$ |
| $U_L$          | overall heat loss coefficient of a collector with uni-<br>form absorber temperature $t_m$ | $\text{Wm}^{-2}\text{K}^{-1}$ |
| $u$            | surrounding air speed                                                                     | $\text{ms}^{-1}$              |

|                          |                                                                                                          |                   |
|--------------------------|----------------------------------------------------------------------------------------------------------|-------------------|
| $V_f$                    | fluid capacity of the collector                                                                          | $m^3$             |
| $\Delta p$               | pressure difference between fluid inlet and outlet                                                       | Pa                |
| $\Delta t$               | time interval                                                                                            | s                 |
| $\Delta T$               | temperature difference between fluid outlet and inlet ( $t_e - t_{in}$ )                                 | K                 |
| $\alpha$                 | solar absorptance                                                                                        |                   |
| $\beta$                  | tilt angle of a plane with respect to horizontal                                                         | degrees           |
| $\gamma$                 | azimuth angle                                                                                            | degrees           |
| $\varepsilon$            | hemispherical emittance                                                                                  |                   |
| $\omega$                 | solar hour angle                                                                                         | degrees           |
| $\theta$                 | angle of incidence                                                                                       | degrees           |
| $\Phi$                   | latitude                                                                                                 | degrees           |
| $\lambda$                | wavelength                                                                                               | $\mu m$           |
| $\eta$                   | collector efficiency, with reference to $T_m^*$                                                          |                   |
| $\eta_0$                 | zero-loss collector efficiency ( $\eta$ at $T_m^* = 0$ ), reference to $T_m^*$                           |                   |
| $\sigma$                 | Stefan-Boltzmann constant                                                                                | $W m^{-2} K^{-4}$ |
| $\rho$                   | density of heat transfer fluid                                                                           | $kg m^{-3}$       |
| $\tau_c$                 | collector time constant                                                                                  | s                 |
| $\tau$                   | transmittance                                                                                            |                   |
| $(\tau\alpha)_e$         | effective transmittance-absorptance product                                                              |                   |
| $(\tau\alpha)_{ed}$      | effective transmittance-absorptance product for<br>diffuse solar irradiance                              |                   |
| $(\tau\alpha)_{en}$      | effective transmittance-absorptance product for<br>direct solar radiation at normal incidence            |                   |
| $(\tau\alpha)_{e\theta}$ | effective transmittance-absorptance product for<br>direct solar radiation at angle of incidence $\theta$ |                   |

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

NOTE 2  $C$  is often denoted  $(mC)_e$  in basic literature (see also Annex F)

NOTE 3 For more information about thermal performance coefficients (parameters)  $c_1$  to  $c_6$ , see Annex F.

## **5 Reliability testing of liquid heating collectors**

### **5.1 General**

The details regarding the number of collectors and sequences used to carry out the qualifications tests detailed in the list below (Table 1) shall be given in the report.

For some qualification tests, a part of the collector may have to be tampered with in some way, for example a hole may have to be drilled in the back of the collector to attach a temperature sensor to the absorber. In these cases care should be taken to ensure that any damage caused does not affect the results of subsequent qualification tests, for example by allowing water to enter into a previously raintight collector.

Table 1 - Test List

| Subclause                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Test                                        |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------|
| 5.2                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | Internal pressure                           |
| 5.3                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | High-temperature resistance <sup>a, b</sup> |
| 5.4                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | Exposure <sup>b</sup>                       |
| 5.5                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | External thermal shock <sup>c</sup>         |
| 5.6                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | Internal thermal shock <sup>c</sup>         |
| 5.7                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | Rain penetration <sup>d</sup>               |
| 5.8                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | Freeze resistance <sup>e</sup>              |
| 5.9                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | Mechanical load                             |
| 5.10                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | Impact resistance (optional test)           |
| 6.1-6.2-6.3                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | Thermal performance <sup>f</sup>            |
| <p><sup>a</sup> For organic absorbers, the high-temperature resistance test shall be performed first in order to determine the collector stagnation temperature needed for the internal pressure test.</p> <p><sup>b</sup> The high temperature and exposure test shall be carried out on the same collector</p> <p><sup>c</sup> The external and internal thermal shock tests may be combined with the exposure test or the high-temperature resistance test.</p> <p><sup>d</sup> The rain penetration test shall be carried out only for glazed collectors.</p> <p><sup>e</sup> The freeze resistance test shall be carried out only for collectors claimed to be freeze resistant.</p> <p><sup>f</sup> The Thermal performance test shall be carried out on a collector that had not been used for other tests.</p> |                                             |

NOTE Regarding the durability and reliability of elastic materials it is recommended to refer to ISO 9808 and ISO 9553.

## 5.2 Internal pressure tests for absorbers

### 5.2.1 Inorganic absorbers

#### 5.2.1.1 Objective

The absorber shall be pressure-tested to assess the extent to which it can withstand the pressures which it might meet in service.

#### 5.2.1.2 Apparatus and procedure

The apparatus, shown in Figure A.1, consists of a hydraulic pressure source (electrical pump or hand pump), a safety valve, an air-bleed valve and a pressure gauge with a standard uncertainty better than 5 %. The air-bleed valve shall be used to empty the absorber of air before pressurisation. The inorganic absorber shall be filled with water at room temperature and pressurised to the test pressure for the test period (see 5.2.1.3.2). This pressure shall be maintained while the absorber is inspected for swelling, distortion or ruptures.

#### 5.2.1.3 Test conditions

##### 5.2.1.3.1 Temperature

Inorganic absorbers shall be pressure-tested (see 5.2.1.3.2) at ambient temperature within the range 5 °C to 30 °C.

##### 5.2.1.3.2 Pressure

The test pressure shall be 1,5 times the maximum collector operating pressure specified by the manufacturer.

The test pressure shall be maintained for 15 min.

##### 5.2.1.4 Results

The collector shall be inspected for leakage, swelling and distortion. The results of this inspection shall be reported together with the values of pressure and temperature used and the duration of the test.

#### 5.2.2 Absorbers made of organic materials (plastics or elastomers)

##### 5.2.2.1 Objective

The absorber shall be pressure-tested (see 5.2.1.3.2) to assess the extent to which it can withstand the pressures which it might meet in service while operating at elevated temperature. The tests shall be carried out at elevated temperatures, because the pressure resistance of an organic absorber may be adversely affected as its temperature is increased. One of the methods described in 5.2.2.2.2 through 5.2.2.2.4 may be chosen.

##### 5.2.2.2 Apparatus and procedure

###### 5.2.2.2.1 General

The apparatus consists of either a hydraulic or a pneumatic pressure source, and a means of heating the absorber to the required test temperature.

The characteristics of a solar irradiance simulator shall be the same as those of the simulator used for efficiency testing of liquid heating solar collectors.

A temperature sensor shall be attached to the absorber to monitor its temperature during the test. The sensor shall be positioned at two-thirds of the absorber height and half the absorber width. It shall be fixed firmly in a position to ensure good thermal contact with the absorber. The sensor shall be shielded from solar radiation.

The test conditions specified in 5.2.2.3 shall be maintained for at least 30 min prior to test and for the full duration of the test.

The pressure in the absorber shall be raised in stages as specified in 5.2.2.3, and the absorber shall be inspected for swelling, distortion or rupture after each increase in pressure. The pressure shall be maintained while the absorber is being inspected.

For safety reasons, the collector shall be encased in a transparent box to protect personnel in the event of explosive failure during this test.

One of the methods described in 5.2.2.2.2 through 5.2.2.2.4 may be chosen.

#### **5.2.2.2.2 Organic absorbers for use in unglazed collectors (test temperature < 90 °C)**

Where the maximum test temperature is below 90 °C, absorbers may be submerged in a heated water bath and pressure-tested. The pressurised fluid supply to the absorber shall be fitted with a safety valve, air-bleed valve (if required) and pressure gauge having a standard uncertainty better than 5 %. The apparatus is shown in Figure A.2.

#### **5.2.2.2.3 Organic absorbers for use with oil-based fluids (test temperature > 90 °C)**

When the test temperature exceeds 90 °C, the absorber may be connected to a hot oil circuit. The absorber and hot oil circuit are then pressurised. The hot oil circuit shall be fitted with a safety valve, air-bleed valve and pressure gauge having a standard uncertainty better than 5 %.

The absorber may be heated by any of the following methods:

- a) connecting a heater in the oil circuit (see Figure A.3);
- b) heating the whole collector in a solar irradiance simulator (see Figure A.4);
- c) heating the whole collector outdoors under natural solar irradiance (see Figure A.4).

Safety measures should be taken to protect personnel from hot oil in the event of explosive failure during this test.

#### **5.2.2.2.4 Organic absorbers - high temperature pneumatic pressure test**

The absorber may be pressure-tested using compressed air, when heated by either of the following methods:

- a) heating the whole collector in a solar irradiance simulator (see Figure A.5);
- b) heating the whole collector outdoors under natural solar irradiance (see Figure A.5).

The compressed air supply to the absorber shall be fitted with a safety valve and a pressure gauge having a standard uncertainty better than 5 %.

### **5.2.2.3 Test conditions**

#### **5.2.2.3.1 Temperature**

For absorbers made of organic materials, the test temperature shall be the maximum temperature which the absorber will reach under stagnation conditions.

The reference conditions given in Table 2 shall be used.

The calculations employed to determine the test temperature are included in Annex C and shall either:

- use measured collector performance characteristics, or
- extrapolate from average values, measured in the high-temperature resistance test (see 5.3.3), of the global solar irradiance (natural or simulated) on the collector plane, the surrounding air temperature and the absorber temperature.

**Table 2 - Climate reference conditions to determine test temperatures for internal pressure test of organic absorbers**

| Climate parameter                                                 | Value for all climate classes |
|-------------------------------------------------------------------|-------------------------------|
| Global solar irradiance on collector plane, $G$ in $\text{W/m}^2$ | 1000                          |
| Surrounding air temperature, $t_a$ in $^{\circ}\text{C}$          | 30                            |

#### **5.2.2.3.2 Pressure**

The test pressure shall be 1,5 times the maximum collector operating pressure specified by the manufacturer.

For absorbers made of organic materials, the pressure shall be raised to the test pressure in equal stages of 20 kPa (approximately) and maintained at each intermediate pressure for 5 min. The test pressure shall then be maintained for a least 1 h.

#### **5.2.2.4 Results**

The collector shall be inspected for leakage, swelling and distortion. The results of the inspection shall be reported.

Full details of the test procedure used, including the temperature, intermediate pressures and test periods used, shall be reported with the test results.

### **5.3 High-temperature resistance test**

#### **5.3.1 Objective**

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

#### **5.3.2 Apparatus and procedure**

The collector shall be tested outdoors, or in a solar irradiance simulator. A schema for testing is shown in Figure A.6.

The characteristics of the solar irradiance simulator to be used for the high-temperature resistance test shall be those of the solar irradiance simulator used for efficiency testing of liquid heating solar collectors.

The collector shall be mounted outdoors or in a solar simulator, and shall not be filled with fluid. All of the fluid pipes except for one shall be sealed to prevent cooling by natural circulation of air.

A temperature sensor shall be attached to the absorber to monitor its temperature during the test. The sensor shall be positioned at two-thirds of the absorber height and half the absorber width. It shall be fixed firmly in a position to ensure good thermal contact with the absorber. The sensor shall be shielded from solar radiation.

NOTE 1 When testing collectors, such as evacuated tubular collectors, for which it is not appropriate to measure the stagnation temperature at the absorber, the temperature sensor should be placed at a suitable location in the collector, and this location should be clearly described with the test results.

NOTE 2 In some cases, such as evacuated collectors, it may be difficult to attach a thermocouple to the absorber. In such cases, instead of attaching a thermocouple to the absorber, the testing laboratory may partially fill the absorber with a special fluid, seal the absorber and measure the temperature of the fluid directly or measure the pressure in the absorber. The relationship between the internal pressure in the absorber and its temperature should be known from the standard vapour pressure/temperature relationship for the fluid.

NOTE 3 It is recommended to perform the determination of the stagnation temperature together with the high-temperature resistance test.

The test shall be performed for a minimum of 1 h after steady-state conditions have been established, and the collector shall be subsequently inspected for signs of damage as specified in 5.3.4.

### 5.3.3 Test conditions

The set of reference conditions given in Table 3 or conditions resulting in the same collector temperature according to Equation C.1, shall be used for all climate classes.

**Table 3 - Climate reference conditions for high-temperature resistance test**

| Climate parameter                                                 | Value for all climate classes |
|-------------------------------------------------------------------|-------------------------------|
| Global solar irradiance on collector plane, $G$ in $\text{W/m}^2$ | >1000                         |
| Surrounding air temperature, $t_a$ in $^{\circ}\text{C}$          | 20 - 40                       |
| Surrounding air speed in m/s                                      | < 1                           |

### 5.3.4 Results

The collector shall be inspected for degradation, shrinkage, outgassing and distortion.

The results of the inspection shall be recorded together with the average values of solar irradiance (natural or simulated) on the collector plane, surrounding air temperature and speed, and absorber temperature (and the pressure of the special fluid in the absorber, if that method is used) recorded during the test.

## 5.4 Exposure test

### 5.4.1 Objective

The exposure test provides a low-cost reliability test sequence, indicating (or simulating) operating conditions which are likely to occur during real service and also allows the collector to "settle", such that subsequent qualification tests are more likely to give repeatable results.

### 5.4.2 Apparatus and procedure

The collector shall be mounted outdoors (see Figure A.7), but not filled with fluid. All except one of the fluid pipes shall be sealed to prevent cooling by natural circulation of air. One shall be left open to permit free expansion of air in the absorber.

The air temperature shall be recorded to a standard uncertainty of 1 K and the global irradiance on the plane of the collector recorded using a pyranometer of class I or better in accordance with ISO 9060. Irradiation and mean air temperature values shall be recorded at least every 5 min and rainfall shall be recorded daily. The collector shall be exposed until the test conditions have been met.

At the end of the exposure, a visual inspection shall be made for signs of damage as specified in 5.4.4.

### 5.4.3 Test conditions

The set of reference conditions given in Table 4 shall be used.

The collector shall be exposed until at least 30 days (which need not be consecutive) have passed with the minimum irradiation  $H$  shown in Table 4. The irradiation is determined by recording irradiance measurements using a pyranometer.

The collector shall also be exposed for at least 30 h to the minimum irradiance level  $G$  given in Table 4, as recorded by a pyranometer, when the surrounding air temperature is greater than the value shown in Table 4 or conditions resulting in the same collector temperature according to Equation C.1. These hours shall be made up of periods of at least 30 min.

**NOTE** In regions where these conditions cannot be met during certain periods of the year, the 30-h exposure to high irradiance levels (Table 4) can be conducted in a solar irradiance simulator having characteristics identical to those of a simulator used for efficiency testing of liquid heating solar collectors. The 30-h exposure test should be conducted after the collector has completed at least 10 days, but no more than 15 days, of the exposure to the minimum irradiation level (Table 4).

If the external and internal thermal shock tests are combined with the exposure test, the first external and internal shocks shall be caused during the first 10 of the 30 h defined above, and the second during the last 10 of the 30 h.

**Table 4 - Climate reference conditions for exposure test as well as for external and internal thermal shock tests**

| Climate parameter                                                   | Value for all climate classes |
|---------------------------------------------------------------------|-------------------------------|
| Global solar irradiance on collector plane, $G$ in $\text{W/m}^2$   | 850                           |
| Global daily irradiation on collector plane, $H$ in $\text{MJ/m}^2$ | 14                            |
| Surrounding air temperature, $t_a$ in $^{\circ}\text{C}$            | 10                            |
| NOTE Values given are minimum values for testing.                   |                               |

### 5.4.4 Results

The collector shall be inspected for damage or degradation. The results of the inspection shall be reported together with a record of the climatic conditions during the test, including daily irradiation, surrounding air temperature and rain.

## 5.5 External thermal shock test

### 5.5.1 Objective

Collectors may from time to time be exposed to sudden rainstorms on hot sunny days, causing a severe external thermal shock. This test is intended to assess the capability of a collector to withstand such thermal shocks without a failure.

### 5.5.2 Apparatus and procedure

The collector shall be mounted either outdoors or in a solar irradiance simulator, but shall not be filled with fluid. All except one of the fluid pipes shall be sealed to prevent cooling by natural circulation of air. One shall be left open to permit free expansion of air in the absorber (see Figure A.8).

A temperature sensor may be optionally attached to the absorber to monitor its temperature during the test. The sensor shall be positioned at two-thirds of the absorber height and half the absorber width. It shall be fixed firmly in a position to ensure good thermal contact with the absorber. The sensor shall be shielded from solar radiation.

NOTE 1 When testing collectors, such as evacuated tubular collectors, for which it is not appropriate to measure the stagnation temperature at the absorber, the temperature sensor should be placed at a suitable location in the collector, and this location should be clearly described with the test results.

NOTE 2 In some cases, such as evacuated collectors, it may be difficult to attach a thermocouple to the absorber. In such cases, instead of attaching a thermocouple to the absorber, the testing laboratory may partially fill the absorber with a special fluid, seal the absorber and measure the pressure in the absorber. The relationship between the internal pressure in the absorber and its temperature should be known from the standard vapour pressure/temperature relationship for the fluid.

An array of water jets shall be arranged to provide a uniform spray of water over the collector.

The collector shall be maintained under a high level of solar irradiance for a period of 1 h before the water spray is turned on. It is then cooled by the water spray for 15 min before being inspected.

The collector shall be subjected to two external thermal shocks.

### 5.5.3 Test conditions

The set of reference conditions given in Table 4 shall be used.

The specified operating conditions shall be:

- solar (or simulated solar) irradiance  $G$  greater than the value shown in Table 4.
- surrounding air temperature  $t_a$  greater than the value shown in Table 4.

Or conditions resulting in the same collector temperature according to Equation C.1

The water spray shall have a temperature of less than 25 °C and a flowrate in the range 0,03 kg/s to 0,05 kg/s per square metre of collector aperture.

If the temperature of the water which first cools the collector is likely to be greater than 25 °C (for example if the water has been sitting in a pipe in the sun for some time), then the water shall be diverted until it has reached a temperature of less than 25 °C before being directed over the collector.

#### 5.5.4 Results

The collector shall be inspected for any cracking, distortion, condensation, water penetration or loss of vacuum. The results of the inspection shall be reported. The measured values of solar irradiance, surrounding air temperature, absorber temperature (if measured), water temperature and water flowrate shall also be reported.

### 5.6 Internal thermal shock test

#### 5.6.1 Objective

Collectors may from time to time be exposed to a sudden intake of cold heat transfer fluid on hot sunny days, causing a severe internal thermal shock, for example, after a period of shutdown, when the installation is brought back into operation while the collector is at its stagnation temperature. This test is intended to assess the capability of a collector to withstand such thermal shocks without failure.

#### 5.6.2 Apparatus and procedure

The collector shall be mounted either outdoors or in a solar irradiance simulator (see Figure A.9), but shall not be filled with fluid. One of its fluid pipes shall be connected via a shutoff valve to the heat transfer fluid source and the other shall be left open initially to permit the free expansion of air in the absorber and also to permit the heat transfer fluid to leave the absorber (and be collected). If the collector has more than two fluid pipes, the remaining openings shall be sealed in a way that ensures the designed flow pattern within the collector.

A temperature sensor may be optionally attached to the absorber to monitor its temperature during the test. The sensor shall be positioned at two-thirds of the absorber height and half the absorber width. It shall be fixed firmly in a position to ensure good thermal contact with the absorber. The sensor shall be shielded from solar radiation.

NOTE 1 When testing collectors, such as evacuated tubular collectors, for which it is not appropriate to measure the stagnation temperature at the absorber, the temperature sensor should be placed at a suitable location in the collector, and this location should be clearly described with the test results.

NOTE 2 In some cases, such as evacuated collectors, it may be difficult to attach a thermocouple to the absorber. In such cases, instead of attaching a thermocouple to the absorber, the testing laboratory may partially fill the absorber with a special fluid, seal the absorber and measure the pressure in the absorber. The relationship between the internal pressure in the absorber and its temperature should be known from the standard vapour pressure/temperature relationship for the fluid.

The collector shall be maintained under a high level of solar irradiance for a period of 1 h before it is cooled by supplying it with heat transfer fluid for at least 5 min or until the absorber temperature drops below 50 °C.

The collector shall be subjected to two internal thermal shocks.

#### 5.6.3 Test conditions

The set of reference conditions given in Table 4 shall be used.

The specified operating conditions shall be:

- solar (or simulated solar) irradiance  $G$  greater than the value shown in Table 4;

- surrounding air temperature  $t_a$  greater than the value shown in Table 4.

or conditions resulting in the same collector temperature according to Equation C.1

The heat transfer fluid shall have a temperature of less than 25 °C. The recommended fluid flowrate is at least 0,02 kg/s per square metre of collector aperture (unless otherwise specified by the manufacturer).

#### 5.6.4 Results

The collector shall be inspected for any cracking, distortion, deformation, water penetration or loss of vacuum. The results of the inspection shall be reported. The measured values of solar irradiance, surrounding air temperature, absorber temperature (if measured), heat transfer fluid temperature and heat transfer fluid flowrate shall also be reported.

### 5.7 Rain penetration test

#### 5.7.1 Objective

This test is applicable only for glazed collectors and is intended to assess the extent to which glazed collectors are substantially resistant to rain penetration. They shall normally not permit the entry of either free-falling rain or driving rain. Collectors may have ventilation holes and drain holes, but these shall not permit the entry of drifting rain.

#### 5.7.2 Apparatus and procedure

##### 5.7.2.1 General

The collector shall have its fluid inlet and outlet pipes sealed (unless hot water is circulated through the absorber, see 5.7.2.2), as shown in Figure A.10, and be placed in a test rig at the shallowest angle to the horizontal recommended by the manufacturer. If this angle is not specified, then the collector shall be placed at a tilt of 30° to the horizontal. Collectors designed to be integrated into a roof structure shall be mounted in a simulated roof and have their underside protected. Other collectors shall be mounted in a conventional manner on an open frame or a simulated roof.

The collector shall be sprayed on exposed sides, using spray nozzles or showers.

##### 5.7.2.2 Detection of ingress of water

The collector shall be mounted and sprayed as explained above while the absorber in the collector is kept warm (minimum 50 °C). This can be done either by circulating hot water at about 50 °C through the absorber or by exposing the collector to solar radiation. The penetration of water into the collector shall be determined by inspection (looking for water droplets, condensation on the cover glass or other visible signs) and by one of the following methods:

- a) by weighing the collector (standard uncertainty better than 5 g/m<sup>2</sup> collector area); or
- b) by means of humidity measurement (standard uncertainty better than 5 %) or
- c) by means of measuring the condensation level.

The heating up of the collector should be started before the spraying of the water in order to ensure that the collector box is dry before testing.

In cases of collectors having wood in the backs (or other special cases), the laboratory shall take all necessary measures during the conduction of the test so that the final result will not be influenced or altered by the special construction of the collector.

### 5.7.3 Test conditions

The collector shall be sprayed with water at a temperature lower than 30 °C with a flowrate of more than 0,05 kg/s per square metre of sprayed area. The duration of the test shall be 4 h.

#### 5.7.3.1 Weighing method

If the weighing method is chosen, the collector shall be put on the scale before the start of the test on three consecutive occasions. The weights recorded shall not vary by more than  $\pm 5 \text{ g/m}^2$  collector area.

#### 5.7.3.2 Humidity measurement method

When measuring the penetration of water into the collector by means of humidity measurement, an absolute humidity sensor is placed in the air gap between absorber and glazing. Collector and sensor are connected to a hot fluid loop for at least five hours before the rain is switched on in order to stabilise. When testing outdoors, in order to minimize disturbances of the measurement, the collector shall be shaded during the whole test. The humidity shall be monitored from five hours before the raining till at least five hours after the raining. Ingress of water might also be detected at a later stage, during the "Final Inspection" (5.11).

#### 5.7.3.3 Condensation level method

If the condensation level method is chosen, the penetration of water is determined by measuring the condensation level on the cover glass and by measuring the water that comes out of the collector when tipping it.

The heating of the collector shall be started at least 30 min before the spraying of water and shall continue until it can be ensured that the collector box is dry before testing. This shall be done by circulating hot water (or other fluid) above 50 °C through the absorber before but also during the complete test. The water will thereafter condense on the inside of the glazing, which is being cooled by cold water on the outside. After 2 h an intermediate inspection of condensation on the cover glass shall be done in order to facilitate the reporting of the places where water penetrates.

After finishing the spraying the inspection of condensation should be done after a short time for ventilating, in order to distinguish collectors with good ventilation qualifications that are without accumulation of humidity inside the collector. However, the inspection should be done within one minute after finishing the spraying before the collector will make any temperature changes.

### 5.7.4 Results

The collector shall be inspected for water penetration. The results of the inspection, i.e. the extension of water penetration and the places where water penetrated shall be reported.

## 5.8 Freeze resistance test

### 5.8.1 Objective

This test is intended to assess the extent to which water heating collectors which are claimed to be freeze resistant can withstand freezing, and freeze/thaw cycling. This test is not intended for use with collectors for which it is clearly stated in the installation manual that they may only be used with an antifreeze fluid.

Two test procedures are recommended:

- one for collectors which are claimed to be freeze-resistant when filled with water, and
- one for collectors which are claimed to resist freezing after being drained.

## 5.8.2 Apparatus and procedure

### 5.8.2.1 Freeze-resistant collectors

For collectors which are claimed to be able to withstand freezing, the collector shall be mounted in a cold chamber (see Figure A.11). The collector shall be fitted correctly, shut completely and inclined at the shallowest angle to the horizontal recommended by the manufacturer. If no angle is specified by the manufacturer, then the collector shall be inclined at an angle of 30° to the horizontal. Unglazed collectors shall be tested in a horizontal position unless this is excluded by the manufacturer. Next, the collector shall be filled with water at the operating pressure.

The cold-chamber temperature shall be cycled, and at the end of each cycle the collector shall be refilled with water at operating pressure.

The temperature of the water shall be monitored throughout the test.

### 5.8.2.2 Collectors with drain-down protection

For collectors which employ a drain-down system to protect them from freezing damage, the collector shall be mounted in a cold chamber (see Figure A.11). The collector shall be then inclined at the shallowest angle to the horizontal recommended by the manufacturer. If no angle is specified by the manufacturer, then the collector shall be inclined at an angle of 30° to the horizontal. Unglazed collectors shall be tested in a horizontal position unless this is excluded by the manufacturer. The collector shall be next filled with water, kept at operating pressure for 10 min and then drained using the device installed by the manufacturer.

If, 5 min after the start of the drain process, the amount of drained water from the collector corresponds to approximately 95 % of the total water which filled that collector, then in that case, no test in cold chamber is required.

The cold-chamber temperature shall be cycled.

The temperature shall be measured inside the absorber close to the inlet.

After the last cycle the collector shall be refilled with water at operating pressure.

## 5.8.3 Test conditions

The contents of the absorber shall be maintained at  $(-20 \pm 2) ^\circ\text{C}$  for at least 30 min during the freezing part of the cycle, and are raised to above 10 °C during the thawing part of the cycle. The duration of the thawing part of the cycle shall be at least 30 min.

The collector shall be subjected to three freeze-thaw cycles.

## 5.8.4 Results

The number of cycles carried out shall be reported. The collector shall be inspected for leakage, breakage, distortion and deformation. These shall be reported together with the absorber temperatures reached during the cycles and the times spent by the collector at the test temperatures. The tilt angle used for the test shall also be reported.

## 5.9 Mechanical load test

### 5.9.1 Positive pressure test of the collector

#### 5.9.1.1 Objective

This test is intended to assess the extent to which the transparent cover of the collector and the collector box are able to resist the positive pressure load due to the effect of wind and snow.

#### 5.9.1.2 Apparatus and procedure

The collector shall be placed horizontally on an even ground. On the collector a foil shall be laid and on the collector frame a wooden or metallic frame shall be placed, high enough to contain the required amount of gravel or similar material (see Figure A.12).

The gravel, preferably type 2-32 mm, shall be weighed in portions and distributed in the frame so that everywhere the same load is created (pay attention to the bending of the glass), until the desired height is reached.

The test can also be carried out installing the collector in accordance with 5.9.2.2 and loading the cover using suction cups, gravel or other suitable means (e.g. water).

As a further alternative, the necessary load may be created by applying an air pressure on the collector cover.

The load may also be created by applying a negative pressure on the collector cover. In this case, apparatus in accordance to EN 12211 can be used. However this method cannot be applied on all collector types.

#### 5.9.1.3 Test conditions

The test pressure shall be increased at maximum steps of 250 Pa until a failure occurs or up to the value specified by the manufacturer. The test pressure shall be at least 1000 Pa. A failure can be the destruction of the cover and also the permanent deformation of the collector box or the fixings.

**NOTE** A permanent deformation should be assigned to a load value, while it is completely relieved after every load increment of 250 Pa and the distortion is measured compared to the beginning of the test sequence. The value of an inadmissible permanent deformation amounts to max. 0,5 %. (Example: 10 mm distortions at 2 m length of collector frame).

#### 5.9.1.4 Results

The pressure at which any failure of the collector cover or the box or fixings occurs shall be reported together with details of the failure. If no failure occurs, then the maximum pressure which the collector sustained shall be reported.

The maximum positive pressure is the pressure reached before occurring a failure. The permissible positive pressure is the maximum pressure divided by the safety factor  $SF+ = 1,5$ :

$$F_{perm+} = F_{max+} / SF+ \text{ with } SF+ = 1,5$$

**NOTE** When the test is done with an on-roof mounting system the test results are also valid for the roof integrated mounting system.

## 5.9.2 Negative pressure test of the collector

### 5.9.2.1 Objective

This test is intended to assess the extent to which the fixings between the collector cover and collector box are able to resist uplift forces caused by the wind.

For the design of the statics of the mounting system the national and European Guidelines for Structural Planning according to EN 1991 have to be applied.

### 5.9.2.2 Apparatus and procedure

The collector shall be installed horizontally on a stiff frame by means of its mounting fixtures. The frame which secures the cover to the collector box shall not be restricted in any way.

A lifting force which is equivalent to the specified negative pressure load shall be applied evenly over the cover. The load shall be increased in steps up to the final test pressure. If the cover has not been loosened at the final pressure, then the pressure may be stepped up until failure occurs. The time between each pressure step shall be the time needed for the pressure to stabilise.

Either of two alternative methods may be used to apply pressure to the cover:

- Method (a): The load may be applied to the collector cover by means of a uniformly distributed set of suction cups (see Figure A.13).
- Method (b): For collectors which have an almost airtight collector box, the following procedure may be used to create a negative pressure on the cover (see Figure A.14). Two holes are made through the collector box into the airgap between the collector cover and absorber, and an air source and pressure gauge are connected to the collector airgap through these holes. A negative pressure on the cover is created by pressurising the collector box. For safety reasons the collector shall be encased in a transparent box to protect personnel in the event of failure during this test.

During the test, the collector shall be visually inspected and any deformations of the cover and its fixings reported. The collector shall be examined at the end of the test to see if there are any permanent deformations.

### 5.9.2.3 Test conditions

The test pressure shall be increased in steps of 250 Pa until a failure occurs or up the value specified by the manufacturer. The test pressure shall be at least 1000 Pa. A failure can be the destruction of the cover and also the permanent deformation of the collector box or the fixings.

**NOTE** A permanent deformation should be assigned to a load value, while it is completely relieved after every load increment of 250 Pa and the distortion is measured compared to the beginning of the test sequence. The value of an inadmissible permanent deformation amounts to max. 0,5 %. (Example: 10 mm distortions at 2 m length of collector frame).

### 5.9.2.4 Results

The pressure at which any failure of the collector cover or the box or fixings occurs shall be reported together with details of the failure. If no failure occurs, then the maximum pressure which the collector sustained shall be reported.

The maximum negative pressure is the pressure reached before occurring a failure. The permissible negative pressure is the maximum pressure divided by the safety factor  $SF = 2$ :

$$F_{\text{perm}} = F_{\text{max}} / \text{SF- with SF-} = 2$$

## 5.10 Impact resistance test (optional)

### 5.10.1 Objective

This test is intended to assess the extent to which a collector can withstand the effects of heavy impacts caused by hailstones.

### 5.10.2 Apparatus and procedure

#### 5.10.2.1 General

The testing of the solar collector to determine its impact resistance can be done by one of two methods, i.e. by using steel balls or ice balls.

#### 5.10.2.2 Method 1

The collector shall be mounted either vertically or horizontally on a support (see Figure A.15). The support may be stiff enough so that there is negligible distortion or deflection at the time of impact.

Steel balls shall be used to simulate a heavy impact. If the collector is mounted horizontally then the steel balls are dropped vertically, or if it is mounted vertically then the impacts are directed horizontally by means of a pendulum. In both cases, the height of the fall is the vertical distance between the point of release and the horizontal plane containing the point of impact.

The point of impact shall be no more than 5 cm from the edge of the collector cover, and no more than 10 cm from the corner of the collector cover, but it shall be moved by several millimetres each time the steel ball is dropped.

A steel ball shall be dropped onto the collector 10 times from the first test height, then 10 times from the second test height, etc. until the maximum test height is reached (as specified by the manufacturer). The test is to be stopped when the collector sustains some damage or when the collector has survived the impact of 10 steel balls at the maximum test height.

NOTE This method does not correspond to the physical effect of hailstones as the deformation energy absorbed by the ice particles is not being considered.

#### 5.10.2.3 Method 2

The apparatus consists of the following equipment:

- a) Moulds of suitable material for casting spherical ice balls of the required diameter (25 mm).
- b) A freezer, controlled at  $-10\text{ }^{\circ}\text{C} \pm 5\text{ }^{\circ}\text{C}$ .
- c) A storage container for storing the ice balls at a temperature of  $-4\text{ }^{\circ}\text{C} \pm 2\text{ }^{\circ}\text{C}$ .
- d) A launcher capable of propelling an ice ball at the specified velocity (as specified by the manufacturer), within  $\pm 5\%$ , so as to hit the collector within the specified impact location. The path of the ice ball from the launcher to the collector may be horizontal, vertical or at any intermediate angle.

- e) A rigid frame for supporting the collector, with the impact surface normal to the path of the projected ice ball; the support shall be stiff enough so that there is negligible distortion or deflection at the time of impact.
- f) A balance for determining the mass of an ice ball to a standard uncertainty of  $\pm 2\%$ .
- g) An instrument for measuring the velocity of the ice ball to a standard uncertainty of  $\pm 2\text{ ms}^{-1}$ . The velocity sensor shall be no more than 1 m from the surface of the collector.

As an example, Figure A.16 shows in schematic form a suitable apparatus comprising a horizontal pneumatic launcher, a vertical collector support and a velocity meter which measures electronically the time it takes the ice ball to traverse the distance between two light beams.

The testing procedure shall be the following:

- a) Using the moulds and the freezer, make sufficient ice balls of the required size for the test, including some for the preliminary adjustment of the launcher.
- b) Examine each one for cracks, size and mass. An acceptable ball shall meet the following criteria:
  - no cracks visible to the unaided eye;
  - diameter within  $\pm 5\%$  of the ball (25 mm);
  - mass within  $\pm 5\%$  of the ball (25 mm).
- c) Place the balls in the storage container and leave them there for at least 1 h before use.
- d) Ensure that all surfaces of the launcher likely to be in contact with the ice balls are near room temperature.
- e) Fire a number of trial shots at a simulated target in accordance with step g) below and adjust the launcher until the velocity of the ice ball, as measured with the velocity sensor in the prescribed position, is within  $\pm 5\%$  of the required hailstone test velocity.
- f) Install the collector at room temperature in the prescribed mount, with the impact surface normal to the path of the ice ball.
- g) Take an ice ball from the storage container and place it in the launcher. Take aim at the impact location and fire. The time between the removal of the ice ball from the container and impact on the collector shall not exceed 60 s.

The point of impact shall be no more than 5 cm from the edge of the collector cover, and no more than 10 cm from the corner of the collector cover, but it shall be moved by several millimetres each time the ice ball is launched.

An ice ball shall be launched onto the collector 10 times; the test shall be stopped when the collector sustains some damage or when the collector has survived the impact of 10 ice balls.

### 5.10.3 Test conditions

If the test is conducted according to method 1, the steel ball shall have a mass of  $150\text{ g} \pm 10\text{ g}$  and the following series of test heights shall be used: 0,4 m, 0,6 m, 0,8 m, 1,0 m, 1,2 m, 1,4 m, 1,6 m, 1,8 m and 2,0 m.

If the test is conducted according to method 2, the ice ball shall have a diameter of  $25\text{ mm} \pm 5\%$ , a mass of  $7,53\text{ g} \pm 5\%$  and its velocity shall be  $23\text{ m/s} \pm 5\%$ .

### 5.10.4 Results

The collector shall be inspected for damage. The results of the inspection shall be reported, together with the height from which the steel ball was dropped (if method 1 is used) and the number of impacts which caused the damage.

NOTE As test method 2 is closer to reality, this method (5.10.2.3) is preferable.

### 5.11 Final inspection

When the full tests have been completed, the collector shall be dismantled and inspected. All abnormalities shall be reported and accompanied by a photograph.

### 5.12 Test report

The format sheets given in Annex B shall be completed for each test, together with the introductory format sheet (B.1) reporting a summary of main results, including the test methods.

## 6 Thermal performance testing of liquid heating collectors

The thermal performance of glazed solar collectors shall be tested according to either 6.1 or 6.3.

### 6.1 Glazed solar collectors under steady state conditions (including pressure drop)

#### 6.1.1 Collector mounting and location

##### 6.1.1.1 General

The way in which a collector is mounted will influence the results of thermal performance tests. Collectors to be tested shall therefore be mounted in accordance with 6.1.1.2 to 6.1.1.8. Full-size collector modules shall be tested, because the edge losses of small collectors may significantly reduce their overall performance.

##### 6.1.1.2 Collector mounting frame

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), an open mounting structure shall be used which allows air to circulate freely around the front and back of the collector. The collector shall be mounted such that the lower edge is not less than 0,5 m above the local ground surface. 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.

#### 6.1.1.3 Tilt angle

The collector shall be tested at tilt angles such that the incidence angle modifier for the collector varies by no more than  $\pm 2\%$  from its value at normal incidence. For single glazed flat plate collectors, this condition will usually be satisfied if the angle of incidence of direct solar radiation at the collector aperture is less than  $20^\circ$ .

NOTE For many collectors, the influence of tilt angle is small, but it can be an important variable for specialized collectors such as those incorporating heat pipes.

#### 6.1.1.4 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 acceptance range of incidence angles. A more versatile approach is to move the collector to follow the sun in azimuth, using manual or automatic tracking.

#### 6.1.1.5 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.

#### 6.1.1.6 Diffuse and reflected solar irradiance

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. With some collector types, such as evacuated tubular collectors, it may be equally important to minimize reflections on both the back and the front fields 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 approximately  $15^\circ$  to the horizontal in front of the collectors. 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.

Surfaces to be avoided in the collector's field of view include large expanses of glass, metal or water. 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.

#### 6.1.1.7 Thermal irradiance

The performance of some collectors is particularly sensitive to the levels of thermal irradiance. 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 thermal radiation. For example, the outdoor field of view of the collector shall not include chimneys, cooling towers or hot exhausts. For indoor and simulator 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.

#### 6.1.1.8 Air speed

The performance of many collectors is sensitive to air speeds. In order to maximize the reproducibility of results, collectors shall be mounted such that air can freely pass over the aperture, back and sides of the collector. The mean air speed, parallel to the collector aperture, shall be between the limits specified in 6.1.4.3. Where necessary, artificial wind generators shall be used to achieve these air speeds. 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.

## **6.1.2 Instrumentation**

### **6.1.2.1 Solar radiation measurement**

#### **6.1.2.1.1 Pyranometer**

##### **6.1.2.1.1.1 General**

A class I or better, as specified in ISO 9060, pyranometer shall be used to measure the global short-wave radiation from both the sun and the sky. The recommended practice for use given in ISO/TR 9901 should be observed. Before each test the pyranometer should be checked for dust, soiling etc. on the outer dome and it should be cleaned if necessary.

A class I or better pyranometer equipped with a shading ring or alternatively a pyrhelimeter together with a pyranometer shall be used to measure the diffuse short-wave radiation.

##### **6.1.2.1.1.2 Precautions for effects of temperature gradient**

The pyranometer used during the test(s) shall be placed in a typical test position and allowed to equilibrate for at least 30 min before data-taking commences.

##### **6.1.2.1.1.3 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 on a regular basis.

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

Pyranometers used to measure the irradiance of the 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  $\mu\text{m}$  from the simulator light source.

##### **6.1.2.1.1.5 Mounting of pyranometers outdoors**

The pyranometer shall be mounted such that its sensor is coplanar, within a tolerance of  $\pm 1^\circ$  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.

NOTE For angles of incidence of  $50^\circ$ , a deviation of  $\pm 1^\circ$  leads to an error of 2 % when measuring the solar irradiance.

For outdoor testing, the pyranometer shall be mounted at the midheight of the collector. The body of the pyranometer and the emerging leads of 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.

#### 6.1.2.1.1.6 Use of pyranometers in solar irradiance simulators

Pyranometers may be used to measure the distribution of simulated solar irradiance over the collector aperture, and the variation in simulated irradiance with time (see 6.1.5.6). Alternatively, other types of radiation detector may be used, provided that they have been evaluated and calibrated for simulated solar radiation in question.

The pyranometer(s) shall be mounted such that its sensor(s) is (are) coplanar, with a tolerance of  $\pm 1^\circ$  with the plane of the collector aperture. The pyranometer(s) shall not cast a shadow onto the collector aperture at any time during the test period. The pyranometer(s) shall be mounted so as to receive the same levels of indirect, diffuse and reflected solar radiation as are received by the collector.

The method and equipment used to measure any variation in simulated irradiance with time during the test period, shall be well proven to give the required accuracy.

NOTE E.g. for the most commonly used type of solar simulator, using an electrical arc in a sealed beam parabolic reflector as the light source, the mounting of a pyranometer in a typical test position at the midheight of the collector as described for outdoor testing, will not be adequate. Especially, when the lamp array is powered from unstabilized mains power supply and from 3 different phases. For solar simulators of this kind not equipped with stabilized power supply, integration of power supply voltage during each test period is recommended. Solar simulators equipped with stabilized power supply, capable of stabilizing the power supply voltage within  $\pm 0,5\%$ , normally will need no integration of simulated irradiance during (each) test period. For most types of solar simulators, the relationship between the spatially integrated value of the simulated solar irradiance and the integrated power supply voltage during each test period, can be found. In all cases, sufficient knowledge of burn in and life time characteristics of the lamp type used, is assumed.

#### 6.1.2.1.2 Measurement of the angle of incidence of direct solar radiation

A simple device for measuring the angle of incidence of direct solar radiation can be produced by mounting a pointer normal to a flat plate on which graduated concentric rings are marked. The length of the shadow cast by the pointer may be measured using the concentric rings and used to determine the angle of incidence. The device shall be positioned in the collector plane and to one side of the collector.

### 6.1.2.2 Thermal radiation measurement

#### 6.1.2.2.1 Measurement of thermal irradiance outdoors

The variations of thermal irradiance outdoors are not normally taken into account for collector testing. However, a pyrgeometer may be mounted in the plane of the collector aperture and to one side at midheight, to determine the thermal irradiance at the collector aperture.

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

##### 6.1.2.2.2.1 Measurement

The thermal irradiance may be measured using a pyrgeometer as indicated in 6.1.2.2.1. for outdoor measurements. Pyrgeometer shall be well ventilated in order to minimize the influence of solar or simulated solar irradiance. For indoor testing, the thermal irradiance shall be determined to a standard uncertainty of  $10 \text{ Wm}^{-2}$ .

##### 6.1.2.2.2.2 Calculation

Provided that all sources and sinks of thermal radiation in the field of view of the collector can be identified, the thermal irradiance at the collector aperture may be calculated using temperature measurements, surface emittance measurements and radiation view factors. The thermal irradiance incident on a collector surface (designated 1), from a hotter surface (designated 2) is given by

$$\sigma \varepsilon_2 F_{12} T_2^4 \quad (1)$$

Or, more usefully, the additional thermal irradiance (compared with that which would be present if surface 2 had been a perfect black body at ambient temperature) is given by

$$\sigma F_{12} (\varepsilon_2 T_2^4 - T_a^4) \quad (2)$$

Radiation view factors are given in textbooks on radiation heat transfer. The thermal irradiance at the collector aperture may also be calculated from a series of measurements made for small solid angles in the field of view. Such measurements can be made using a pyrheliometer with and without a glass filter to identify the thermal component of the global irradiance.

### 6.1.2.3 Temperature measurements

#### 6.1.2.3.1 General

Three temperature measurements are required for solar collector testing. These are the fluid temperature at the collector inlet, the fluid temperature at the collector outlet, and the ambient air temperature. The required accuracy and the environment for these measurements differ, and hence the sensor for temperature measurement and associated equipment may be different.

#### 6.1.2.3.2 Measurement of heat transfer fluid inlet temperature ( $t_{in}$ )

##### 6.1.2.3.2.1 Required accuracy

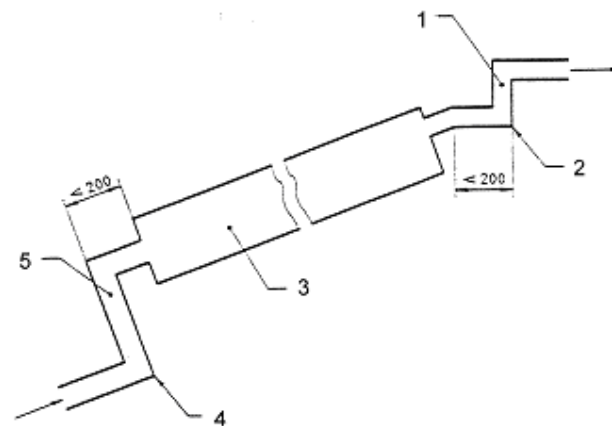
The temperature of the heat transfer fluid at the collector inlet shall be measured to a standard uncertainty of 0,1 K, but in order to check that the temperature is not drifting with time, a very much better resolution of the temperature signal to  $\pm 0,02$  K is required.

**NOTE** This resolution is needed for all temperatures used for collector testing (i.e. over the range 0 °C to 100 °C) which is a particularly demanding accuracy for recording by data logger, as it requires a resolution of one part in 4.000 or a 12-bit digital system.

##### 6.1.2.3.2.2 Mounting of sensors

The sensor for temperature measurement shall be mounted at no more than 200 mm from the collector inlet, and insulation shall be placed around the pipework both upstream and downstream of the sensor. If it is necessary to position the sensor more than 200 mm away 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 sensor, and the sensor probe shall point upstream and in a pipe where the flow is rising (to prevent air from being trapped near the sensor), as shown in Figure 1.

Dimensions in millimetres

**Key**

- 1 Temperature transducer ( $t_e \Delta T$ )
- 2 Pipework bend or mixing device
- 3 Solar collector
- 4 Pipework bend or mixing device
- 5 Temperature transducer ( $t_{in} \Delta T$ )

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

#### 6.1.2.3.3 Determination of heat transfer fluid temperature difference ( $\Delta T$ )

The difference between the collector outlet and inlet temperatures ( $\Delta T$ ) shall be determined to a standard uncertainty of  $<0,05$  K. Standard uncertainties approaching  $0,02$  K can be achieved with modern well-matched and calibrated transducers, and hence it is possible to measure heat transfer fluid temperature differences of  $1$  K or  $2$  K with a reasonable accuracy. Delta-T sensors shall be calibrated in the relevant temperature range.

#### 6.1.2.3.4 Measurement of surrounding air temperature ( $t_a$ )

##### 6.1.2.3.4.1 Required accuracy

The ambient or surrounding air temperature shall be measured to a standard uncertainty of  $0,5$  K.

##### 6.1.2.3.4.2 Mounting of sensors

For outdoor measurements the sensor shall be shaded from direct and reflected solar radiation by means of a white-painted, well-ventilated shelter, preferably with forced ventilation. The shelter itself shall be shaded and placed at the midheight of the collector but at least  $1$  m above the local ground surface to ensure that it is removed from the influence of ground heating.

The shelter shall be positioned to one side of the collector and not more than  $10$  m from it. If air is forced over the collector by a wind generator, the air temperature shall be measured in the outlet of the wind generator and checks made to ensure that this temperature does not deviate from the ambient air temperature by more than  $\pm 1$  K.

#### 6.1.2.4 Measurement of collector liquid flowrate

Mass flowrates may be measured directly or, alternatively, if the density is known, they may be determined from measurements of volumetric flowrate and temperature. The standard uncertainty of the liquid flowrate measurement shall be within  $\pm 1$  % of the measured value, in mass per unit time. The flowmeter shall be calibrated over the range of fluid flowrates and temperatures to be used during collector testing.

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

#### 6.1.2.5 Measurement of air speed

##### 6.1.2.5.1 General

The heat losses from a collector increase with increasing air speed over the collector, but the influence of air speed direction is not well understood. Measurements of air speed direction are therefore not used for collector testing.

The relationship between the meteorological wind speed and the air speed over the collector depends on the location of the test facility, so meteorological wind speed is not a useful parameter for collector testing. By using the air speed measured over the collector, it is possible to define clearly the conditions in which the tests were performed.

##### 6.1.2.5.2 Required accuracy

The speed of the surrounding air over the front surface of the collector shall be measured to a standard uncertainty of  $0,5 \text{ ms}^{-1}$  for both indoor and outdoor testing. 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.

##### 6.1.2.5.3 Mounting of sensors for the measurement of air velocity over the collector

During indoor testing, the air speed may vary from one end of the collector to the other. A series of air speed measurements shall therefore be taken, at a distance of 10 mm to 50 mm in front of the collector aperture, at equally spaced positions over the collector area.

An average value shall then be determined. Air speed measurements indoors in stable conditions shall be made before and after performance test points to avoid obscuring the collector aperture.

When testing outdoors in locations where the mean wind speed is below  $2 \text{ ms}^{-1}$ , an artificial wind generator shall be used, and anemometer measurements shall be fitted for the continuous measurement of air velocity. This anemometer shall be mounted on a board so that there is continuous surface pointing towards the wind generator from the collector edge to 0,3 m behind the anemometer. The uniformity of air speed in the field of collector aperture shall be checked. The wind speed shall be measured while adjusting the wind generator, using a hand held anemometer in a height of 10 mm to 50 mm above the collector aperture plane.

In windy locations, wind speed measurement shall be made near to the collector at the mid height of the collector. The sensor shall not be shielded from the wind and it shall not cast a shadow on the collector during the test periods.

NOTE The recorded value of the wind speed is different to the air speed above the collector aperture.

#### 6.1.2.6 Elapsed time

Elapsed time shall be measured to a standard uncertainty of 0,2 %.

#### 6.1.2.7 Instrumentation/data recorders

In no case shall the smallest scale division of the instrument or instrument system exceed twice the specified standard uncertainty. For example, if the specified standard uncertainty is 0,1 K, the smallest scale division shall not exceed 0,2 °C. Digital techniques and electronic integrators shall have a standard uncertainty equal to or better than 1,0 % of the measured value.

Analog and digital recorders shall have an error equal to or better than 0,5 % of the full-scale reading and have a time constant of 1s or less. The peak signal indication shall be between 50 % and 100 % of full scale. The input impedance of recorders shall be greater than 1000 times the impedance of the sensors or 10 M $\Omega$  whichever is higher.

#### 6.1.2.8 Collector area

The collector area (absorber, gross or aperture) shall be measured to a standard uncertainty of 0,3 %. Area measurements shall take place at a collector temperature of  $(20 \pm 10)$  °C and under operating pressure if the absorber is made of organic material.

#### 6.1.2.9 Collector fluid capacity

The fluid capacity of the collector shall be measured to a standard uncertainty of no more than 10 %. Measurements may be made either by weighing the collector when empty and again when filled with fluid, or by filling and emptying the collector to determine the mass of fluid which it will contain.

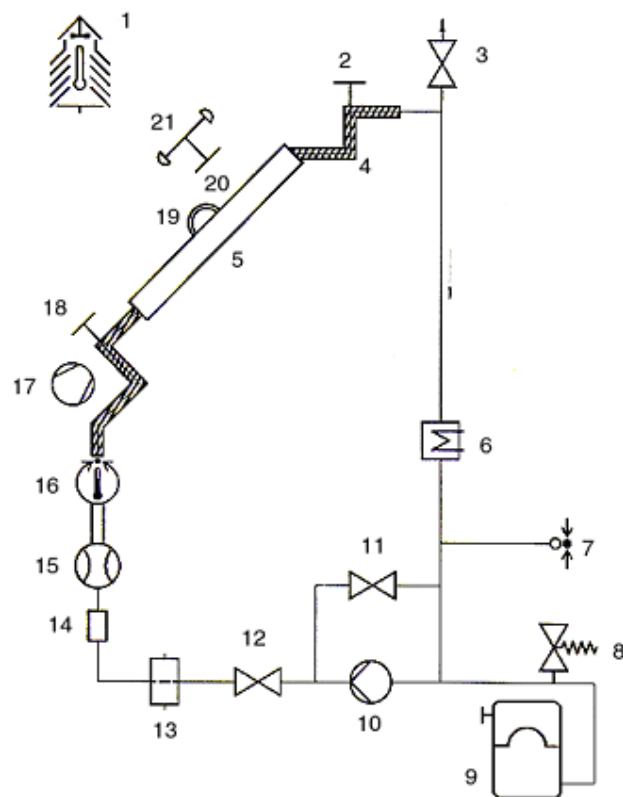
The temperature of the fluid shall be kept within  $\pm 2$  K of the ambient temperature.

As an alternative, a determination by calculation, which is based on the geometrical circumstances, can be given.

### 6.1.3 Test installation

#### 6.1.3.1 General consideration

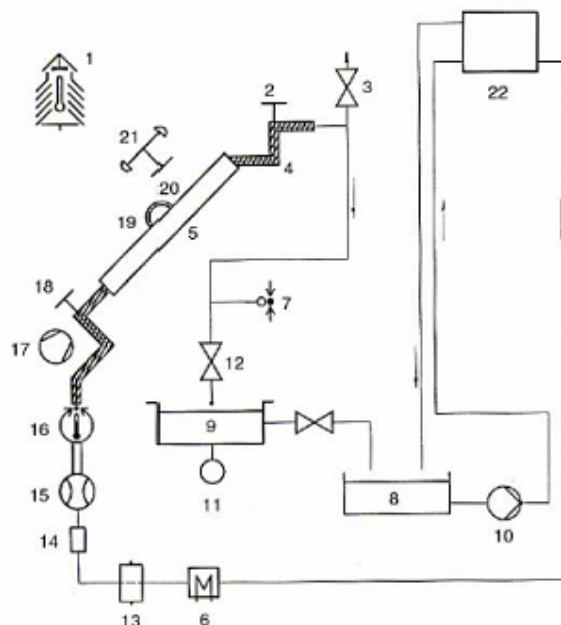
Examples of test configurations for testing solar collectors employing liquid as the heat transfer fluid are shown in Figures 2 and 3. These are schematic only, and are not drawn to scale.



# Key

- 1 Surrounding air temperature sensor
- 2 Temperature sensor ( $t_e$ )
- 3 Air vent
- 4 Insulated pipe
- 5 Solar collector
- 6 Heater/cooler for primary temperature control
- 7 Pressure gauge
- 8 Safety valve
- 9 Expansion tank
- 10 Pump
- 11 Bypass valve
- 12 Flow control valve
- 13 Filter (200  $\mu$ m)
- 14 Sight glass
- 15 Flowmeter
- 16 Secondary temperature regulator
- 17 Artificial wind generator
- 18 Temperature sensor ( $t_{in}$ )
- 19 Pyrgeometer
- 20 Pyranometer
- 21 Anemometer

Figure 2 – Example of a closed test loop



### Key

- 1 Surrounding air temperature sensor
- 2 Temperature sensor ( $t_e$ )
- 3 Air vent
- 4 Insulated pipe
- 5 Solar collector
- 6 Heater/cooler for primary temperature control
- 7 Pressure gauge
- 8 Reservoir
- 9 Weighing vessel
- 10 Pump
- 11 Balance
- 12 Flow control valve
- 13 Filter (200  $\mu\text{m}$ )
- 14 Sight glass
- 15 Flowmeter
- 16 Secondary temperature regulator
- 17 Artificial wind generator
- 18 Temperature sensor ( $t_{in}$ )
- 19 Pyrgeometer
- 20 Pyranometer
- 21 Anemometer
- 22 Constant head tank

Figure 3 – Example of an open test loop

### 6.1.3.2 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  $\pm 1\%$  over the range of fluid temperatures used during the tests. These values are given for water in Annex I.

Some fluids may need to be changed periodically to ensure that their properties remain well defined.

The mass or volume flowrate of the heat transfer fluid shall be the same throughout the test sequence used to determine the thermal efficiency curve, time constant and incident angle modifiers for a given collector.

#### 6.1.3.3 Pipework and fittings

The piping used in the collector loop shall be resistant to corrosion and (for testing of glazed collectors) suitable for operation at temperatures up to 95 °C. If nonaqueous fluids are used, then compatibility with system materials shall be confirmed. 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  $0,2 \text{ WK}^{-1}$ , and shall be protected by a reflective weatherproof coating. Pipework between the temperature sensing points and the collector (inlet and outlet) shall be protected with insulation and reflective (for outdoor measurements also weatherproof) covers to beyond the positions of the temperature sensors, such that the calculated temperature gain or loss along either pipe portion does not exceed  $\pm 0,01 \text{ K}$  under test conditions. Flow-mixing devices such as pipe bends are required immediately upstream of temperature sensors (see 6.1.2.3).

NOTE 1A short length of transparent tube should be installed in the fluid loop so that air bubbles and any other contaminants will be observed if present. The transparent tube should be placed close to the collector inlet but should 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 should be placed at the outlet of the collector, and at other points in the system where air can accumulate.

NOTE 2 Filters should be placed upstream of the flow measuring device and the pump, in accordance with normal practice (a nominal filter size of 200  $\mu\text{m}$  is usually adequate).

#### 6.1.3.4 Pump and flow control devices

The fluid pump shall be located in the collector test loop in such a position that the heat from it which is dissipated in the fluid does not affect 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 or volume flowrate through the collector stable to within 1 % despite temperature variations, at any inlet temperature chosen within the operating range.

#### 6.1.3.5 Temperature regulation of the heat transfer fluid

The collector test loop shall 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.

NOTE 1 Test loops may contain two stages of fluid inlet temperature control, as shown in Figures 2 and 3. The primary temperature controller should be placed upstream of the flowmeter and flow controller. A secondary temperature regulator should 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  $\pm 2$  K.

NOTE 2 A secondary temperature controller close to the collector inlet is useful, provided that it does not introduce problems with measuring the 'mean cup' inlet temperature. On the other hand, bypasses should also remain allowed as a means to reduce the influence of heat loss and to improve the control characteristics of the heating circuits. A constant and high flowrate through the heaters will allow PID controlling with fast I and D action, while any flowrate through the collector can be chosen.

#### 6.1.4 Outdoor steady-state performance test

##### 6.1.4.1 Test installation

The collector shall be mounted in accordance with the specifications given in 6.1.1, and coupled to a test loop as described in 6.1.3. The heat transfer fluid shall flow from the bottom to the top of the collector, or as recommended by the manufacturer.

##### 6.1.4.2 Preconditioning of the collector

The collector shall be visually inspected and any damage recorded. The collector aperture cover shall be thoroughly cleaned. If moisture is formed on the collector components, then the heat transfer fluid shall be circulated at approximately 80 °C for as long as is necessary to dry out the insulation and collector enclosure.

If this form of preconditioning is carried out, then it shall be reported with the test results. The collector pipework shall be vented of trapped air by means of an air valve or by circulating the fluid at a high flowrate, 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.

The empty collector shall be exposed to irradiation for 5 h at the level of more than 700 Wm<sup>-2</sup>.

##### 6.1.4.3 Test conditions

At the time of the test, the hemispherical solar irradiance at the plane of the collector aperture shall be greater than 700 Wm<sup>-2</sup>.

NOTE 1 If the manufacturer has limitations on operation with respect to maximum irradiance but not less than 800 Wm<sup>-2</sup>, this can be requested with the test. That maximum value should be clearly reported.

The angle of incidence 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. For single glazed flat plate collectors, this condition will usually be satisfied if the angle of incidence of direct solar radiation at the collector aperture is less than 20°.

However, much lower angles may be required for particular designs. In order to characterize collector performance at other angles, an incident angle modifier may be determined (see 6.1.7).

Where diffuse solar irradiance is less than 30 %, its influence may be neglected. The collector shall not be tested at diffuse irradiance levels of greater than 30 %.

The average value of air speed parallel to the collector aperture, taking into account spatial variations over the collector and temporal variations during the test period, shall be 3 ms<sup>-1</sup>  $\pm$  1 ms<sup>-1</sup>.

Unless otherwise specified, the fluid flowrate shall be set at approximately  $0,02 \text{ kg s}^{-1}$  per square metre of collector aperture area. It shall be held stable to within  $\pm 1 \%$  of the set value during each test period, and shall not vary by more than  $\pm 10 \%$  of the set value from one test period to another.

The testing at other flowrates may be accommodated by adhering to manufacturer's specification.

In some collectors the recommended fluid flowrate may be close to the transition region between laminar and turbulent flow. This may cause instability of the internal heat transfer coefficient and hence variations in measurements of collector efficiency. In order to characterize such a collector in a reproducible way, it may be necessary to use a higher flowrate, but this shall be clearly stated with the test results.

NOTE 2 In the transition regime, the flowrate should first be set high (turbulent) and then reduced to the setpoint value. This will prevent transition from laminar to turbulent during the measurements.

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

#### 6.1.4.4 Test procedure

The collector shall be tested over its operating temperature range under clear sky conditions in order to determine its performance characteristic. Data points, which satisfy the requirements given below shall be obtained for at least four fluid inlet temperatures spaced evenly over the operating temperature range of the collector. If possible, one inlet temperature shall be selected such that the mean fluid temperature in the collector lies within  $\pm 3 \text{ K}$  of the ambient air temperature, in order to obtain an accurate determination of  $\eta_0$ . If water is the heat transfer fluid, the maximum temperature shall be at least around  $80^\circ\text{C}$ . A maximum value of  $T_m^*$  of at least 0,09 is recommended if test conditions permit.

At least four independent data points shall be obtained for each fluid inlet temperature, to give a total of 16 data points. If test conditions permit, an equal number of data points shall be taken before and after solar noon for each fluid inlet temperature. The latter is not required if the collectors are moved to follow the sun in azimuth and altitude using automatic tracking.

During a test, measurements shall be made as specified in 6.1.4.5. These may then be used to identify test periods from which satisfactory data points can be derived.

#### 6.1.4.5 Measurements

The following data shall be measured:

- gross collector area  $A_G$ , the absorber area  $A_A$  and the aperture area  $A_a$ ;
- fluid capacity
- hemispherical solar irradiance at the collector aperture
- diffuse solar irradiance at the collector aperture (only outdoors)
- angle of incidence of direct solar radiation  
(alternatively, this angle may be determined by calculation)
- air speed parallel to the collector aperture
- surrounding air temperature
- temperature of the heat transfer fluid at the collector inlet

- temperature of the heat transfer fluid at the collector outlet
- flowrate of the heat transfer fluid

#### 6.1.4.6 Test period (steady-state)

The test period for a steady state data point shall include a pre-conditioning period of at least 4 times the time constant of the collector (if known), or not less than 15 min (if time constant is not known), with the correct fluid temperature at the inlet, followed by a steady state measurement period of at least 4 times the time constant of the collector (if known), or not less than 10 min (if time constant is not known).

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 5. 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 5 - Permitted deviation of measured parameters during a measurement period**

| Parameter                                | Permitted deviation from the mean value |
|------------------------------------------|-----------------------------------------|
| (Global)Test solar irradiance            | $\pm 50 \text{ Wm}^{-2}$                |
| Surrounding air temperature (indoor)     | $\pm 1 \text{ K}$                       |
| Surrounding air temperature (outdoor)    | $\pm 1,5 \text{ K}$                     |
| Fluid mass flowrate                      | $\pm 1 \%$                              |
| Fluid temperature at the collector inlet | $\pm 0,1 \text{ K}$                     |

#### 6.1.4.7 Presentation of results

The measurements shall be collated to produce a set of data points which meet the required test conditions (see 6.1.4.3), including those for steady-state operation. These shall be presented using the data format sheets given in Annex D.

#### 6.1.4.8 Computation of collector output

##### 6.1.4.8.1 General

The actual useful power extracted,  $\dot{Q}$ , is calculated from:

$$\dot{Q} = \dot{m} c_f \Delta T \quad (3)$$

A value of  $c_f$  corresponding to the mean fluid temperature shall be used. If  $\dot{m}$  is obtained from volumetric flowrate measurement, then the density shall be determined for the temperature of the fluid in the flowmeter.

#### 6.1.4.8.2 Solar energy intercepted by the collector

Provided that the angle of incidence is less than 20°, the use of an incident angle modifier, as described in 6.1.7, is not required for single glazed flat plate collectors.

The solar energy intercepted is  $A \cdot G$  where the area is  $A_A$  when referred to the absorber area of the collector and  $A_a$  when referred to the aperture area of the collector. Introducing the collector efficiency, the actual useful power extracted,  $\dot{Q}$ , can also be written as

$$\dot{Q} = AG\eta \quad (4)$$

#### 6.1.4.8.3 Reduced temperature difference

When the mean temperature of the heat transfer fluid  $t_m$  is used, where

$$t_m = t_{in} + \frac{\Delta T}{2} \quad (5)$$

the reduced temperature difference is calculated as:

$$T_m^* = \frac{t_m - t_a}{G} \quad (6)$$

#### 6.1.4.8.4 Modeling of instantaneous efficiency

##### 6.1.4.8.4.1 General

The instantaneous efficiency  $\eta$  shall be calculated by statistical curve fitting, using the least squares method, to obtain an instantaneous efficiency curve of the form

$$\eta = \eta_0 - a_1 T_m^* - a_2 G (T_m^*)^2 \quad (7)$$

Normally a second-order curve shall be used which can be achieved by least squares regression. A second-order fit shall not be used if the value deduced for  $a_2$  is negative. The test conditions shall be recorded on the data format sheets given in Annex D.

Where necessary, tables of measurements of the collector performance are admitted.

##### 6.1.4.8.4.2 Instantaneous efficiency based on absorber area / aperture area

With reference to the reduced temperature difference  $T_m^*$  the equations for instantaneous efficiency are :