भारतीय मानक
Indian Standard

IS 12933 (Part 5) : 2025

सौर सपाट पट्टिका संग्राहक — विशिष्टि

भाग 5 परीक्षण पद्धति

(तीसरा पुनरीक्षण)

Solar Flat Plate Collector — Specification

Part 5 Method of Test

(Third Revision)

ICS 27.160

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September 2025 **Price Group 8**

Renewable Energy Sources Sectional Committee, MED 04

FOREWORD

This Indian Standard (Third Revision) was adopted by the Bureau of Indian Standards, after the draft finalized by the Renewable Energy Sources Sectional Committee had been approved by the Mechanical Engineering Division Council.

This standard was first published in 1990 and subsequently revised in 1992 and 2003. This standard is being revised again to keep pace with the latest technological developments and international practices. Also, in this revision, the standard has been brought into the latest style and format of Indian Standards, and references of Indian Standards, wherever applicable have been updated. BIS certification marking clause has been modified to align with the revised *Bureau of Indian Standards Act,* 2016. In this revision all the amendments have been incorporated.

The following major modifications have been incorporated to the revision of the standard:

a) Symbols have been added and modified; and

b) Basic performance equations have been modified.

This standard has been published in various parts. The other parts in this series are:

Part 1 Requirements (*third revision*)

Part 2 Components (*second revision*)

Part 3 Measuring instruments (*first revision*)

The composition of the Committee, responsible for the revision of this standard is given in Annex A.

In reporting the result of a test or analysis made in accordance with this standard, if the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 2022 'Rules for rounding off numerical values (*second revision*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

Indian Standard

SOLAR FLAT PLATE COLLECTOR — SPECIFICATION

PART 5 METHOD OF TEST

(Third Revision)

1 SCOPE

1.1 This Indian Standard (Part 5) specifies the test methods for solar flat plate collector for water heating.

1.2 This standard does not apply to the following:

a) Collector in whom heat transfer fluid may change phase (that is, heat pipe collectors and steam generating collectors);

b) Concentrating collectors, used in a system designed to generate mechanical energy/electricity;

c) Collectors in which the thermal storage unit is an integral part of the collector so that the collection and the storage processes cannot be separated;

d) Unglazed flat plate collector;

e) Installation or mounting of solar collectors; and

f) Tracking mechanism of the sun following collector system.

2 REFERENCES

The standards given below contain provisions which through reference in this text, constitute provisions of this standard. At the time of publication, the editions indicated were valid. All standards are subject to revision and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of these standards:

IS No.	*Title*
IS/ISO 9488 : 2022	Solar energy — Vocabulary (*first revision*)
IS 12933 (Part 2) : 2003	Solar flat plate collector — Specification: Part 2 Components (*second revision*)

3 TERMINOLOGY

For the purpose of this standard, the terminology and definitions given in IS/ISO 9488 shall apply, in addition to the following:

3.1 Effective Heat Capacity — It refers to the ability of the collector system to store and release thermal energy efficiently. It represents the thermal mass of the collector components (such as absorber plates, tubes, and insulation materials) and their capacity to absorb and retain heat from sunlight.

3.2 Specific Heat — It refers to the amount of heat energy required to raise the temperature of one unit mass of the fluid by one degree celsius (or kelvin).

3.3 Overall Heat Loss Coefficient — It represents the rate at which a solar collector system loses heat to its surroundings per unit area per degree of temperature difference between the collector and the ambient environment.

3.4 Thermal Shocks — Thermal shocks refer to rapid and extreme changes in temperature experienced by a material or a system. These abrupt temperature variations can induce stress within the material, potentially leading to mechanical failure or degradation of its properties.

3.5 Specific Heat Capacity — It describes the amount of heat energy required to raise the temperature of a unit mass of a substance by one degree celsius (or one kelvin).

3.6 Kinematic Viscosity — It is a fluid property that describes its resistance to flow under the influence of gravity. It represents the ratio of dynamic viscosity (viscosity) to the fluid's density.

3.7 Dynamic Viscosity — It is a fundamental property of fluids that quantifies their resistance to flow. It describes the internal frictional force within a fluid that opposes its motion when subjected to a shearing force or stress.

3.8 Collector Aperture — It is the net area available for transmission of solar radiation through the outer air cover interface.

3.9 Symbols

A_a = Transparent frontal area of a solar collector, m^2;

A_g = Gross collector area, m^2;

b_o = Constant used in incident angle modifier equation, dimensionless;

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https://www.services.bis.gov.in/php/BIS_2.0/bisconnect/knowyourstandards/Indian_standards/isdetails/

C = Effective heat capacity of the solar collector, J/°C;

c_i = Heat capacity of i^{th} constituent element of the collector, J/°C;

c_f = Specific heat of the heat transfer fluid, J/(kg°C) ;

F_R = Solar collector heat removal factor, dimensionless;

G = Solar irradiance on collector plane, W/m^2;

G_r = Reflected insolation, W/m^2;

K_v = Incident angle modifier, dimensionless;

$\dot{m}$ = Mass flow rate of the heat transfer fluid, kg/s;

m_i = Mass of i^{th} constituent element of collector, kg;

P_i = Weighting factor defined in Table 4, dimensionless;

Q = Rate of useful energy extraction from the solar collector, W;

T_a = Ambient air temperature, °C;

T_i = Temperature of the heat transfer fluid entering the collector, °C;

T_o = Temperature of the heat transfer fluid leaving the collector, °C;

$T_{o,initial}$ = Temperature of the heat transfer fluid leaving collector at the beginning of time constant test period, °C;

$T_{o,t}$ = Temperature of the heat transfer fluid leaving collector at a specified time t, °C;

U_L = Solar collector overall heat loss coefficient, W/(m^2 °C);

ΔT = Temperature difference, °C;

α = Absorptance of the collector absorber surface for solar radiation, dimensionless;

r = Reflectance of collector covers, dimensionless;

θ = Angle of incidence between direct solar rays and the normal to the collector surface, degree;

η = Collector efficiency based on gross collector area, percent;

τ = Transmittance of the solar collector cover plate, dimensionless;

$(\tau\alpha)_{c,n}$ = Represents property of cover-absorber system taking into account absorptance of the absorber and transmittance of the cover at normal incidence;

$(\tau\alpha)_e$ = Takes into account multiple reflections between the cover and the absorber; and

$(\tau\alpha)_{e,n}$ = Represents $(\tau\alpha)_e$ at normal incidence.

4 SEQUENCE OF TESTS

The sequence in which qualification, thermal performance, and component tests are performed may have an influence on whether or not a collector passes any given test. A general guideline on the sequence of tests envisages to perform outdoor no-flow exposure test near to the beginning of any sequence of tests. A recommended test sequence is given in Table 1.

Table 1 Sequence of Tests

(*Clause* 4)

Sl No.	**Name or Tests**
(1)	(2)
i)	Outdoor no flow exposure test (*see* **5.2**)
ii)	Static pressure leakage test (*see* **5.3**)
iii)	Rain penetration test (*see* **5.6**)
iv)	Thermal efficiency test (*see* **6.4**)
v)	Time constant test (*see* **6.5**)
vi)	Incident angle modifier test (*see* **6.6**)
vii)	External thermal shock test (*see* **5.4**)

Sl No.	Name or Tests
(1)	(2)
viii)	Internal thermal shock test (*see* **5.5**)
ix)	Impact resistance test (*see* **5.7**)
x)	Transmittance test on cover plate [*see* **5.1** of IS 12933 (Part 2)]

5 QUALIFICATION TESTS ON SOLAR COLLECTORS

5.1 Mounting of Solar Collectors

The solar collector is mounted outdoors at an angle of 30° from horizontal. One of the fluid pipes of the solar collector is sealed to prevent cooling by natural circulation of air, whereas the other fluid pipe is left open to permit free expansion of air in the absorber. The collector is kept empty without any water. For rain penetration test (as defined in **5.6**), both the ends of the solar collector shall be sealed.

5.2 Outdoor No-Flow Exposure Test

5.2.1 *Purpose*

This test intends to evaluate the durability of a solar collector by inspecting it after a specified period of outdoor no-flow exposure.

5.2.2 *Procedure*

The solar collector shall be mounted in accordance with **5.1**. The collector is exposed until at least 30 days with a minimum irradiation of 4 kWh/m^2/day have passed. These days need not be consecutive. The collector must also be exposed for at least 30 h to an irradiance greater than 850 W/m^2. These hours must be made up of periods at least 30 min long.

The glazing of the collector shall be cleaned periodically. The ambient air temperature is recorded to an accuracy of 0.5 °C and the total irradiance on the plane of the solar collector is recorded using a pyranometer. Integrated values of data shall be recorded every 30 min.

The collector shall be visually inspected for any damage or degradation, especially that of rubber material and black paint.

5.3 Static Pressure Leakage Test

5.3.1 *Purpose*

The purpose of this test is to ensure the integrity of liquid collectors to withstand the pressures which it might meet in service.

5.3.2 *Apparatus*

The basic apparatus shall consist of a hydraulic pressure source (electrical pump or hand pump), a pressure gauge, an air bleed valve and an isolation valve. The pressure gauge shall permit determination of the test pressure with an accuracy of 5 percent of the actual reading.

5.3.3 *Procedure*

A test arrangement is made as shown in Fig. 1. Initially, air bleed valve is kept open, and it is ensured that all air is removed from the collector by circulating water through it. The solar collector is then filled with water at room temperature and pressurized by closing the bleed valve and applying a hydraulic pressure in accordance with **9.2.1** of IS 12933 (Part 2). This pressure is maintained for a period of 15 min while the collector is inspected for swelling, distortion or ruptures.

Adequate precautions are taken to protect personnel in the laboratory for failure of the pressure test. Results of the test in terms of the initial and final reading of the pressure gauge, temperature of the water and duration of the test shall be reported.

5.4 External Thermal Shock Test

5.4.1 *Purpose*

External thermal shock test intends to assess the capability of a solar collector to withstand thermal shocks which might generate when it gets exposed to sudden rainstorms on hot sunny days.

5.4.2 *Procedure*

The solar collector shall be mounted in accordance with **5.1**.

An array of water jets is arranged to provide a uniform spray of water over the collector, as shown in Fig. 2.

The collector is maintained in stagnant conditions with a level of solar irradiance greater than 700 W/m^2 for a period of 1 h. The solar collector is subjected to water sprays for at least 15 min and then inspected. The water spray shall have a temperature near to ambient and a flow rate in the range (0.30 to 0.50) l/s per sq m gross area of the collector.

The collector shall be inspected for any cracking, distortion, condensation, or water penetration. The results of the inspection shall be reported. The measured values of solar irradiance, surrounding air temperature, absorber temperature, water temperature, and water flow rate shall also be reported.

5.5 Internal Thermal Shock Test

5.5.1 *Purpose*

Internal thermal shock test is intended to assess the capability of a solar collector to withstand thermal shocks arising from a sudden intake of cold heat transfer fluid on hot sunny days. This situation may be encountered, for example, when an installation is brought back into operation after a period of shutdown while the collector is at its stagnation temperature.

5.5.2 *Procedure*

The solar collector shall be mounted in accordance with **5.1**.

The collector is maintained in stagnant conditions with a level of solar irradiance greater than 700 W/m^2 for a period of 1 h. It is then cooled by supplying it with heat transfer fluid for at least 5 min at a temperature near to ambient. The recommended minimum fluid flow rate is 0.02 l/s per sq m gross area of the solar collector (unless otherwise specified by the manufacturer).

The collector shall be inspected for any cracking, distortion, or deformation. The results of the inspection shall be reported. The measured values of solar irradiance, surrounding air temperature, heat transfer fluid temperature, and heat transfer fluid flow rate shall also be reported.

5.6 Rain Penetration Test

5.6.1 *Purpose*

This test is intended to assess the extent to which 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 driving rain.

5.6.2 *Procedure*

The solar collector shall be mounted in accordance with **5.1**.

The collector shall be sprayed (*see* Fig. 3) on all sides using spray nozzles or showers for a test period of 4 h. The collector shall be at approximately the same temperature as the surrounding air. The water spray shall be done at a normal temperature of cold-water supply and at a flow rate in the range 0.03 to 0.05 l/s per sq m gross area of the solar collector. Spray angle of nozzle shall be 60° ± 5º. The maximum distance between two spraying nozzles is 150 cm. The spray heads are at a distance of 250 mm ± 50 mm from the collector. The spray nozzles are directed at an angle of 30º ± 5º onto the plane of the collector.

After the spray, the external surfaces of the solar collector shall be wiped off and inspection shall be made to assess the extent of rain penetration. The results of the inspection that is the places where water penetrated shall be reported.

NOTE — Rain penetration is more easily visible if it is made to form condensation on the cover glass. This can be done either by circulating hot water at about 50 °C through the absorber or by exposing the collector to solar radiation.

5.7 Impact Resistance Test

5.7.1 *Purpose*

This test is intended to assess the extent to which a collector can withstand the effects of heavy impacts, such as those caused by petty vandalism or by hailstones.

5.7.2 *Procedure*

The collector is mounted either vertically or horizontally on a support (*see* Fig. 4). The support shall 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 [method (a) (*see* Fig. 4)], or if it is mounted vertically then the impacts are directed horizontally by means of a pendulum [method (b) (*see* Fig. 4)]. In both the cases, 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 the 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 millimeters each time the steel ball is dropped.

A steel ball, having a mass of 150 g ± 10 g, shall be dropped on to the collector from test heights of 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 at each of the four corners.

The collector shall be inspected for damages. The results of the inspection shall be reported in the following format.

Maximum ball diameter without damage (if ice ball testing)	________________mm
Maximum drop height (1 digit precision) without damage (if steel ball testing)	________________m
Any evident problems, damages and failures (description and photos)	________________
Other observations and remarks	________________

6 THERMAL PERFORMANCE TESTS

Thermal tests on solar collectors are performed to evaluate the extent of their capability to provide useful heat under given climatic and operating conditions. The methods of tests as given here are based on steady state conditions of operation. Thermal performance data generated out of these tests provide valuable information for system design calculations.

The thermal tests are performed to obtain values of efficiency as a function of solar irradiance, ambient air temperature and inlet fluid temperature, to determine the time response characteristics of the collector and to find out dependence of efficiency on the incident angle at various sun and collector positions.

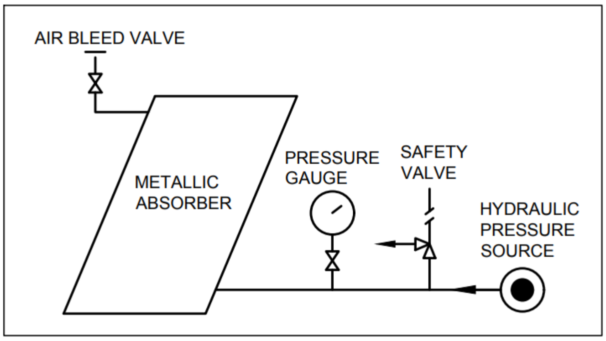


FIG. 1 TEST ARRANGEMENT FOR STATIC PRESSURE LEAKAGE TEST

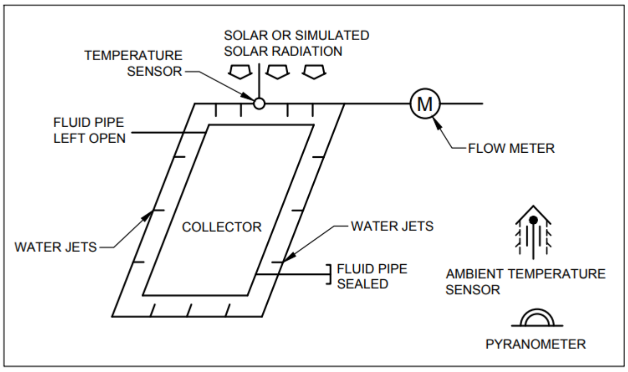


FIG. 2 EXTERNAL THERMAL TEST

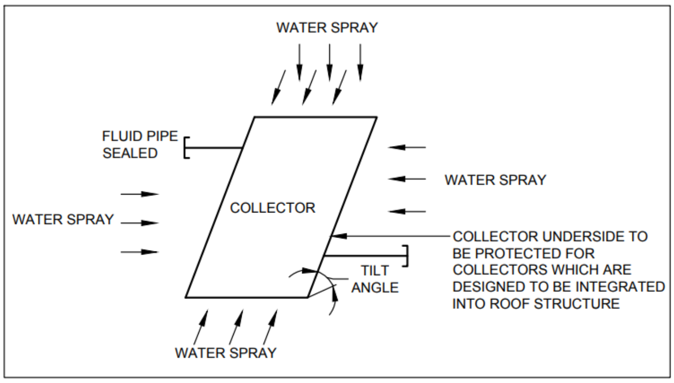


FIG. 3 RAIN PENETRATION TEST

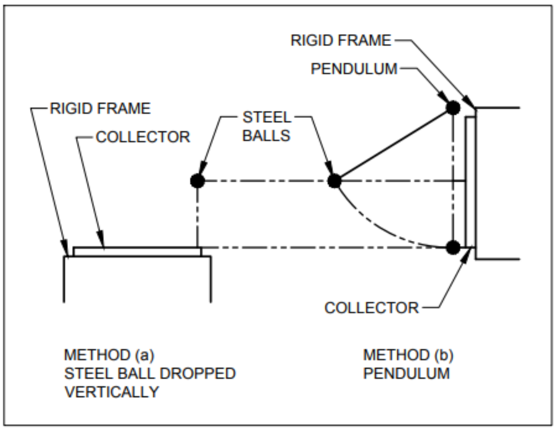


FIG. 4 IMPACT RESISTANCE TEST

6.1 Basic Performance Equations

The performance of a non-concentrating solar collector operating under steady state conditions can be described by the following equation:

$$\frac{Q}{A_g} = GF_R(\tau\alpha)_{e,n} - F_R U_L (T_i - T_a) \quad (1)$$

where

$$(\tau\alpha)_{e,n} = \tau - \frac{\left(\frac{G_r}{G} - r\right)}{\tau} \quad (2)$$

The useful energy extracted by the solar collector may be expressed as follows:

$$\frac{Q}{A_g} = \frac{\dot{m}c_f}{A_g}(T_o - T_i) \quad (3)$$

If the thermal efficiency of a solar collector is defined as a ratio of the actual useful energy collected to that of the solar energy intercepted by the gross area of solar collector, then the efficiency of non-concentrating collector may be defined as follows:

$$\eta = F_R(\tau\alpha)_{e,n} - F_R U_L \left[\frac{T_i - T_a}{G}\right] \quad (4)$$

The equation (4) indicates that the thermal efficiency of a flat plate solar collector is a linear function of $(T_i - T_a)/G$ assuming that U_L is constant. Graphical representation of the data is made by plotting $(T_i - T_a)/G$ on X-axis and η on Y-axis, and by adopting statistical curve fitting using the least squares method. However, linear representation of the efficiency curve may not be sufficient for some of the collectors. In such situations, second order representation is required, namely:

$$\eta = \eta_o - a_1\left(\frac{T_i - T_a}{G}\right) - a_2 G\left(\frac{T_i - T_a}{G}\right)^2 \quad (5)$$

The choice between a first or a second order curve is based on the closeness of fit which can be achieved by least squares regression. A second order fit is not used if the values deduced for a_2 is negative.

In order to predict the collector performance at other incident angles, as would be the case with actual field installations, a multiplying factor called the incident angle modifier, K_V is introduced in equation (1), that is:

$$\eta = F_R K_V (\tau\,\alpha)_{e,n} - F_R U_L \left[\frac{T_i - T_a}{G}\right] \quad (6)$$

Hence, for flat plate solar collectors:

$$K_v = \frac{F_R\,(\tau\alpha)_e}{F_R\,(\tau\alpha)_{e,n}} \quad (7)$$

For flat plate solar collectors whose radiation properties are symmetrical with respect to angle of incidence, variation of K_v with incident angle can be given as follows:

$$K_v = 1 - b_o\left(\frac{1}{\cos\theta} - 1\right) \quad (8)$$

6.2 Mounting of Solar Collector

The way in which collector is mounted influences the results from thermal performance tests. The following considerations shall be taken into account in respect of the collector mounting frame, orientation and tilt angle and choice of location.

6.2.1 *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, an open mounting structure shall be used which allows air to circulate freely around the front and back of the collector. In case, the mounting structure is not open at the back, a gap of at least 150 mm shall be maintained between the back of the collector and the mounting structure to allow reasonable flow of air.

The collector shall be mounted such that its lower edge is higher than 500 mm above the local ground surface. Warm currents of 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 the building, they shall be located at least 2 m away from the edge of the roof surface.

6.2.2 *Collector Orientation and Tilt Angle*

Ideally, the collector shall be mounted outdoor, so as to have a normal incidence of solar radiation. It may be mounted in a fixed position facing equator and may also be moved to follow the sun in azimuth and altitude using manual or automatic tracking. When mounted in a fixed position, time available for testing becomes restricted by the acceptance range of incidence angles.

6.2.3 *Location*

The collector shall be located such that a shadow will not be cast on to the collector at any time during the test period, there will be no significant solar radiation reflected on to it from surrounding buildings or surfaces during the tests. Surface, such as, large expanses of glass, metal or water, or having high temperature (namely chimneys, cooling towers, hot exhausts) should be avoided from field view of the collector.

6.3 Test Apparatus

6.3.1 *Test Set-Up*

Examples of test configurations for testing solar collectors employing liquid as the heat transfer fluid are shown in Fig. 5 and Fig. 6, which are representative rather than exact and are not drawn to scale.

6.3.2 *Heat Transfer Fluid*

The heat transfer fluid used for collector testing may be water or a fluid recommended by the manufacturer. Some fluids may need to be changed periodically to ensure that their properties remain defined. The specific heat capacity and density of the fluid shall be known to within ± 1 percent over the range of temperature used during the tests. Values for different water properties are given in Table 2.

6.3.3 *Pipe Work and Fittings*

The piping used in the test load shall be resistant to corrosion and suitable for operation at temperatures up to 95 °C. Pipe lengths shall generally be kept short. In particular, the piping between the outlet of fluid temperature regulator and the inlet to the collector shall be minimized to reduce the effects of the environment on the fluid inlet temperature. The pipe lengths shall be adequately insulated and be protected by a weatherproof coating.

The pipe work between the temperature sensing points and the collector (inlet and outlet) shall be protected with insulation and weatherproof covers extending beyond the positions of temperature sensors. Flow mixing devices, such as pipe bends are required immediately upstream of temperature sensor.

The pump shall be located in the fluid loop in such a position that the heat which is dissipated in the fluid does not influence the inlet temperature to the collector or the measurements of the fluid temperature.

6.3.4 *Pre-conditioning of the Collector*

Before carrying out thermal performance tests, the collector shall have been exposed to the outdoor no flow exposure test in accordance with **5.2**.

The collector shall be visually inspected, and any damage recorded. The collector aperture cover shall be thoroughly cleaned. If moisture has formed on the collector components, then the heat transfer fluid shall be circulated at a temperature greater than 50 °C for about 1 h duration to dry out the insulation and collector enclosure. The collector pipe work shall be vented of trapped air by means of an air valve or by circulating the fluid at a high flow rate, as necessary.

6.4 Thermal Efficiency Test

6.4.1 *Test Procedure*

The solar collector shall be tested over its operating temperature range under clear sky conditions for determining its efficiency. The measurements are carried out under steady state conditions. Data points which satisfy the requirements given below shall be obtained for at least four inlet temperatures spaced evenly over the operating range of the collector. One inlet temperature shall be selected such that the mean fluid temperature in the collector lies within ± 3 °C of the ambient temperature in order to obtain an accurate determination of η_o. At least four independent data points shall be obtained for each fluid inlet temperature to collect a total of 16 data points. If test conditions permit as specified in **6.4.5**, an equal number of data points shall be taken before and after the solar noon for each fluid inlet temperature. This, however, may not be required for two axis tracking system.

6.4.2 *Measurements*

The following measurements shall be obtained:

a) gross area (A_g) and aperture area (A_a);

b) global solar irradiance;

c) diffuse solar irradiance at the collector aperture;

d) surrounding air speed;

e) surrounding air temperature;

f) temperature of the heat transfer fluid at the collector inlet;

g) temperature of the heat transfer fluid at the collector outlet; and

h) mass flow rate of the heat transfer fluid.

6.4.3 *Steady State Conditions*

A collector may be considered to have been operating in steady state conditions over given test period if none of the experimental parameters deviate from the mean values over the test period by more than the limits given in Table 3. For the purpose of establishing that a steady state exists, average values of each parameter taken over successive periods of 30 s shall be compared with the mean values over the test period.

Table 2 Properties of Water

(*Clause* 6.3.2)

Sl No.	Temperature °C	Density kg/m^3	Specific Heat Capacity kJ/kg K	Kinematic Viscosity, 10^{-6} m^2/s	Dynamic Viscosity, 10^{-6} Ns/m^2
(1)	(2)	(3)	(4)	(5)	(6)
i)	5	999.9	4.204	1.501 0	1 501
ii)	10	999.7	4.193	1.300 0	1 300
iii)	15	999.0	4.186	1.137 0	1 136
iv)	20	998.2	4.183	1.004 0	1 002
v)	25	997.0	4.181	0.892 7	890
vi)	30	995.6	4.179	0.800 5	797
vii)	35	994.0	4.178	0.722 3	718
viii)	40	992.2	4.179	0.656 1	651
ix)	45	990.2	4.181	0.599 9	594
x)	50	988.1	4.182	0.550 5	544
xi)	55	985.2	4.183	0.508 5	501
xii)	60	983.3	4.185	0.470 9	463
xiii)	65	980.4	4.188	0.438 6	430
xiv)	70	977.5	4.191	0.409 2	400
xv)	75	974.7	4.194	0.383 7	374
xvi)	80	971.8	4.198	0.361 2	351
xvii)	85	969.0	4.203	0.340 6	330
xviii)	90	965.3	4.208	0.322 2	311
xix)	95	961.5	4.213	0.305 8	294

Table 3 Steady State Conditions

(*Clause* 6.4.3)

Sl No.	Parameter	Deviation from the Mean Value Over the Test Period
(1)	(2)	(3)
i)	Total solar irradiance	± 50 W/m^2
ii)	Surrounding air temperature	± 1 °C
iii)	Fluid mass flow rate	± 1 percent
iv)	Collector fluid inlet temperature	± 0.1 °C
v)	Fluid temperature at the collector outlet	± 0.2 °C

6.4.4 *Test Period*

6.4.4.1 *Determination of effective thermal capacity*

The thermal capacity of the collector is calculated as the sum for each constituent element of the collector (namely, glass, absorber, liquid contained, insulation) suitably adjusted by multiplying with appropriate weighting factors to allow for the fact that certain elements are only partially involved in collector thermal inertia. The relevant expression is:

$$C = \sum_i p_i m_i c_i \qquad (9)$$

The values of p_i given in the Table 4.

6.4.4.2 The test period for a steady state data point shall contain a pre-conditioning period of at least 15 min with the correct fluid inlet temperature followed by a steady state test period. The length of the steady state test period shall be determined from the thermal capacity, C of the collector and the thermal flow rate, $\dot{m}\ c_f$ of the fluid through the collector. To ensure that a steady state has reached, the test period shall be greater than 4 times the period defined by $(C/\dot{m}\ c_f)$.

6.4.5 *Test Conditions*

The following test conditions shall be observed for conducting the efficiency and incident angle modifier tests.

a) the total solar irradiance at the plane of collector aperture shall not be less than 700 W/m^2;

b) the average value of the surrounding air speed shall lie between 2 m/s and 5 m/s;

c) the fluid flow rate shall be set at approximately 0.02 kg/s m^2 based on collector gross area;

d) the flow rate shall be held stable to within ± 1 percent of the set value during each test period and shall not vary by more than ± 10 percent of the set value from one test period to an-other; and

e) for the purpose of cross checking, manual measurement of flow rate can also be carried out two times in 5 min interval.

6.4.6 *Computation of Collector Efficiency*

The instantaneous efficiency η shall be calculated from the following expression:

$$\eta = \frac{\dot{m} c_f (T_o - T_i)}{A_g G} \qquad (10)$$

An appropriate value of c_f at mean fluid temperature shall be used in the above expression. If $\dot{m}$ is obtained from volumetric flow rate measurement, then the density shall be determined for the temperature of the fluid in the flow meter.

The instantaneous efficiency shall be presented graphically as a function of (T_i – T_a)/G. All the data points shall be plotted along with a statistical curve fitting using the least squares method. If a linear representation is made, a straight line is resulted. The slope of the line is equal to $F_R U_L$ and the Y-intercept is equal to $F_R(\tau\alpha)_{e,n}$.

6.5 Determination of the Time Constant

The heat transfer fluid is circulated through the solar collector and the inlet temperature is adjusted as close to ambient temperature as possible, preferably within ± 1 °C. The steady state and test conditions are maintained as specified in **6.4.3** and **6.4.5**. The incident solar energy is then abruptly reduced to zero by shielding the collector from the sun by using a white opaque cover. The cover shall be suspended off in such a way that ambient air is allowed to pass freely over the collector surface as prior to the use of cover. The following parameters shall be measured during the test.

a) collector fluid inlet temperature;

b) collector fluid outlet temperature; and

c) surrounding air temperature.

The measurements are continued until:

$$\frac{T_{o,1} - T_i}{T_{o,initial} - T_i} < 0.30 \qquad (11)$$

The actual time constant is the time required for the quantity on left hand side of equation (11) to change from 1.0 to 0.368.

6.6 Incident Angle Modifier Test

Experimental determination of incident angle modifier may be done by either of the two methods given below. During each test period, the orientation of the collector shall be maintained to be within ± 2.5° of the angle of incidence for which the test is being conducted.

6.6.1 *Method* 1

This method is applicable for testing outdoors using the moveable test rack, so that the orientation of the collector can be adjusted with respect to the direction of incident solar radiation as per requirement. The collector is oriented so that the test incident angles between it and the direct solar radiation for the four test conditions are respectively, approximately 0, 30, 45, and 60 degrees. It is recommended that these data can be taken during a single day. For each data point, the inlet temperature of the heat transfer fluid shall be controlled as closely as possible to the ambient air temperature, preferably within ± 1 °C. The four separate efficiency values are determined in accordance with **6.4**.

6.6.2 *Method* 2

This method is applicable for testing outside using a stationary test rack where the collector orientation cannot be adjusted arbitrarily with respect to the direction of the incident solar radiation.

For each data point, the inlet fluid temperature shall be controlled within ± 1 °C of the ambient air temperature. The efficiency values are determined in pairs, where each pair includes a value of efficiency before solar noon and a second value after solar noon. The average incident angle between the collector and the solar beam for both data points is the same. The efficiency of the collector for the specific incident angles should be considered equal to the average of two values. Efficiency values are determined in accordance with the method described in **6.4**. As with method (1), data should be collected for incident angles of approximately 0, 30, 45, and 60 degrees.

6.6.3 *Computation of Incident Angle Modifier*

Efficiency values obtained for four values of angles of incidence that is 0, 30, 45, and 60 degrees are used to calculate four values of K_v using equation (7). The values for $F_R(\tau\alpha)_{e,n}$ used in these calculations will have already been obtained as the Y-axis intercept of the efficiency curve. A graphical presentation is made by plotting values of $[(1/\cos\theta) - 1]$ on X-axis and the values of K_v on Y-axis. The constant b_o is then obtained as slope of a straight line plotted by a least squares fit to a first order polynomial.

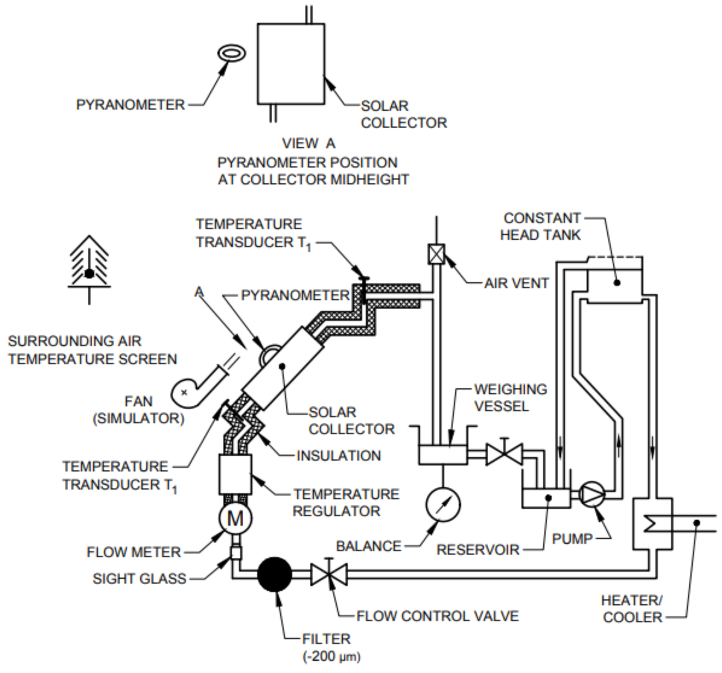
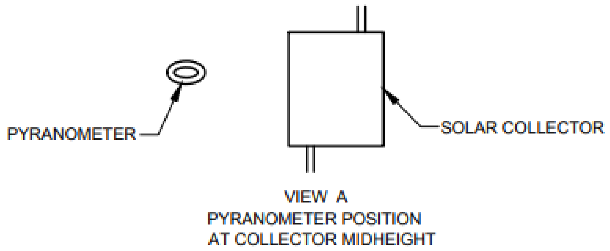


FIG. 5 AN EXAMPLE OF AN OPEN TEST LOOP



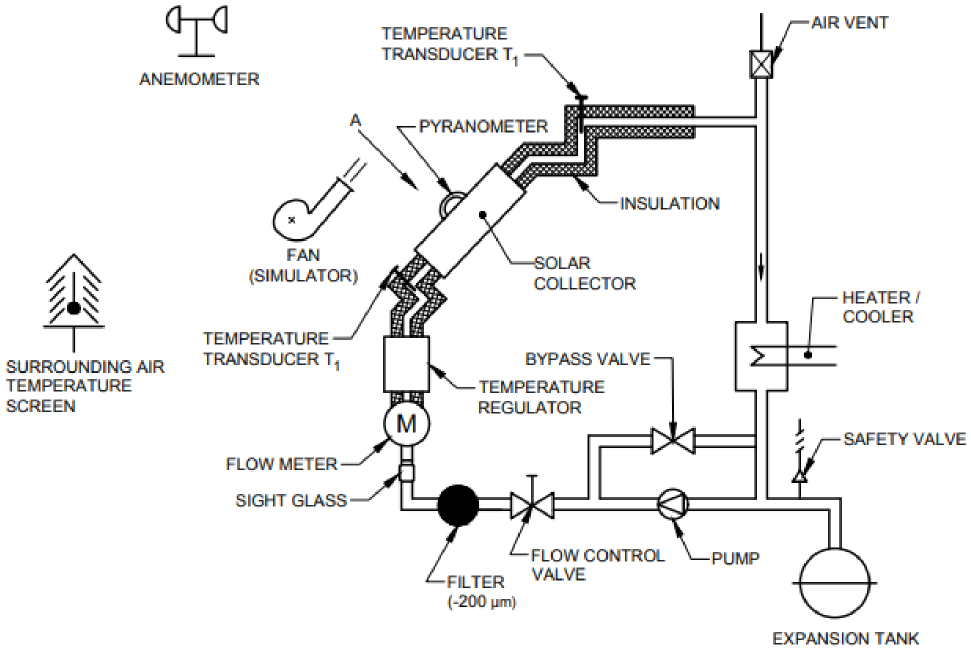


FIG. 6 AN EXAMPLE OF A CLOSED TEST LOOP

Table 4 Recommended Values of p_i for Determination of Thermal Capacity

(*Clauses* 3.9 *and* 6.4.4.1)

Sl No.	Elements	P_i
(1)	(2)	(3)
i)	Absorber	1
ii)	Insulation	0.5
iii)	Heat transfer liquid	1
iv)	External glazing	$0.06\ a_1$
v)	Second glazing	$0.21\ a_1$

NOTE — In a non-linear representation of efficiency equation, a_1 denotes the second parameter of the instantaneous efficiency expression. Where its exact value is unknown, the following approximate values should be used to determine P_i:

a) 7.5 (single glazing); and

b) 4.0 (double glazing).

ANNEX A

(*Foreword*)

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