

Methods of test for

Thermal performance of solar collectors

UDC 697.329.004.15:536.24

NO COPYING WITHOUT BSI PERMISSION EXCEPT AS PERMITTED BY COPYRIGHT LAW

BSI
Documents

AVA

Document Sharing Hub

Committees responsible for this British Standard

The preparation of this British Standard was entrusted by the Refrigeration Heating and Air Conditioning Standards Committee (RHE/-) to Technical Committee RHE/25, upon which the following bodies were represented:

- British Gas Corporation
- British Precast Concrete Federation Ltd.
- Chartered Institution of Building Services Engineers
- Consumer Standards Advisory Committee of BSI
- Consumers' Association
- Copper Development Association
- Cranfield Institute of Technology
- Department of the Environment
- Department of the Environment (Building Research Establishment)
- Design Council
- Engineering Equipment and Materials Users' Association
- Flat Glass Manufacturers' Association
- Institute of Plumbing
- Institution of Gas Engineers
- International Solar Energy Society
- National Centre for Alternative Technology
- Royal Institute of British Architects
- Solar Trade Association
- Swimming Pool and Allied Trades Association Ltd.
- University College Cardiff

The following bodies were also represented in the drafting of the standard, through subcommittees and panels:

- Aluminium Federation
- British Plastics Federation
- Building Services Research and Information Association
- Copper Cylinder and Boiler Manufacturers
- Department of Energy (Energy Technology Support Unit)
- Department of the Environment (Building Research Establishment, Princes Risborough Laboratory)
- Department of the Environment (Housing and Construction)
- Heating and Ventilating Contractors' Association
- National House-building Council
- National Water Council
- Society of Laundry Engineers and Allied Trades Limited
- Co-opted members

This British Standard, having been prepared under the direction of the Refrigeration, Heating and Air Conditioning Standards Committee, was published under the authority of the Board of BSI and comes into effect on 29 August 1986

© BSI 01-2000

The following BSI references relate to the work on this British Standard:
Committee reference RHE/25
Draft for comment DD 77

ISBN 0 580 15375 4

Amendments issued since publication

Amd. No.	Date of issue	Comments

Contents

	Page
Committees responsible	Inside front cover
Foreword	ii
0 Introduction	1
1 Scope	1
2 Definitions and nomenclature	1
3 Collector location and mounting	4
4 Test apparatus	5
5 Instrumentation and measurement methods	9
6 Determination of the thermal performance characteristic of a collector under variable solar radiation conditions	14
7 Determination of the thermal performance characteristic of a collector using a solar simulator	16
8 Test report	19
Appendix A Design of a shade ring	20
Appendix B Corrections to measured irradiance at large angles of incidence	21
Appendix C Theory of transient test method	23
Appendix D Analysis of data for the transient test method	27
Appendix E Computer program for analysis of data using the transient test method	28
Appendix F Format for the presentation of test results	33
Figure 1 — Closed loop test system	7
Figure 2 — Open loop test system	8
Figure 3 — Shading of absorber plate	24
Table 1 — Spectral distribution of simulated solar radiation	9
Table 2 — Measurement items and accuracies	10
Table 3 — Coefficients a_0 to a_4 for 4 mm float glass	22
Publications referred to	Inside back cover

Foreword

This British Standard has been prepared under the direction of the Refrigeration, Heating and Air Conditioning Standards Committee.

The methods of test were originally published as DD 77:1982 in order to gain sufficient experience and information on which to base a British Standard. In the event, DD 77 proved to be satisfactory with only very minor technical changes which have been embodied in the text of this British Standard.

It is anticipated that work on this subject will continue, including work by ISO/TC 180, Solar energy, of the International Organization for Standardization (ISO), so that further experience in the use of such methods will be gained during the next few years.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 36, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

0 Introduction

This British Standard describes a method of test for solar collectors for use where the solar irradiance varies during the test, i.e. when the collector is subject to transient conditions. This “transient” method of test has been prepared to complement the “steady-state” method already developed in the USA¹⁾.

The results of the “transient” test method are expressed as a thermal performance characteristic of the same form as that obtained by the “steady-state” method, with which it has been found to agree to within about 3 % for a range of flat plate collectors. The procedures in the “transient” method for both the collection of the test data and more particularly for its subsequent analysis have been developed especially for this British Standard. The theory of the analysis is described in Appendix C.

A “steady-state” method of test for use in solar simulators is also described in this British Standard. Details are given for the specification of the simulator and for the correction necessary to take account of the extra thermal irradiance present indoors.

The requirements for test facilities, instrumentation and reporting formats used in this British Standard are as far as possible in accordance with the Recommendations for European Solar Collector Test Methods²⁾.

1 Scope

This British Standard describes methods of test for the thermal performance of a non-concentrating solar collector using a liquid heat transfer fluid which enters the collector at a single inlet and leaves the collector at a single outlet. It may also be applied to a collector with more than one inlet or outlet, or to a combination of collectors, provided that the external piping is connected so as to provide effectively a single inlet and a single outlet.

NOTE The titles of the publications referred to in this standard are listed on the inside back cover.

2 Definitions and nomenclature

2.1 Definitions

For the purposes of this British Standard the following definitions apply.

2.1.1

absorber plate (absorber)

the element of a collector that receives and absorbs solar radiation and converts it into heat

2.1.2

absorptance

the ratio of the solar radiation absorbed by a surface to that which falls on the surface

2.1.3

ambient air temperature

the temperature of the air surrounding the collector as measured by a thermometer in a vented enclosure and shielded from solar, sky and ground radiation

2.1.4

angle of incidence

the angle between direct solar radiation and the normal to the collector aperture

2.1.5

aperture

that part of the outer surface of the collector which admits solar radiation to the absorber plate, including any glazing bars or supports over the absorber

2.1.6

aperture area

the maximum area projected by the aperture

¹⁾ ASHRAE Standard 93-77, “*Methods of testing to determine the thermal performance of solar collectors*”, The American Society of Heating, Refrigerating and Air-conditioning Engineers, Inc., 345 East 47th Street, New York, N.Y. 10017.

²⁾ Solar collectors: Test methods and design guidelines (1985), W.B. Gillett, J.E. Moon (eds), D. Reidel, Dordrecht, for the Commission of the European Communities.

2.1.7

collector (solar collector)

the general term for a device in which solar radiation is absorbed and converted to heat which is removed by a heat transfer fluid

2.1.8

collector efficiency factor

the ratio of the efficiency of a collector to the value it would have if the whole absorber plate were at the mean fluid temperature

2.1.9

collector flow factor

the ratio of the collector heat removal factor to the collector efficiency factor (F_R/F')

2.1.10

collector heat loss coefficient

the product of the collector efficiency factor and the overall heat loss coefficient ($F'U_L$), the negative of the slope of the thermal performance characteristic

2.1.11

collector heat removal factor

the ratio of the efficiency of a collector to the value it would have if the whole absorber plate were at the fluid inlet temperature

2.1.12

efficiency (of a collector)

the ratio of the output power, as heat in the heat transfer fluid, per unit area of collector to the equivalent normal irradiance

2.1.13

emittance

the ratio of the thermal radiation from unit area of a surface to the radiation from unit area of a full emitter (black body) at the same temperature

2.1.14

flat plate collector

a non-concentrating collector in which the absorber plate is essentially planar

2.1.15

fluid inlet temperature

the temperature of the heat transfer fluid as it enters the collector

2.1.16

fluid outlet temperature

the temperature of the heat transfer fluid as it leaves the collector

2.1.17

heat transfer fluid

the fluid that passes through the collector and removes heat from the absorber plate

2.1.18

irradiance (diffuse solar)

the irradiance of solar radiation incident from the whole of the sky except that contributing to the direct solar irradiance

2.1.19

irradiance (direct solar)

the irradiance of solar radiation incident from the sun's disc and from the circum-solar region of the sky within a subtended half angle of 8°

2.1.20**irradiance (equivalent normal solar)**

the irradiance normal to the plane of the aperture whose effect on the thermal output of the collector would be the same as that of the total solar irradiance on the aperture

2.1.21**irradiance (thermal)**

the irradiance of radiation at wavelengths greater than 4 μm

2.1.22**irradiance (total solar)**

the sum of the direct and diffuse solar irradiance

2.1.23**mean fluid temperature**

the average temperature of the heat transfer fluid in the collector. Its value is taken to be the arithmetic mean of the fluid inlet and outlet temperatures

2.1.24**non-concentrating collector**

a collector that does not concentrate onto the absorber the solar radiation passing through the aperture

2.1.25**overall heat loss coefficient**

the mean heat transfer coefficient from the heat transfer fluid in the collector to the ambient air

2.1.26**reduced temperature**

the ratio of the difference between the mean fluid temperature in the collector and the ambient temperature to the equivalent normal solar irradiance

2.1.27**thermal performance characteristic**

a plot of the steady-state efficiency of a collector against reduced temperature

2.1.28**zero-loss collector efficiency**

the efficiency of the collector when the mean fluid temperature is equal to the ambient air temperature $[F'(\alpha\tau)_0]$

2.2 Nomenclature

For the purposes of this British Standard, the following nomenclature applies.

A	aperture area (m^2)
c	specific heat capacity of heat transfer fluid [$\text{J}/(\text{kg K})$]
D	day of year (dimensionless)
E	equation of time (h)
F'	collector efficiency factor (dimensionless)
F''	collector flow factor (dimensionless)
F_R	collector heat removal factor (dimensionless)
G	equivalent normal solar irradiance (W/m^2)
G_b	direct solar irradiance in plane of collector (W/m^2)
G_d	diffuse solar irradiance in plane of collector (W/m^2)
G_L	thermal irradiance in plane of collector (W/m^2)
G_R	thermal irradiance typical of outdoor conditions (W/m^2)
G_T	total solar irradiance in plane of collector (W/m^2)
GMT	Greenwich Mean Time (h)

$\dot{m}$	mass flowrate (kg/s)
M	fluid capacity of collector (kg)
$\dot{q}$	output power per unit aperture area (W/m ²)
T^*	derived value of reduced temperature for steady outdoor conditions (K m ² /W)
T_a	ambient air temperature (°C)
T_e	fluid outlet temperature (°C)
T_i	fluid inlet temperature (°C)
T_m	mean fluid temperature (°C)
u	air speed (m/s)
U	collector heat loss coefficient [W/(m ² K)]
U_b	back loss coefficient [W/(m ² K)]
U_{ca}	heat transfer coefficient from cover to ambient air [W/(m ² K)]
U_L	overall heat loss coefficient [W/(m ² K)]
α	absorptance (dimensionless)
α	solar azimuth (degrees measured from N through E)
α_p	collector azimuth (degrees measured from N through E)
$(\alpha\tau)_d$	effective absorptance-transmittance product for uniformly diffuse irradiance (dimensionless)
$(\alpha\tau)_\theta$	effective absorptance-transmittance product for angle of incidence θ (dimensionless)
β	collector tilt (degrees from horizontal)
γ	solar altitude (degrees)
δ	solar declination (degrees N of equator)
Δt	increment of time over which transient data are averaged (s)
ϵ	emittance of aperture cover plate (dimensionless)
η	derived value of collector efficiency for steady outdoor conditions (dimensionless)
η_o	zero-loss collector efficiency (dimensionless)
θ	angle of incidence (degrees from normal)
λ	longitude (degrees E of Greenwich)
μ	collector parameter (dimensionless)
ρ	density (kg/m ³)
σ	Stefan-Boltzmann constant [W/(m ² K ⁴)]
ϕ	latitude (degrees N of equator)
τ	transmittance (dimensionless)
τ_d	Heat discharge time of collector (s)
ω	solar hour angle (degrees W of solar noon)

3 Collector location and mounting

3.1 General. For convenience, the information relating to collector location and mounting for both methods of test specified by this British Standard is gathered together in this clause. Guidance is also given about the choice of test site for the outdoor method of test. The applicability of this clause to each method of test is indicated in clauses 6 and 7.

3.2 Location of collector

3.2.1 Except when using a solar simulator, the collector shall be located where there will be no significant obstructions in its field of view.

NOTE This condition will be satisfied if not more than 5 % of the sky in the field of view of the collector is obstructed.

3.2.2 The collector shall be located such that a shadow will not be cast on to the collector at any time during the test period.

3.2.3 The collector shall be located where there will be no significant solar energy reflected on to the collector from surrounding buildings or any other surfaces in the vicinity during the test period.

NOTE The reflectance of most rough surfaces, such as grass, weathered concrete or chippings is usually low enough to satisfy this condition. Surfaces to be avoided in the collector's field of view are large expanses of glass, metal or water.

3.2.4 The collector shall be located so as to allow the free passage of air in front of and behind the collector.

3.2.5 The collector shall be located such that within its field of view there will be no significant sources of thermal radiation at temperatures different from ambient.

NOTE If care is taken in choosing a site devoid of adjacent surfaces that could be significantly warmer than ambient, this condition will be met. For example, it is essential that care is taken when locating the collector on the roof of a building to ensure that there are no chimneys (including possible exhaust plumes) in the collector's field of view. In a solar simulator the area of surfaces in the field of view of the collector which are not at ambient temperature should be minimized. It is important that the thermal irradiance at the collector aperture does not exceed that of a black body at ambient temperature by more than 100 W/m² (see 4.7.6).

3.3 Mounting of collector

3.3.1 *Collectors not designed as free standing units.* Collectors not designed as free standing units (e.g. those which do not have a weatherproof casing, or are designed to be an integral part of a roof structure) shall be mounted in accordance with the manufacturer's recommendations and with those conditions of 3.3.2 which are not in conflict with the manufacturer's recommendations. Where the conditions are not met this shall be reported with the test results (see F.2).

3.3.2 *Collectors designed as free standing units.* The collector shall be mounted such that its lowest edge is more than 0.5 m above the local ground or floor surface.

The collector mounting shall not obstruct the aperture of the collector.

Except when using a solar simulator, the collector shall either be mounted in a fixed position facing approximately south or be moved to follow the sun in azimuth. If the angle of incidence is not recorded directly, the collector azimuth shall be determined to within $\pm 2^\circ$ for each collector position.

The angle of tilt shall be determined to within $\pm 2^\circ$ and stated in the test report (see F.2).

NOTE The collector should normally be mounted such that the angle of tilt between the plane of the aperture and the horizontal can be fixed at $45 \pm 10^\circ$, but if it is necessary to perform the test at some other angle of tilt, e.g. one corresponding to a particular roof structure, then this is permitted provided that the angle of tilt is clearly stated in the test report (see F.2).

4 Test apparatus

4.1 General

4.1.1 This clause describes the test apparatus, other than the location and mounting of the collector, for the methods of test described in clauses 6 and 7.

4.1.2 The purpose of the apparatus is to provide a steady flow of fluid through the collector, in such a manner that the fluid inlet temperature can be held at any value between ambient temperature and the maximum fluid inlet temperature adopted for any test in accordance with 6.5.1 or 7.5.1.

4.2 Test systems. The system shall be designed to circulate the heat transfer fluid through either a closed loop such as is shown in Figure 1, or an open loop such as is shown in Figure 2.

NOTE In a closed test system the amount of air in the fluid can be kept small, once it has been released, by heating the fluid to the highest operating temperature before a test. An open test system has the disadvantage that air can be entrained in the fluid and can also be released from solution within the collector. The use of a constant head tank minimizes fluctuations in the flowrate.

4.3 Pipework and fittings

4.3.1 Pipework and fittings shall be compatible with the fluid used over the range of operating temperatures, so as to minimize corrosion (especially with aqueous fluids) or other failures (such as swelling of gaskets with some non-aqueous fluids).

4.3.2 The pipe between the temperature regulator and the inlet to the collector shall be insulated to ensure a rate of heat loss of not more than 0.2 W/K, and any part of it that lies outdoors shall be protected by a reflective weatherproof cover.

4.3.3 Any pipes separating the inlet of the collector from the point at which the fluid inlet temperature is sensed or the outlet of the collector from the point at which the fluid outlet temperature is sensed shall be protected by insulating reflective weatherproof covers extending beyond the positions of the temperature sensors, such that the calculated temperature gain or loss along either pipe under test conditions does not exceed 0.01 K. (See also 5.7.2 and 5.7.4 on the positioning of the temperature sensors and on means for thoroughly mixing the fluid, for example, by a sharp bend in the pipeline.)

4.3.4 A short length of transparent tube shall be installed in the fluid system such that air bubbles or other contaminants will be observed, if present.

NOTE 1 The test is invalid if air bubbles or other contaminants are observed.

The transparent tube shall be placed as close as possible to the collector inlet without influencing the fluid inlet temperature control or temperature measurements.

NOTE 2 It has been found convenient to make use of a variable area flowmeter for this purpose, because this simultaneously gives a visual indication of the flowrate.

4.3.5 A filter shall be placed upstream of the flowmeter.

NOTE In the absence of recommendations by the manufacturer of the flowmeter, a filter mesh of 200 μm is recommended.

Filters should be installed to protect other components as necessary.

4.4 Pump and flow control device

4.4.1 The pump shall be located in the system in such a position that the heat which it dissipates in the fluid does not impair the control of the fluid temperature at the inlet to the collector or affect the fluid temperature rise through the collector.

4.4.2 The pump and flow control device shall be capable of maintaining a flow through the collector at a flowrate that is steady to within $\pm 1\%$, despite temperature variations, at any chosen inlet temperature in the operating range.

NOTE The flowrates necessary for testing are given in **6.5.2** and **7.5.2**. To allow for variations in collector size and in manufacturers' recommended flowrates, it is recommended that for water the pump and control device be capable of working in the range 40 L/h to 200 L/h. With non-aqueous fluids higher flowrates may be necessary. For some types of pump a valved by-pass, as shown in Figure 1, may improve the control of flow.

4.5 Heat transfer fluid

4.5.1 The heat transfer fluid shall be water or any liquid recommended by the collector manufacturer.

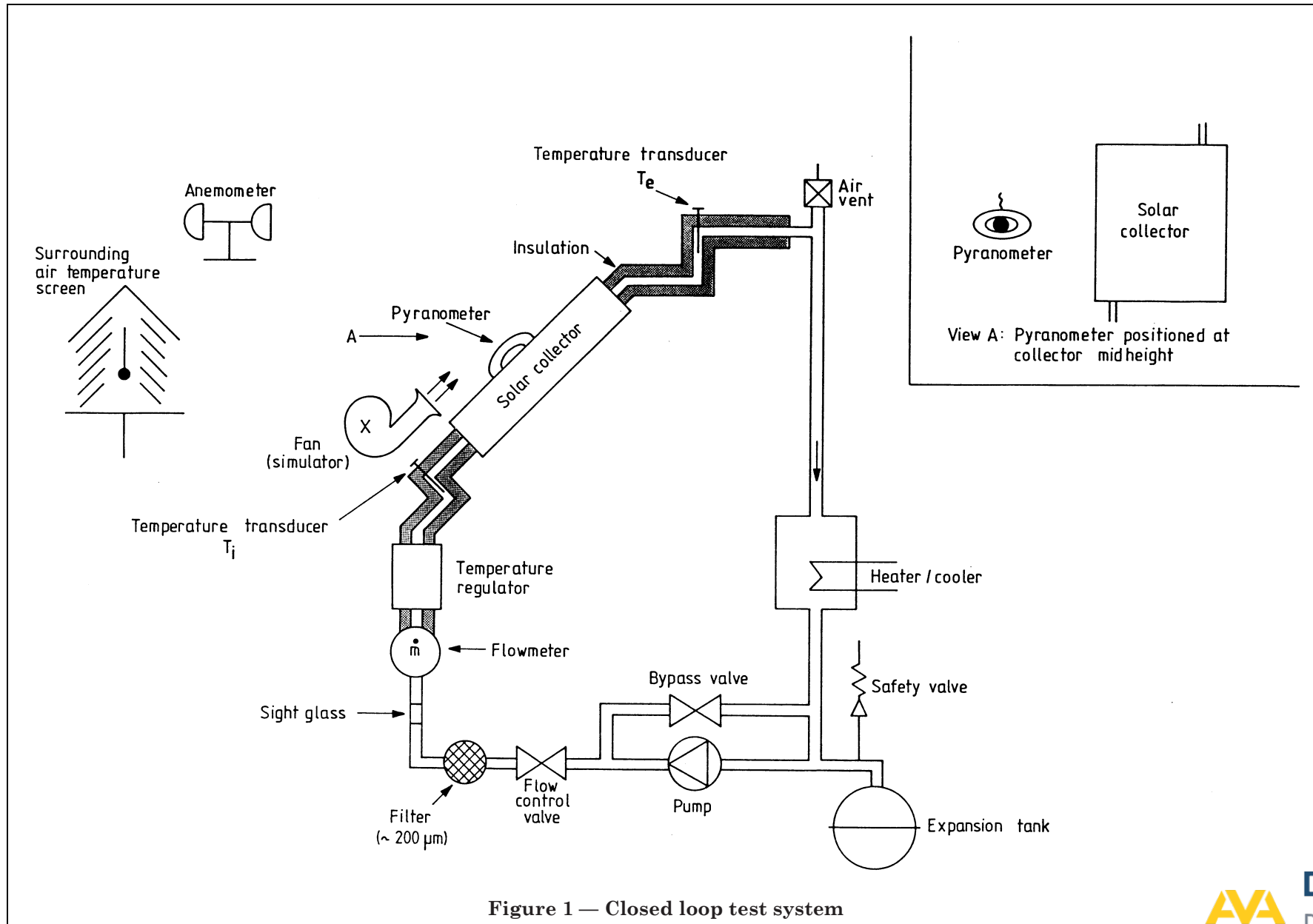
4.5.2 The specific heat capacity and the density of the fluid used shall be known to within $\pm 1\%$ over the range of operating temperatures.

4.5.3 The condition of the fluid shall be checked periodically, and the fluid changed if necessary, to ensure that its properties are well defined during the test.

4.6 Temperature regulator. The temperature regulator shall be capable of providing a constant fluid inlet temperature at any chosen value in the operating range, at the required flowrate of heat transfer fluid, and despite any variation of the irradiance on the collector. To meet this condition fluctuations in the fluid inlet temperature shall not exceed $\pm 0.1\text{ K}$.

NOTE It will be found convenient to use a temperature regulator with which it is possible to change the fluid inlet temperature by 20 K in a period of 15 min or less. It may then be possible for the whole test procedure of either of the methods of test to be performed in a day.

To achieve both rapid changes of fluid inlet temperature and precise control of the fluid inlet temperature, it is recommended that provision be made both for cooling and heating the fluid. This can be achieved by using two heat exchangers in series in the system, the first being used to cool the fluid to a temperature below the desired value and the second to bring the temperature up to the desired value. An alternative method is to use controlled mixing of fluid from high and low temperature reservoirs. Further fine control of the fluid inlet temperature may be provided by using a small controlled in-line electric heater near the collector inlet. This may be found particularly useful where a long pipe between the temperature controller and the collector inlet cannot be avoided. Boiling of the fluid on the surface of the electric element may occur if the power dissipated in the element is too high, and it is essential that this is avoided.



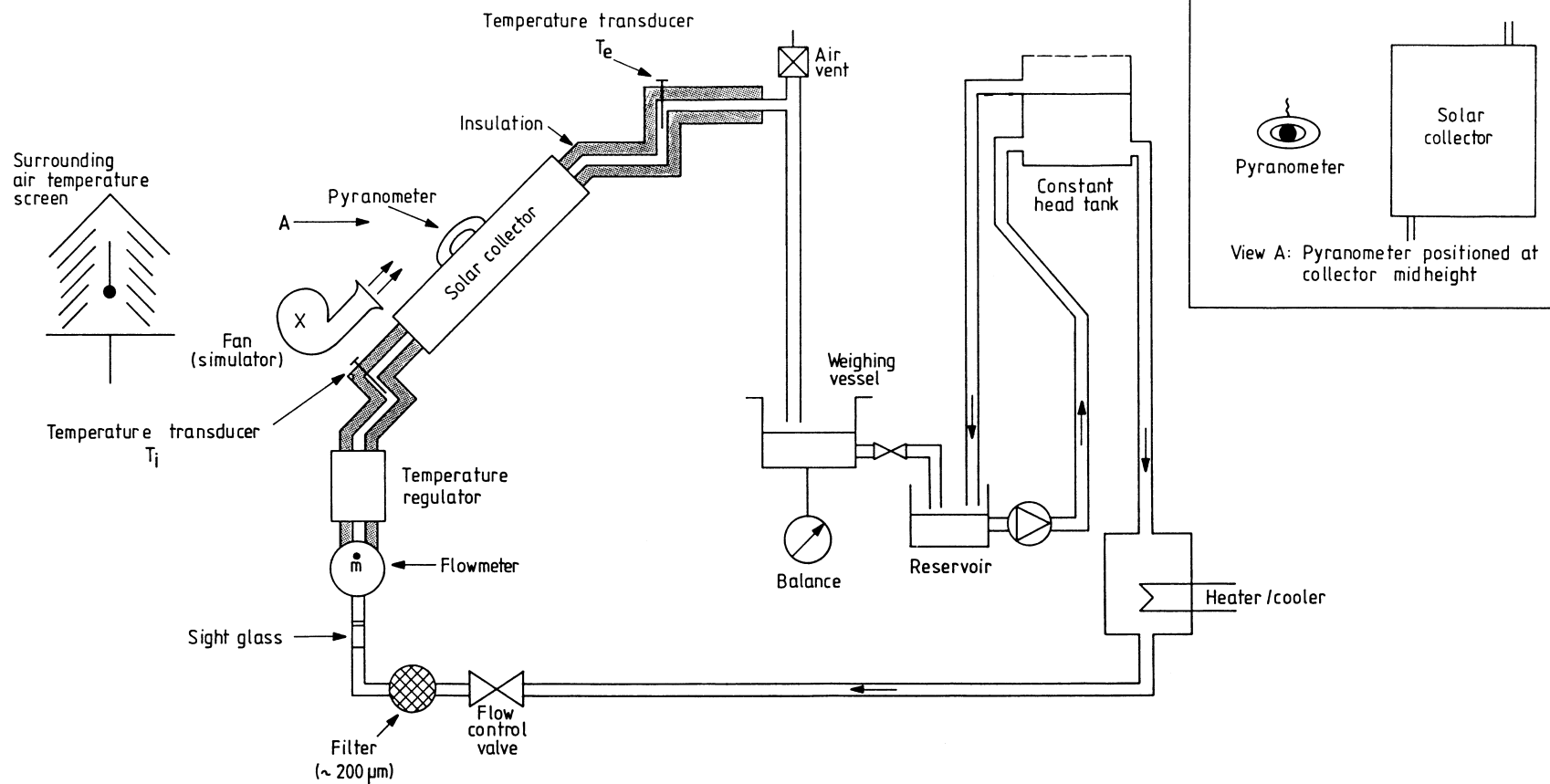


Figure 2 — Open loop test system

4.7 Simulator

4.7.1 Simulators for use in the method of test described in clause 7 shall have the characteristics given in 4.7.2 to 4.7.6. A wind generator, as described in 4.8, shall be used with the simulator.

4.7.2 The mean irradiance over the collector aperture, measured in accordance with 5.3.4, shall not be less than 400 W/m² at any time, and shall not vary in time by more than ± 50 W/m².

4.7.3 At any time the irradiance at any point on the collector aperture shall not differ from the mean irradiance over the aperture by more than ± 30 %.

4.7.4 In order that near-normal incidence may be assumed, none of the simulated solar radiation shall have an angle of incidence greater than 25°.

4.7.5 The spectral distribution of the simulated solar radiation shall lie within the limits shown in Table 1.

NOTE This is particularly important when the optical properties of the collector are spectrally dependent.

These limits may be relaxed where the absorptance of the absorber plate and transmittance of the cover(s) are each substantially independent of wavelength in the range 0.3 μ m to 4 μ m. Any relaxation shall be stated in the test report [see F.2 b)].

4.7.6 The thermal irradiance at the collector aperture, measured in accordance with 5.5, shall not exceed that of a black enclosure at ambient air temperature by more than 100 W/m².

Table 1 — Spectral distribution of simulated solar radiation

Waveband μ m	Irradiance %
0.3 to 0.4	1 to 4
0.4 to 0.7	35 to 53
0.7 to 1.0	21 to 37
1.0 to 4.0	14 to 34

4.8 Wind generator

A wind generator shall be used with the solar simulator to produce an air flow across the face of the collector such that the distribution of air speed across the aperture cover plate, measured in accordance with 5.6, has a mean value between 2 m/s and 8 m/s. The same value of mean speed to within ± 50 % shall be maintained throughout a test. The air issuing from the wind generator shall not differ in temperature from ambient air by more than ± 1 K.

5 Instrumentation and measurement methods

5.1 General. The test methods involve measurement of the items shown in Table 2, using the instrumentation and measurement methods described in this clause.

5.2 Measurements of time. The standard time necessary for calculating the angle of incidence of direct solar radiation is Greenwich Mean Time, expressed on the 24 h clock; it shall be recorded to the accuracy and precision given in Table 2, item a). Time intervals shall be measured, by the same clock or otherwise, to the accuracy and precision given in Table 2, item b).

NOTE It may be convenient to use the data logger as a clock.

5.3 Measurements of solar irradiance

5.3.1 General. The direct and diffuse components of the irradiance in the plane of the collector aperture shall be measured.

NOTE 1 The desired accuracy of measurement of ± 1 % for these variables is not achievable with the pyranometers presently available. The World Meteorological Organisation has drawn up specifications for pyranometers for general meteorological purposes, and until better equipment becomes commercially available pyranometers of W.M.O. Classes 1 and 2 should be used for collector testing.

Pyranometers shall have their bodies shaded from solar radiation.

NOTE 2 If a pyranometer is tilted from the horizontal, then additional shading from sky radiation may be necessary.

Pyranometers shall be calibrated to the World Radiometric Reference upon receipt from the manufacturer, and recalibrated each year. The place of origin of the certificates of calibration shall be stated with the test results (see F.3).