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Method of Testing for Rating Solar Collectors Based on Thermal Performance

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Interim Report

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U. S. DEPARTMENT OF COMMERCE, Frederick B. Dent, Secretary
NATIONAL BUREAU OF STANDARDS, Richard W. Roberts, Director

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ABSTRACT

The National Bureau of Standards has made a study of the different techniques that could be used for testing solar collectors and rating them on the basis of thermal performance. This document outlines a proposed standard test procedure based on that study. It is written in the format of a standard of the American Society of Heating, Refrigerating, and Air Conditioning Engineers and specifies the recommended apparatus, instrumentation, and test procedure.

Key Words: Solar collector; standard test; thermal performance; solar energy; standard; solar radiation.

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SECTION 1. PURPOSE

1.1 The purpose of this standard is to provide test methods for determining the thermal performance of solar collectors which heat fluids and are used in systems to provide the thermal requirements for heating, cooling, and the generation of domestic hot water in buildings.

SECTION 2. SCOPE

2.1 This standard applies to solar collectors in which a fluid enters the device through a single inlet and leaves the device through a single outlet. The collector containing more than one inlet and/or outlet can be tested according to this standard provided that the external piping can be connected in such a way as to effectively provide a single inlet and/or outlet for the determination of the bulk properties of the fluid entering and leaving the collector. The fluid can be either a gas or liquid but not a mixture of the two. The collector can be a concentrating collector provided that the aperture or interception area for the device can be determined. The collector may have the capability of rotating so as to track the sun.

2.2 This standard is not applicable to those configurations in which the flow into the collector and out of the collector cannot be reduced effectively to one inlet and one outlet. This standard is not applicable to those collectors in which the thermal storage unit is an integral part of the collector such that the collection process and storage process cannot be separated for the purpose of making measurements.

2.3. This standard does not address factors relating to cost or consideration of requirements for interfacing with a specific heating and cooling system.

2.4 The present version of the standard provides test methods for determining the steady-state efficiency of solar collectors. The transient response of solar collectors cannot be determined with the test methods outlined herein.

SECTION 3. DEFINITIONS

3.1 AMBIENT AIR

Ambient air is the outdoor air in the vicinity of the solar collector being tested.

3.2 ABSORBER

The absorber is that part of the solar collector that receives the incident solar radiation and transforms it into thermal energy. It is usually a solid surface through which energy is transferred to the transfer fluid; however, the transfer fluid itself could be the absorber in the case of a "black liquid".

3.3 APERTURE

The aperture is the opening or projected area of a solar collector through which the unconcentrated solar energy is admitted and directed to the absorber.

3.4 CONCENTRATING COLLECTOR

A concentrating collector is a solar collector that contains reflectors, lenses, or other optical elements to concentrate the energy falling on the aperture onto a heat exchanger of surface area smaller than the aperture.

3.5 CONCENTRATOR

The concentrator is that part of a concentrating collector which directs the incident solar radiation onto the absorber.

3.6 COVER PLATE

The cover plate designates the diathermanous material or materials covering the aperture and most directly exposed to the solar radiation. These materials are generally used to reduce the heat loss from the absorber to the surroundings and to protect the absorber.

3.7 FLAT-PLATE COLLECTOR

A flat-plate collector is a solar collector in which the solid surface absorbing the incident solar radiation is essentially flat and employs no concentration.

3.8 GROSS CROSS-SECTIONAL AREA

Gross cross-sectional area is the overall or outside area of a flat-plate collector. It is usually slightly larger than the absorber area since it includes the framework required to hold the absorber.

3.9 INCIDENT ANGLE

The incident angle is the angle between the sun's rays and the outward drawn normal from the solar collector.

3.10 INSOLATION

Insolation is the rate of solar radiation received by a unit surface area in unit time (W/m^2, $Btu/(h \cdot ft^2)$).

3.11 INSTANTANEOUS EFFICIENCY

The instantaneous efficiency of a solar collector is defined as the amount of energy removed by the transfer fluid per unit of transparent frontal area over a given 15 minute period divided by the total incident solar radiation onto the collector per unit area for the 15 minute period.

3.12 INTEGRATED AVERAGE INSOLATION

The integrated average insolation is the total energy per unit area received by a surface for a specified time period divided by the time period (W/m^2, $Btu/(h \cdot ft^2)$).

3.13 PYRANOMETER

A pyranometer is a radiometer used to measure the total incident solar energy per unit time per unit area upon a surface which includes the beam radiation from the sun, the diffuse radiation from the sky, and the shortwave radiation reflected from the foreground.

3.14 PYRHELIOMETER

A pyrheliometer is a radiometer used to measure the direct or beam radiation on a surface normal to the sun's rays.

3.15 QUASISTEADY

Quasisteady is the term used in this document to describe the state of the solar collector test when the flow rate and temperature of the fluid entering the collector is constant but the exit fluid temperature changes "gradually" due to the normal change in insolation that occurs with time for clear sky conditions.

3.16 SOLAR COLLECTOR

A solar collector is a device designed to absorb incident solar radiation and to transfer the energy to a fluid passing in contact with it.

3.17 TOTAL INCIDENT INSOLATION

Total incident insolation is the total energy received by a unit surface area for a specified time period (J/m^2).

3.18 TRANSFER FLUID

The transfer fluid is the medium such as air, water, or other fluid which passes through or in contact with the solar collector and carries the thermal energy away from the collector.

3.19 TRANSPARENT FRONTAL AREA

The transparent frontal area is the area of the transparent frontal surface for flat-plate collectors.

3.20 STANDARD AIR

Standard air is air weighing 1.2 kg/m^3 (0.075 lb/ft^3), and is equivalent in density to dry air at a temperature of 21.1°C (70°F) and a barometric pressure of 1.01×10^5 N/m^2 (29.92 in. of Hg)

3.21 STANDARD BAROMETRIC PRESSURE

1.01×10^5 N/m^2 (29.92 in. of Hg)

SECTION 4. CLASSIFICATIONS

4.1 Solar collectors may be classified according to their collecting characteristics, the way in which they are mounted, and the type of transfer fluid they employ.

4.1.1 Collecting Characteristics. A non-concentrating or "flat-plate" collector is one in which the absorbing surface for solar radiation is essentially flat with no means for concentrating the incoming solar radiation. A concentrating or "focusing" collector is one which usually contains reflectors or employs other optical means to concentrate the energy falling on the aperture onto a heat exchanger of surface area smaller than the aperture.

4.1.2 Mounting. A collector can be mounted to remain stationary, be adjustable as to tilt angle (measured from the horizontal) to follow the change in solar declination, or be designed to track the sun. Tracking is done by employing either an equatorial mount or an altazimuth mounting, for the purpose of increasing the absorption of the daily solar irradiation.

4.1.3 Type of Fluid. A collector will usually use either a liquid or a gas as the transfer fluid. The most common liquids are water or a water-ethylene glycol solution. The most common gas is air.

SECTION 5. REQUIREMENTS

5.1 Solar collectors shall be tested for rating in accordance with the provisions set forth below and in Section 8.

5.1.1 The size of collector tested shall be large enough so that the performance characteristics determined will be indicative of those that would occur when the collector is part of an installed system. If the collector is modular and the test is being done on one module, it should be mounted and insulated in such a way that the back and edge losses will be characteristic of those that will occur during operation on a structure.

5.1.2 The collector shall be mounted in a location such that there will be no significant energy reflected or reradiated onto the collector from surrounding buildings or any other surfaces in the vicinity of the test stand for the duration of the test(s). This will be satisfied if the ground and immediately adjacent surfaces are diffuse with a reflectance of less than 0.20. If significent reflection will occur, provision shall be made to shield the collector by the use of a non-reflective shield. In addition, the test stand shall be located so that a shadow will not be cast onto the collector at any time during the test period.

5.1.3 The test(s) shall be conducted on days having weather conditions such that the 15 minute integrated average insolation measured in the plane of the collector or aperture, reported, and used for the computation of instantaneous efficiency values shall be a minimum of 630 W/m^2 (199.8 Btu/(h.ft^2)). Specific values that can be expected for clear sky conditions are shown in Tables A1 through A6 taken from reference [1]. More accurate estimates can be made using the tables in conjunction with clearness numbers*.

5.1.4 The orientation of the collector shall be such that the incident angle (measured from the normal to the collector surface or aperture) is less than 45° during the period in which test data is being taken. Angles of incidence can be estimated from Tables A7 through A12 taken from reference [2]. More accurate estimates can be made using the procedures outlined in references [3], p. 393 or [4], pp. 283-292.

5.1.5 The air velocity across the collector surface of a flat-plate collector or aperture of a concentrating collector during the test(s) shall be measured. The measurement shall be made at a distance of approximately 1 m (3.3 ft) from the collector along the direction it faces and at a height corresponding to the center of the collector panel.

5.1.6 The range of ambient temperatures for all reported test points comprising the "efficiency curve" shall be less than 30°C (54°F).

5.1.7 The transfer fluid used in the solar collector shall have a known specific heat which varies by less than 0.5% over the temperature range of the fluid during a particular 15 minute test period.

SECTION 6. INSTRUMENTATION

6.1 SOLAR RADIATION MEASUREMENT

6.1.1 A pyranometer shall be used to measure the total short-wave radiation from both the sun and the sky. The instrument shall have the following characteristics [5]:

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* Reference [3], p. 394, Figure 4.

6.1.1.1 Change of Response Due to Variation in Ambient Temperature. The instrument shall either be equipped with a built-in temperature compensation circuit and have a temperature sensitivity of less than ± 1 percent over the range of ambient temperature encountered during the test(s) or have been tested in a temperature-controlled chamber over the same temperature range so that its temperature coefficient has been determined in accordance with reference [5].

6.1.1.2 Variation in Spectral Response. Errors caused by a departure from the required spectral response of the sensor shall not exceed ± 2 percent over the range of interest*.

6.1.1.3 Nonlinearity of Response. Unless the pyranometer was supplied with a calibration curve relating the output to the insolation, its response shall be within ± 1 percent of being linear over the range of insolation existing during the tests.

6.1.1.4 Time Response of Pyranometer. The time constant of the pyranometer shall be less than 5 s.

6.1.1.5 Variation of Response With Attitude. The calibration factor of a pyranometer can change when the instrument is used in other than the orientation for which it was calibrated. The instruments' calibration factor (including corrections) shall change less than ± 0.5 percent compared with the calibrated orientation when placed in the orientation used during the test(s).

6.1.1.6 Variation of Response With Angle of Incidence. Ideally the response of the receiver is proportional to the cosine of the zenith angle of the solar beam and is constant at all azimuth angles. The pyranometer's deviation from a true cosine response shall be less than ± 1 percent for the incident angles encountered during the test(s).

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* Pyranometer thermopiles which are "all black" and which are coated with Parson's black or 3M 101C10 velvet black paint and which have selected optical grade hemispheres usually satisfy this requirement [5]. Note: Identification of commercial materials does not imply recommendation or endorsement by the National Bureau of Standards.

6.1.2 The pyranometer shall be calibrated within six months of the collector test(s) against other pyranometers whose calibration uncertainty relative to recognized measurement standards is known*.

6.2 TEMPERATURE MEASUREMENTS

6.2.1 Temperature measurements shall be made in accordance with ASHRAE Standard 41-66, Part 1 [6].

6.2.2 Temperature Difference Measurements Across the Solar Collector. The temperature difference of the transfer fluid across the solar collector shall be measured with:

a. Thermopile (air or water as the transfer fluid)

b. Calibrated resistance thermometers connected in two arms of a bridge circuit (only when a liquid is the transfer fluid)

6.2.3 The accuracy and precision of the instruments and their associated readout devices shall be within the limits as follows:

	Instrument Accuracy**	Instrument Precision***
Temperature	$\pm$ 0.5°C ($\pm$ 0.9°F)	$\pm$ 0.2°C ($\pm$ 0.4°F)
Temperature Difference	$\pm$ 0.1°C ($\pm$ 0.2°F)	$\pm$ 0.1°C ($\pm$ 0.2°F)

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* One nationally recognized calibration center is the Eppley Laboratory in Newport, Rhode Island. The calibration data are commonly expressed in cal/(cm^2· min) or in langleys/min. In some meteorological services, calibration data are supplied in milliwatt/cm^2. The following equivalent units shall be used:

$$1 \text{ cal/(cm}^2\cdot \text{ min)} = 1 \text{ ly/min} = .001434 \text{ W/m}^2$$

$$1 \text{ mW/cm}^2 = 0.1 \text{ W/m}^2$$

** The ability of the instrument to indicate the true value of the measured quantity.

*** Closeness of agreement among repeated measurements of the same physical quantity.

6.2.4 In no case should the smallest scale division of the instrument or instrument system exceed 2 1/2 times the specified precision. For example, if the specified precision is ± 0.1 °C (± 0.2 °F), the smallest scale division shall not exceed 0.25 °C (0.5 °F).

6.2.5 The instruments shall be configured and used in accordance with Section 7. of this standard.

6.2.6 When using thermopiles, they shall be constructed in accordance with ANSI Standard C96.1-1964 (R 1969) [7].

6.3 LIQUID FLOW MEASUREMENTS

6.3.1 The accuracy of the liquid flow rate measurement using the calibration, if furnished shall be equal to or better than ± 1.0% of the measured value.

6.4 INTEGRATORS AND RECORDERS

6.4.1 Strip chart recorders used shall have an accuracy equal to or better than ± 0.5% of the temperature difference and/or voltage measured and have a time constant of 1 s or less.

6.4.2 Electronic integrators used shall have an accuracy equal to or better than ± 1.0% of the measured value.

6.5 AIR FLOW MEASUREMENTS

When air is used as the transfer fluid, air flow rate shall be determined as described in Section 7.

6.6 PRESSURE MEASUREMENTS

6.6.1 Nozzle Throat Pressure. The pressure measurement at the nozzle throat shall be made with instruments which shall permit measurements of pressure to within ± 2.0% absolute and whose smallest scale division shall not exceed 2 1/2 times the specified accuracy [11].

6.6.2 Air Flow Measurements. The static pressure across the nozzle and the velocity pressure at the nozzle throat shall be measured with manometers which have been calibrated to have an accuracy to within ± 1.0% of the reading. The smallest manometer scale division shall not exceed 2.0% of the reading [11].

6.6.3 Pressure Drop Across Collector. The static pressure drop across the solar collector shall be measured with a manometer having an accuracy of 2.49 N/m^2 (0.01 in. of water).

6.7 TIME AND MASS MEASUREMENTS

Time measurements and mass measurements shall be made to an accuracy of ± 0.20% [11].

6.8 WIND VELOCITY

The wind velocity shall be measured with an instrument and associated readout device that can determine the integrated average wind velocity for each 15 minute test period to an accuracy of ± 0.08 m/s (1.8 mph).

SECTION 7. APPARATUS AND METHOD OF TESTING

7.1 LIQUID AS THE TRANSFER FLUID

The test configuration for the solar collector employing liquid as the transfer fluid is shown in Figure A1*.

7.1.1 Solar Collector. The solar collector should be mounted in its rigid frame at the predetermined tilt angle (for stationary collectors) or movable frame (for movable collectors) and anchored rigidly enough to a foundation so that the collector can hold its selected angular position against a strong gust of wind.

7.1.2 Ambient Temperature. The ambient temperature sensor shall be housed in a well-ventilated instrumentation shelter with its bottom 1.25 m (4.1 ft) above the ground and with its door facing north, so that the sun's direct beam cannot fall upon the sensor when the door is opened. The instrument shelter shall be painted white outside and shall not be closer to any obstruction than twice the height of the obstruction itself (i.e., trees, fences, buildings, etc.) [15].

7.1.3 Pyranometer. The pyranometer shall be mounted on the surface parallel to the collector surface in such a manner that it does not cast a shadow onto the collector plate. Precautions should be always taken to avoid subjecting the instrument to mechanical shocks or vibration during the installation. The pyranometer should be oriented so that the emerging leads or the connector are located north of the receiving surface (in the Northern Hemisphere) or are in some other manner shaded. This minimizes heating of the electrical connections by the sun.

Care should also be taken to minimize reflected and reradiated energy from the solar collector onto the pyranometer. Some pyranometers come supplied with shields. This should be adjusted so that the highest point on the shield lies parallel to and just below the plane of the thermopile. Some pyranometers not supplied with a shield may be susceptible to error due to reflections by radiation that originates below the plane of the thermopile. Precautions can be taken by constructing a cylindrical shield, the top of which should be coplaner with the thermopile [5].

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* The recommended apparatus consists of a closed loop configuration. An open loop configuration is an acceptable alternative provided that the test conditions specified herein can be satisfied.

7.1.4 Temperature Measurement Across the Solar Collector. The temperature difference of the transfer fluid between entering and leaving the solar collector shall be measured using either two calibrated resistance thermometers connected in two arms of a bridge or a thermopile made from calibrated, type T thermocouple wire all taken from a single spool. The thermopile shall contain any even number of junctions constructed according to the recommendations in reference [7]. Each resistance thermometer or each end of the thermopile is to be inserted into a well [8] located as shown in Figure A1. To insure good thermal contact, the wells shall be filled with light oil. The wells should be located just downstream of a right angle bend to insure proper mixing [6].

To minimize temperature measurement error, each probe should be located as close as possible to the inlet or outlet of the solar collector device. In addition, the piping between the wells and the collector shall be insulated in such a manner that the calculated heat loss or gain from the ambient air would not cause a temperature change for any test of more than 0.05°C (0.09°F) between each well and the collector.

7.1.5 Additional Temperature Measurements. The temperature of the transfer fluid at the two positions cited above shall also be measured by inserting appropriate sensors into the wells. Reference [6] should be followed in making these measurements.

7.1.6 Pressure Drop Across the Solar Collector. The pressure drop across the solar collector shall be measured using static pressure tap holes and a manometer. The edges of the holes on the inside surface of the pipe should be free of burrs and should be as small as practicable and not exceeding 1.6 mm (1/16 inch) diameter [12]. The thickness of the pipe wall should be 2 1/2 times the hole diameter [12].

7.1.7 Reconditioning Apparatus. As shown in Figure A1, a heat exchanger is used to cool the transfer fluid to simulate the building load and an adjustable electric resistance heater is used to control the inlet temperature to the prescribed test value. This combination of equipment or equivalent shall control the temperature of the fluid entering the solar collector to within $\pm$ 0.5°C ($\pm$ 0.9°F) at all times during the tests.

7.1.8 Additional Equipment. A pressure gauge, a pump, and a means of adjusting the flow rate of the transfer fluid shall be provided at the relative locations shown in Figure A1. Depending upon the test apparatus design, an additional throttle valve may be required in the line just preceding the solar collector for proper control. An expansion tank and a pressure relief valve should be installed to allow the transfer fluid to freely expand and contract in the apparatus*. In addition, filters should be installed within the apparatus as well as a sight glass to insure that the transfer fluid passing through the collector is free of contaminants including air bubbles.

7.2 AIR AS THE TRANSFER FLUID

The test configuration for the solar collector employing air as the transfer fluid is shown in Figure A2**.

7.2.1 Solar Collector. The solar collector should be mounted in its rigid frame at the predetermined tilt angle (for stationary collectors) or movable frame (for movable collectors) and anchored rigidly enough to a foundation so that the collector can hold its selected angular position against a strong gust of wind.

7.2.2 Ambient Temperature. The ambient temperature sensor shall be housed in a well-ventilated instrumentation shelter with its bottom 1.25 m (4.1 ft) above the ground and with its door facing north, so that the sun's direct beam cannot fall upon the sensor when the door is opened. The instrument shelter shall be painted white outside and shall not be closer to any obstruction than twice the height of the obstruction itself (i.e., trees, fences, buildings, etc.) [15].

7.2.3 Pyranometer. The pyranometer shall be mounted on the surface parallel to the collector surface in such a manner that it does not cast a shadow onto the collector plate. Precautions should be always taken to avoid subjecting the instrument to mechanical shocks or vibration during the installation. The pyranometer should be oriented so that the emerging leads or the connector are located north of the receiving surface (in the Northern Hemisphere) or are in some other manner shaded. This minimizes heating of the electrical connections by the sun.

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* Figure A1 should not be interpreted to mean that the relief valve and expansion tank necessarily be located below the solar collector.

** The recommended apparatus consists of a closed loop configuration. An open loop configuration is an acceptable alternative provided that the test conditions specified herein can be satisfied.

Care should also be taken to minimize reflected and reradiated energy from the solar collector onto the pyranometer. Some pyranometers come supplied with shields. This should be adjusted to be parallel to and to lie just below the plane of the thermopile. Some pyranometers not supplied with a shield may be susceptible to error due to reflections by radiation that originates below the plane of the thermopile. Precautions can be taken by constructing a cylindrical shield, the top of which should be coplaner with the thermopile [5].

7.2.4 Test Ducts. The air inlet duct, between the air flow measuring apparatus and the solar collector, shall have the same cross-sectional dimensions as the inlet manifold to the solar collector. The air outlet duct, between the solar collector and the reconditioning apparatus, shall have the same cross-sectional dimensions as the outlet manifold from the solar collector*.

7.2.5 Temperature Measurement Across the Solar Collector. A thermopile shall be used to measure the difference between the inlet air temperature and outlet air temperature of the solar collector. It shall be constructed from calibrated type T thermocouple wire all taken from a single spool. No extension wires are to be used in either its fabrication or installation. The wire diameter must be no larger than 0.51mm (24 AWG) and the thermopile shall be fabricated as shown in Figure A3. There shall be a minimum of six junctions in the air inlet test duct and six junctions in the air outlet test duct. These junctions shall be located at the center of equal cross-sectional areas.

During all tests, the variation in temperature at a given cross section of the air inlet and air outlet test ducts shall be less than $\pm$ 0.5°C ($\pm$ 0.9°F) at the location of the thermopile junctions. The variation shall be checked prior to testing utilizing instrumentation and procedures outlined in reference [6]. If the variation exceeds the limits above, mixing devices shall be installed to achieve this degree of temperature uniformity. Reference [16] discusses the positioning and performance of several types of air mixers.

The ends of the thermopile should be located as near as possible to the inlet and outlet of the solar collector. The air inlet and air outlet ducts shall be insulated in such a manner that the calculated heat loss or gain to or from the ambient air would not cause a temperature change for any test

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*The performance of air heaters is expected to be affected by the ductwork entering and leaving the solar collector considerably more so than in the case of solar collectors using a liquid as the transfer fluid.

of more than 0.05°C (0.09°F) between the temperature measuring locations and the collector.

7.2.6 Temperature Measurements. Sensors and read-out devices meeting the accuracy requirements of Section 6. and giving a continuous reading shall be used to measure the temperature at the locations in the air inlet and air outlet ducts shown in Figure A2. Reference [6] should be followed in making these measurements.

7.2.7 Duct Pressure Measurements. The static pressure drop across the solar collector shall be measured using a manometer as shown in Figures A2 and A4 [11]. Each side of the manometer shall be connected to four externally manifolded pressure taps on the air inlet and air outlet ducts. The pressure taps should consist of 6.4 mm (1/4 inch) nipples soldered to the duct and centered over 1 mm (0.040 inch) diameter holes. The edges of these holes on the inside surfaces of the ducts should be free of burrs and other surface irregularities [12].

7.2.8 Air Flow Measuring Apparatus. Where the air flow rate is sufficiently large, it shall be measured with the nozzle apparatus discussed in Section 7. of reference [11]. As shown in Figure A5, this apparatus consists basically of a receiving chamber, a discharge chamber and an air flow measuring nozzle. The distance from the center of the nozzle to the side walls shall not be less than 1 1/2 times the nozzle throat diameter, and the diffusion baffles shall be installed in the receiving chamber at least 1 1/2 nozzle throat diameters upstream of the nozzle and 2 1/2 nozzle throat diameters downstream of the nozzle. The apparatus should be designed so that the nozzle can be easily changed and the nozzle used on each test shall be selected so that the throat velocity is between 15 m/s (2960 fpm) and 35 m/s (6900 fpm). When nozzles are constructed in accordance with Figure A6 and installed in accordance with Section 7.2.9 of this Standard, the discharge coefficient may be assumed to be as follows:

Reynolds Number, N_{Re}	Coefficient of Discharge, C
20,000	0.96
50,000	0.97
100,000	0.98
150,000	0.98
200,000	0.99
250,000	0.99
300,000	0.99
400,000	0.99
500,000	0.99

If the throat diameter of the nozzle is 0.13 m (5 in.) or larger, the discharge coefficient may be assumed to be 0.99. For nozzles smaller than 0.05 m (2 in.) and where a more precise discharge coefficient than given above is desired, the nozzle should be calibrated. The area of the nozzle shall be determined by measuring its diameter to an accuracy of $\pm$ 0.20% in four places approximately 45 degrees apart around the nozzle in each of two planes through the nozzle throat, one at the outlet and the other in the straight section near the radius [11].

Where the nozzle apparatus is used, an exhaust fan capable of providing the desired flow rates through the solar collector shall be installed in the end wall of the discharge chamber rather than separate from the air flow measuring apparatus as shown in Figure A2. The dry and wet bulb temperature of the air entering the nozzle shall be measured in accordance with reference [6]. The velocity of the air passing through the nozzle shall be determined by either measuring the velocity head by means of a commercially available pitot tube or by measuring the static pressure drop across the nozzle with a manometer. If the latter method is used, one end of the manometer shall be connected to a static pressure tap located flush with the inner wall of the discharge chamber, or preferably, several taps in each chamber should be manifolded to a single manometer. A means shall also be provided for measuring the absolute pressure of the air in the nozzle throat.

Where the air flow rate is sufficiently small so that a nozzle constructed and installed in accordance with the requirements above would have a throat diameter of smaller than 0.025 m (1 in.), the above configuration should not be used and the air flow measuring apparatus as shown in Figure A2 should consist of a calibrated flow element* where at least 10 pipe diameters of upstream and downstream pipe section have been included in the calibration**.

7.2.9 Air Leakage. Air leakage through the air flow measuring apparatus, air inlet test duct, the solar collector and the air outlet test duct shall not exceed $\pm$ 1.0% of the measured air flow.

7.2.10 Air Reconditioning Apparatus. The reconditioning apparatus shall control the dry bulb temperature of the transfer medium entering the solar collector to within $\pm$ 1.0°C ($\pm$ 1.8°F) of the desired test values at all times during the tests. Its heating and cooling capacity shall be selected so that dry bulb temperature of the air entering the reconditioning apparatus may be raised or lowered the required amount to meet the applicable test conditions in Section 8.

SECTION 8. TEST PROCEDURE AND CALCULATIONS

8.1 GENERAL

The performance of the solar collector is determined by obtaining values of instantaneous efficiency for a large combination of values of incident insolation, ambient temperature, and inlet fluid temperature. This requires experimentally measuring the rate of incident solar radiation onto the solar collector as well as the rate of energy addition to the transfer fluid as it passes through the collector, all under quasi-steady conditions.

8.2 INSTANTANEOUS EFFICIENCY

It has been shown and discussed by a number of investigators [17, 18, 19 and 20] that the performance of flat plate solar collector operating under steady conditions can be successfully described by the following relationship:

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* Usually an orifice, venturi, or flow nozzle.

** For small flow elements, the discharge coefficients associated with elements varies considerably from those associated with the larger elements. In addition, for small pipe or duct sizes, the ratio of pipe circumference to pipe area becomes large and the characteristics of the upstream and downstream pipe sections affect the behavior of the element itself.

$$\frac{q_u}{A} = I\ (\tau\alpha)_e - U_L\ (t_p - t_a) \tag{1}$$

A very similar equation can be used to describe the performance of concentrating collectors [21, 22 and 23]. Equation (1) becomes modified as follows [21]:

$$\frac{q_u}{A_a} = I\ (\tau\alpha)_e\ \rho\ \gamma - U_L\ \frac{A_r}{A_a}\ (t_r - t_a) \tag{2}$$

To assist in obtaining detailed information about the performance of collectors and to prevent the necessity of determining some average surface temperature, it has been convenient to introduce a parameter F' where

$$F' \equiv \frac{\text{actual useful energy collected}}{\text{useful energy collected if the entire collector surface were at the average fluid temperature}}$$

Introducing this factor into equation (1) results in

$$\frac{q_u}{A} = F' \left[I\ (\tau\alpha)_e - U_L \left(\frac{t_{f,i} + t_{f,e}}{2} - t_a \right) \right] \tag{3}$$

If the solar collector efficiency can be defined as

$$\eta \equiv \frac{\text{actual useful energy collected}}{\text{solar energy incident upon or intercepted by the collector}}$$

or in equation form

$$\eta = \frac{q_u/A}{I} \quad , \tag{4}$$

then the efficiency of the flat-plate collector is given by:

$$\eta = F'(\tau\alpha)_e - F' U_L \frac{\left(\frac{t_{f,i} + t_{f,e}}{2} - t_a\right)}{I} \qquad (5)$$

Equation (5) indicates that if the efficiency is plotted against an appropriate $\frac{\Delta t}{I}$, a straight line will result where the slope is some function of U_L and the y intercept is some function of $(\tau\alpha)_e$. In reality U_L is not a constant but rather a function of the temperature of the collector and of the ambient weather conditions. In addition, the product $(\tau\alpha)_e$ varies with incident angle to the collector.

The procedures outlined in this document have been developed in an attempt to control the test conditions so that a well defined efficiency "curve" can be obtained with a minimum of scatter. Figure A7 shows typical test results taken from reference [24] for two flat-plate collectors using air as the transfer fluid. The collector tests were conducted outside and the scatter about the two lines in each figure indicates " ... apart from experimental errors, the order of variation on account of the variations in heat loss coefficient U_L, and the parameter F' due to variations in ambient wind speed and sky temperatures". Figure A10 was taken from reference [25] and is for a flat-plate collector using water as the transfer fluid. There is less scatter due to the fact that the tests were conducted indoors using a "solar simulator".

The curves shown in Figures A7 and A10 are duplicates of those reported in references [24] and [25], respectively. The abscissa in the first case is in metric units and in the second, english units. The curves to be presented in the test report described herein should be done so the abscissa is either in the SI units of $(^{\circ}C \cdot m^2)/W$ (as in Figures A8 and A11) or as shown in Figures A9 and A12. Here the experimentally determined temperature difference has been divided by the difference in temperature between the boiling point and freezing point on the respective scale ($100^{\circ}C$, $180^{\circ}F$) and the insolation has been divided by the solar constant, I_{SC} (1353 W/m^2), in appropriate units [26]. The result is an abscissa whose units are dimensionless.

It is expected that a "straight-line" representation will suffice for most conventional flat-plate collectors but that an attempt to represent the performance of a concentrating collector on such a plot will require the use of a "higher-order fit" due to the larger variation in U_L and the product $(\tau\alpha)_e$.

8.3 TESTING PROCEDURE

The testing of the solar collector shall be conducted in such a way that an "efficiency curve" is determined for the collector under test conditions described in Section 5. and 8.3. At least four different values of inlet fluid temperature shall be used to obtain the values of $\Delta t/I$. Ideally the inlet fluid temperature should correspond to 10, 30, 50, and 70°C (18, 54, 90, and 126°F) above the ambient temperature; however the values that can realistically be used will depend upon the particular collector design and the environmental conditions at the location and time of year when the collector is being tested. Consequently, the four different inlet fluid temperatures selected should be as close to the above values as is feasible. At least four "data points" shall be taken for each value of $t_{f,i}$; two during the time period preceding solar noon and two in the period following solar noon, the specific periods being chosen so that the data points represent times symmetrical to solar noon. This latter requirement is made so that any "transient effects" that may be present will not bias the test results when they are used for design purposes. All test data shall be reported in addition to the fitted curve (see Section 9.) so that any difference in efficiency due solely to the operating temperature level of the collector can be discerned in the test report. The curve shall be established by "data points" that represent 15 minute integrated efficiency values. In other words, the integrated value of incident solar energy will be divided into the integrated value of energy obtained from the collector to obtain the efficiency value for that "instant". Care should be taken to insure that the incident solar energy is steady for each 15 minute segment during which an efficiency value is calculated. Either electronic integrators or continuous pen strip chart recorders may be used to determine the integrated values of incident solar radiation and temperature rise across the collector. However, a strip chart recorder with a recommended chart speed of 30 cm/hr must always be used to monitor the output of the pyranometer to insure that the incident radiation has remained steady during the 15 minute segment. Figures A13 and A14 show a strip chart recording of incident solar radiation on a horizontal surface at the National Bureau of Standards site in Gaithersburg, Maryland. Whereas the conditions of Figure A13 would be perfectly acceptable for obtaining efficiency values, those of Figure A14 would not be*.

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* One or two "blips" of 10 s or less occurring during the 15 minute period such as at 12:18 in Figure A11 is acceptable.

The surface of the collector cover plate (if present) as well as exposed envelope of the pyranometer should be wiped clean and dry prior to the tests. If local pollution or sand has formed a deposit on the transparent surfaces, the wiping should be carried out very gently, preferably after blowing off most of the loose material or after wetting it a little, in order to prevent scratching of the surface. This is particularly important for the pyranometer since such abrasive action can appreciably alter the original transmission properties of the enclosing envelope.

The pyranometer shall be checked prior to testing to see if there is any accumulation of water vapor enclosed within the glass cover. The use of "wet" pyranometers (where moisture is visible) shall not be allowed.

In order to obtain sufficiently good "quasi-steady" conditions for the solar collection process, the collector should stand in the sun under no flow conditions until the contained fluid heats up to a temperature equivalent to or slightly greater than the inlet fluid temperature for the test. The transfer fluid should then be circulated through the collector at the appropriate temperature level for at least 30 minutes* prior to the period in which data will be taken to calculate the efficiency values. During this period, a check should be made to insure that the flow rate of the transfer fluid does not vary by more than $\pm$ 1% and that the incident solar radiation is steady as described above.

The flow rate of transfer fluid through the collector shall be standardized at one value for all data points. The recommended value of flow rate per unit area (transparent frontal or aperture) for tests are 0.02 $kg/(s \cdot m^2)$ (14.7 $lbm/(h \cdot ft^2)$) when a liquid is the transfer fluid and 0.01 $m^3/(s \cdot m^2)$ (1.96 cfm per ft^2) of standard are when the transfer fluid is air. It is recognized that in some cases the collector will have been designed for a flow rate much different than specified above. In such cases, the design flow rate should be used.

In order to determine and report the fraction of the incident solar radiation that is diffuse for each efficiency value, the sensing element of the pyranometer shall be shaded from the direct beam of sun just prior and just following each 15 minute testing

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* 30 minutes is felt to be sufficient for typical tube and sheet type solar collectors using water as the transfer fluid. For those collectors having higher thermal capacity, a longer time period may be necessary.

period and the value of the incident radiation determined*. This shall be accomplished by using a small disk attached to a slender rod held on a direct line between the pyranometer and the sun. The disk should be just large enough to shade the sensing element alone. In reference [5], this is accomplished by a disk 100 mm in diameter and held at a distance of 1 m from the sensing element**.

8.4 CALCULATION OF INSTANTANEOUS EFFICIENCY

For each 15 minute segment for which an efficiency value is to be determined, the value is calculated using the equation:

$$\eta = \frac{\left[\dot{m}\, c_p \int_{\tau_1}^{\tau_2} (t_{f,e} - t_{f,i})\, d\tau\right] / A_a}{\int_{\tau_1}^{\tau_2} I\, d\tau} \tag{6}$$

The quantities $\dot{m}$ and c_p have been taken out of the integration in the numerator since they remain essentially constant during the test. Note that the collector area used for the calculation is not the absorbing surface area but rather the transparent frontal area or aperture area.

At least sixteen data points shall be obtained for the establishment of the "efficiency curve" and an equation for the curve shall be obtained using the standard technique of a least-squares fit to a second-order polynomial***.

8.5 AN EXPERIMENTAL CHECK

As an independent check on the experimental results, the inlet temperature, $t_{f,i}$, and the outlet temperature, $t_{f,e}$, of the collector shall be recorded on continuous pen strip chart recorders. The

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* A normal incidence pyrheliometer can be used in lieu of shading the sensing element of the pyranometer.

** This was when using a Moll-Gorszynski Pyranometer made by Kipp and Zonen.

*** One should consult any standard text discussing analysis of experimental data for a presentation of this technique (i.e., [27] and [28]).

quantity $\int_{\tau_1}^{\tau_2} (t_{f,e} - t_{f,i})\, d\tau$ shall be approximated using these recordings and compared with the identical quantity obtained by using the primary method which measures the temperature difference directly.

8.6 CALCULATION OF AIR FLOW RATE

The air flow rate through the nozzle is calculated by the following equations:

$$Q_{mi} = 1.41\ C\ A_n\ (P_v\ v'_n)^{0.5} \tag{7}$$

$$v_n' = 10.1 \times 10^4\ v_n/P_n\ (1 + W_n) \tag{8}$$

The air flow rate of standard air is then:

$$Q_s = Q_{mi}/(1.2\ v'_n) \tag{9}$$

8.7 CALCULATION OF NOZZLE REYNOLDS NUMBER

The Reynolds number is calculated as follows:

$$N_{Re} = f\ V_a\ D \tag{10}$$

The temperature factor is as follows:

Temperature, ^{o}C	Factor, f
-6.7	78275
+4.4	72075
+15.6	67425
+26.7	62775
+37.8	58125
+48.9	55025
+60.0	51925
+71.1	48825

8.8 CALCULATION OF THEORETICAL POWER REQUIREMENTS

In order to calculate the theoretical power required to move the transfer fluid through the solar collector, the following equation shall be used:

$$P_{th} = \dot{m} \ \Delta P / \rho \tag{11}$$

SECTION 9. DATA TO BE RECORDED AND TEST REPORT

9.1 TEST DATA

Table A13 lists the measurements which are to be made at the beginning of the testing day and during the individual tests to obtain an efficiency "data point".

9.2 TEST REPORT

Table A14 specifies the data and information that shall be reported in testing the solar collector.

SECTION 10. NOMENCLATURE

A	cross-sectional area, m^2
A_a	transparent frontal area for a flat-plate collector or aperture for a concentrating collector, m^2
A_n	area of nozzle, m^2
A_r	absorbing or receiving area of the concentrating solar collector, m^2
C	nozzle coefficient of discharge
c_p	specific heat of the transfer fluid, $J/(kg \cdot {}^oC)$
D	nozzle throat diameter, m
f	temperature factor for the calculation of nozzle N_{Re}
F'	solar collector efficiency factor
h	outside surface heat transfer coefficient (includes radiation and convection) for the solar collector, $W/(m^2 \cdot {}^oC)$
I	total solar energy incident upon the plane of the solar collector per unit time per unit area, W/m^2
I_d	diffuse solar energy incident upon the plane of the solar collector per unit time per unit area, W/m^2
I_{sc}	solar constant, 1353 W/m^2

$\dot{m}$ mass flow rate of the transfer fluid, kg/s

N_{Re} Reynolds number

P_n absolute pressure at the nozzle throat, N/m^2

P_{th} theoretical power required to move the transfer fluid through the solar collector, W

P_v velocity pressure at the nozzle throat or the static pressure difference across the nozzle, N/m^2

ΔP pressure drop across the solar collector, N/m^2

Q_{mi} measured air flow rate, m^3/s

Q_s standard air flow rate, m^3/s

q_u rate of useful energy extraction from the solar collector, W

t_a ambient air temperature, ^oC

t_{bp} temperature of the boiling point on a temperature scale, ^oC or ^oF

$t_{f,e}$ temperature of the fluid leaving the collector, ^oC

$t_{f,i}$ temperature of the fluid entering the collector, ^oC

t_{fp} temperature of freezing point on a temperature scale, ^oC or ^oF

t_p average temperature of the absorber surface of the solar collector, ^oC

t_r average temperature of the absorber surface of the concentrating solar collector, ^oC

Δt temperature difference, ^oC

U_L heat transfer loss coefficient for the solar collector, $W/(m^2 \cdot {}^oC)$

V_a velocity of the air at the nozzle throat, m/s

v_n specific volume of the air at dry and wet bulb temperature conditions existing at the nozzle but at standard barometric pressure, m^3/kg dry air

v_n' specific volume of the air at the nozzle, m^3/kg dry air

W_n humidity ratio at the nozzle, kg H_2O/kg dry air

α absorptance of the solar collector absorbing surface to solar radiation

γ the fraction of specularly reflected radiation from the reflector which is intercepted by the solar collector absorbing surface

η solar collector efficiency, %

ρ specular reflectance of the solar collector reflector, or density, kg/m^3

τ time, s, or transmittance of the solar collector cover plate

$(\tau\alpha)_e$ effective transmission-absorptance factor for the solar collector

τ_1 time at the beginning of a 15 minute test period, s

τ_2 time at the end of a 15 minute test period, s

SECTION 11. REFERENCES

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TABLE A1 ... SOLAR POSITION AND INSOLATION VALUES FOR 24 DEGREES NORTH LATITUDE

DATE	SOLAR TIME AM	SOLAR TIME PM	SOLAR POSITION ALT	SOLAR POSITION AZM	BTUH/SQ. FT. TOTAL INSOLATION ON SURFACES NORMAL	HORIZ.	SOUTH FACING SURFACE ANGLE WITH HORIZ. 14	24	34	44	90
JAN 21	7	5	4.8	65.6	71	10	17	21	25	28	31
	8	4	16.9	58.3	239	83	110	126	137	145	127
	9	3	27.9	48.8	288	151	188	207	221	228	176
	10	2	37.2	36.1	308	204	246	268	282	287	207
	11	1	43.6	19.6	317	237	283	306	319	324	226
	12		46.0	0.0	320	249	296	319	332	336	232
	SURFACE DAILY TOTALS				2766	1622	1984	2174	2300	2360	1766
FEB 21	7	5	9.3	74.6	158	35	44	49	53	56	46
	8	4	22.3	67.2	263	116	135	145	150	151	102
	9	3	34.4	57.6	298	187	213	225	230	228	141
	10	2	45.1	44.2	314	241	273	286	291	287	168
	11	1	53.0	25.0	321	276	310	324	328	323	185
	12		56.0	0.0	324	288	323	337	341	335	191
	SURFACE DAILY TOTALS				3036	1998	2276	2396	2446	2424	1476
MAR 21	7	5	13.7	83.8	194	60	63	64	62	59	27
	8	4	27.2	76.8	267	141	150	152	149	142	64
	9	3	40.2	67.9	295	212	226	229	225	214	95
	10	2	52.3	54.8	309	266	285	288	283	270	120
	11	1	61.9	33.4	315	300	322	326	320	305	135
	12		66.0	0.0	317	312	334	339	333	317	140
	SURFACE DAILY TOTALS				3078	2270	2428	2456	2412	2298	1022
APR 21	6	6	4.7	100.6	40	7	5	4	4	3	2
	7	5	18.3	94.9	203	83	77	70	62	51	10
	8	4	32.0	89.0	256	160	157	149	137	122	16
	9	3	45.6	81.9	280	227	227	220	206	186	41
	10	2	59.0	71.8	292	278	282	275	259	237	61
	11	1	71.1	51.6	298	310	316	309	293	269	74
	12		77.6	0.0	299	321	328	321	305	280	79
	SURFACE DAILY TOTALS				3036	2454	2458	2374	2228	2016	483
MAY 21	6	6	8.0	108.4	86	22	15	10	9	9	5
	7	5	21.2	103.2	203	98	85	73	59	44	12
	8	4	34.6	98.5	248	171	159	145	127	106	15
	9	3	48.3	93.6	269	233	224	210	190	165	16
	10	2	62.0	87.7	280	281	275	261	239	211	22
	11	1	75.5	76.9	286	311	307	293	270	240	34
	12		86.0	0.0	288	322	317	304	281	250	37
	SURFACE DAILY TOTALS				3032	2556	2447	2286	2072	1800	246
JUN 21	6	6	9.3	111.6	97	29	20	12	12	11	7
	7	5	22.3	106.8	201	103	87	73	58	41	13
	8	4	35.5	102.6	242	173	158	142	122	99	16
	9	3	49.0	98.7	263	234	221	204	182	155	18
	10	2	62.6	95.0	274	280	269	253	229	199	18
	11	1	76.3	90.8	279	309	300	283	259	227	19
	12		89.4	0.0	281	319	310	294	269	236	22
	SURFACE DAILY TOTALS				2994	2574	2422	2230	1992	1700	204
JUL 21	6	6	8.2	109.0	81	23	16	11	10	9	6
	7	5	21.4	103.8	195	98	85	73	59	44	13
	8	4	34.8	99.2	239	169	157	143	125	104	16
	9	3	48.4	94.5	261	231	221	207	187	161	18
	10	2	62.1	89.0	272	278	270	256	235	206	21
	11	1	75.7	79.2	278	307	302	287	265	235	32
	12		86.6	0.0	280	317	312	298	275	245	36
	SURFACE DAILY TOTALS				2932	2526	2412	2250	2036	1766	246
AUG 21	6	6	5.0	101.3	35	7	5	4	4	4	2
	7	5	18.5	95.6	186	82	76	69	60	50	11
	8	4	32.2	89.7	241	158	154	146	134	118	16
	9	3	45.9	82.9	265	223	222	214	200	181	39
	10	2	59.3	73.0	278	273	275	268	252	230	58
	11	1	71.6	53.2	284	304	309	301	285	261	71
	12		78.3	0.0	286	315	320	313	296	272	75
	SURFACE DAILY TOTALS				2864	2408	2402	2316	2168	1958	470
SEP 21	7	5	13.7	83.8	173	57	60	60	59	56	26
	8	4	27.2	76.8	248	136	144	146	143	136	62
	9	3	40.2	67.9	278	205	218	221	217	206	93
	10	2	52.3	54.8	292	258	275	278	273	261	116
	11	1	61.9	33.4	299	291	311	315	309	295	131
	12		66.0	0.0	301	302	323	327	321	306	136
	SURFACE DAILY TOTALS				2878	2194	2342	2366	2322	2212	992
OCT 21	7	5	9.1	74.1	138	32	40	45	48	50	42
	8	4	22.0	66.7	247	111	129	139	144	145	99
	9	3	34.1	57.1	284	180	206	217	223	221	138
	10	2	44.7	43.8	301	234	265	277	282	279	165
	11	1	52.5	24.7	309	268	301	315	319	314	182
	12		55.5	0.0	311	279	314	328	332	327	188
	SURFACE DAILY TOTALS				2868	1928	2198	2314	2364	2346	1442
NOV 21	7	5	4.9	65.8	67	10	16	20	24	27	29
	8	4	17.0	58.4	232	82	108	123	135	142	124
	9	3	28.0	48.9	282	150	186	205	217	224	172
	10	2	37.3	36.3	303	203	244	265	278	283	204
	11	1	43.8	19.7	312	236	280	302	316	320	222
	12		46.2	0.0	315	247	293	315	328	332	228
	SURFACE DAILY TOTALS				2706	1610	1962	2146	2268	2324	1730
DEC 21	7	5	3.2	62.6	30	3	7	9	11	12	14
	8	4	14.9	55.3	225	71	99	116	129	139	130
	9	3	25.5	46.0	281	137	176	198	214	223	184
	10	2	34.3	33.7	304	189	234	258	275	283	217
	11	1	40.4	18.2	314	221	270	295	312	320	236
	12		42.6	0.0	317	232	282	308	325	332	243
	SURFACE DAILY TOTALS				2624	1474	1852	2058	2204	2286	1808

NOTE:
1) BASED ON DATA IN TABLE 1, P. 387 IN REF. [3]; 0% GROUND REFLECTANCE; 1.0 CLEARNESS FACTOR.
2) SEE FIG. 4, P. 394 IN [3] FOR TYPICAL REGIONAL CLEARNESS FACTORS.
3) GROUND REFLECTION NOT INCLUDED ON NORMAL OR HORIZONTAL SURFACES.

1 BTUH/SQ. FT. = 3.152 W/m^2

TABLE A2 ... SOLAR POSITION AND INSOLATION VALUES FOR 32 DEGREES NORTH LATITUDE

DATE	SOLAR TIME AM	SOLAR TIME PM	SOLAR POSITION ALT	SOLAR POSITION AZM	BTUH/SQ. FT. TOTAL INSOLATION ON SURFACES NORMAL	HORIZ.	SOUTH FACING SURFACE ANGLE WITH HORIZ. 22	32	42	52	90
JAN 21	7	5	1.4	65.2	1	0	0	0	0	1	1
	8	4	12.5	56.5	203	56	93	106	116	123	115
	9	3	22.5	46.0	269	118	175	193	206	212	181
	10	2	30.6	33.1	295	167	235	256	269	274	221
	11	1	36.1	17.5	306	198	273	295	308	312	245
	12		38.0	0.0	310	209	285	308	321	324	253
	SURFACE DAILY TOTALS				2458	1288	1839	2008	2118	2166	1779
FEB 21	7	5	7.1	73.5	121	22	34	37	40	42	38
	8	4	19.0	64.4	247	95	127	136	140	141	108
	9	3	29.9	53.4	288	161	206	217	222	220	158
	10	2	39.1	39.4	306	212	266	278	283	279	193
	11	1	45.6	21.4	315	244	304	317	321	315	214
	12		48.0	0.0	317	255	316	330	334	328	222
	SURFACE DAILY TOTALS				2872	1724	2188	2300	2345	2322	1644
MAR 21	7	5	12.7	81.9	185	54	60	60	59	56	32
	8	4	25.1	73.0	260	129	146	147	144	137	78
	9	3	36.8	62.1	290	194	222	224	220	209	119
	10	2	47.3	47.5	304	245	280	283	278	265	150
	11	1	55.0	26.8	311	277	317	321	315	300	170
	12		58.0	0.0	313	287	329	333	327	312	177
	SURFACE DAILY TOTALS				3012	2084	2378	2403	2358	2246	1276
APR 21	6	6	6.1	99.9	66	14	9	6	6	5	3
	7	5	18.8	92.2	206	86	78	71	62	51	10
	8	4	31.5	84.0	255	158	156	148	136	120	35
	9	3	43.9	74.2	278	220	225	217	203	183	68
	10	2	55.7	60.3	290	267	279	272	256	234	95
	11	1	65.4	37.5	295	297	313	306	290	265	112
	12		69.6	0.0	297	307	325	318	301	276	118
	SURFACE DAILY TOTALS				3076	2390	2444	2356	2206	1994	764
MAY 21	6	6	10.4	107.2	119	36	21	13	13	12	7
	7	5	22.8	100.1	211	107	88	75	60	44	13
	8	4	35.4	92.9	250	175	159	145	127	105	15
	9	3	48.1	84.7	269	233	223	209	188	163	33
	10	2	60.6	73.3	280	277	273	259	237	208	56
	11	1	72.0	51.9	285	305	305	290	268	237	72
	12		78.0	0.0	286	315	315	301	278	247	77
	SURFACE DAILY TOTALS				3112	2582	2454	2284	2064	1788	469
JUN 21	6	6	12.2	110.2	131	45	26	16	15	14	9
	7	5	24.3	103.4	210	115	91	76	59	41	14
	8	4	36.9	96.8	245	180	159	143	122	99	16
	9	3	49.6	89.4	264	236	221	204	181	153	19
	10	2	62.2	79.7	274	279	268	251	227	197	41
	11	1	74.2	60.9	279	306	299	282	257	224	56
	12		81.5	0.0	280	315	309	292	267	234	60
	SURFACE DAILY TOTALS				3084	2634	2436	2234	1990	1690	370
JUL 21	6	6	10.7	107.7	113	37	22	14	13	12	8
	7	5	23.1	100.6	203	107	87	75	60	44	14
	8	4	35.7	93.6	241	174	158	143	125	104	16
	9	3	48.4	85.5	261	231	220	205	185	159	31
	10	2	60.9	74.3	271	274	269	254	232	204	54
	11	1	72.4	53.3	277	302	300	285	262	232	69
	12		78.6	0.0	279	311	310	296	273	242	74
	SURFACE DAILY TOTALS				3012	2558	2422	2250	2030	1754	458
AUG 21	6	6	6.5	100.5	59	14	9	7	6	6	4
	7	5	19.1	92.8	190	85	77	69	60	50	12
	8	4	31.8	84.7	240	156	152	144	132	116	33
	9	3	44.3	75.0	263	216	220	212	197	178	65
	10	2	56.1	61.3	276	262	272	264	249	226	91
	11	1	66.0	38.4	282	292	305	298	281	257	107
	12		70.3	0.0	284	302	317	309	292	268	113
	SURFACE DAILY TOTALS				2902	2352	2388	2296	2144	1934	736
SEP 21	7	5	12.7	81.9	163	51	56	56	55	52	30
	8	4	25.1	73.0	240	124	140	141	138	131	75
	9	3	36.8	62.1	272	188	213	215	211	201	114
	10	2	47.3	47.5	287	237	270	273	268	255	145
	11	1	55.0	26.8	294	268	306	309	303	289	164
	12		58.0	0.0	296	278	318	321	315	300	171
	SURFACE DAILY TOTALS				2808	2014	2288	2308	2264	2154	1226
OCT 21	7	5	6.8	73.1	99	19	29	32	34	36	32
	8	4	18.7	64.0	229	90	120	128	133	134	104
	9	3	29.5	53.0	273	155	198	208	213	212	153
	10	2	38.7	39.1	293	204	257	269	273	270	188
	11	1	45.1	21.1	302	236	294	307	311	306	209
	12		47.5	0.0	304	247	306	320	324	318	217
	SURFACE DAILY TOTALS				2696	1654	2100	2208	2252	2232	1588
NOV 21	7	5	1.5	65.4	2	0	0	0	1	1	1
	8	4	12.7	56.6	196	55	91	104	113	119	111
	9	3	22.6	46.1	263	118	173	190	202	208	176
	10	2	30.8	33.2	289	166	233	252	265	270	217
	11	1	36.2	17.6	301	197	270	291	303	307	241
	12		38.2	0.0	304	207	282	304	316	320	249
	SURFACE DAILY TOTALS				2406	1280	1816	1980	2084	2130	1742
DEC 21	8	4	10.3	53.8	176	41	77	90	101	108	107
	9	3	19.8	43.6	257	102	161	180	195	204	183
	10	2	27.6	31.2	288	150	221	244	259	267	226
	11	1	32.7	16.4	301	180	258	282	298	305	251
	12		34.6	0.0	304	190	271	295	311	318	259
	SURFACE DAILY TOTALS				2348	1136	1704	1888	2016	2086	1794

NOTE: 1) BASED ON DATA IN TABLE 1, P. 387 IN REF. [3]; 0% GROUND REFLECTANCE; 1.0 CLEARNESS FACTOR.

2) SEE FIG. 4, P. 394 IN [3] FOR TYPICAL REGIONAL CLEARNESS FACTORS.

3) GROUND REFLECTION NOT INCLUDED ON NORMAL OR HORIZONTAL SURFACES.

1 BTUH/SQ. FT. = 3.152 W/m^2

TABLE A3 ... SOLAR POSITION AND INSOLATION VALUES FOR 40 DEGREES NORTH LATITUDE

DATE	SOLAR TIME		SOLAR POSITION		BTUH/SQ. FT. TOTAL INSOLATION ON SURFACES						
	AM	PM	ALT	AZM	NORMAL	HORIZ.	SOUTH FACING SURFACE ANGLE WITH HORIZ. 30	40	50	60	90
JAN 21	8	4	8.1	55.3	142	28	65	74	81	85	84
	9	3	16.8	44.0	239	83	155	171	182	187	171
	10	2	23.8	30.9	274	127	218	237	249	254	223
	11	1	28.4	16.0	289	154	257	277	290	293	253
	12		30.0	0.0	294	164	270	291	303	306	263
	SURFACE DAILY TOTALS				2182	948	1660	1810	1906	1944	1726
FEB 21	7	5	4.8	72.7	69	10	19	21	23	24	22
	8	4	15.4	62.2	224	73	114	122	126	127	107
	9	3	25.0	50.2	274	132	195	205	209	208	167
	10	2	32.8	35.9	295	178	256	267	271	267	210
	11	1	38.1	18.9	305	206	293	306	310	304	236
	12		40.0	0.0	308	216	306	319	323	317	245
	SURFACE DAILY TOTALS				2640	1414	2060	2162	2202	2176	1730
MAR 21	7	5	11.4	80.2	171	46	55	55	54	51	35
	8	4	22.5	69.6	250	114	140	141	138	131	89
	9	3	32.8	57.3	282	173	215	217	213	202	138
	10	2	41.6	41.9	297	218	273	276	271	258	176
	11	1	47.7	22.6	305	247	310	313	307	293	200
	12		50.0	0.0	307	257	322	326	320	305	208
	SURFACE DAILY TOTALS				2916	1852	2308	2330	2284	2174	1484
APR 21	6	6	7.4	98.9	89	20	11	8	7	7	4
	7	5	18.9	89.5	206	87	77	70	61	50	12
	8	4	30.3	79.3	252	152	153	145	133	117	53
	9	3	41.3	67.2	274	207	221	213	199	179	93
	10	2	51.2	51.4	286	250	275	267	252	229	126
	11	1	58.7	29.2	292	277	308	301	285	260	147
	12		61.6	0.0	293	287	320	313	296	271	154
	SURFACE DAILY TOTALS				3092	2274	2412	2320	2168	1956	1022
MAY 21	5	7	1.9	114.7	1	0	0	0	0	0	0
	6	6	12.7	105.6	144	49	25	15	14	13	9
	7	5	24.0	96.6	216	214	89	76	60	44	13
	8	4	35.4	87.2	250	175	158	144	125	104	25
	9	3	46.8	76.0	267	227	221	206	186	160	60
	10	2	57.5	60.9	277	267	270	255	233	205	89
	11	1	66.2	37.1	283	293	301	287	264	234	108
	12		70.0	0.0	284	301	312	297	274	243	114
	SURFACE DAILY TOTOLS				3160	2552	2442	2264	2040	1760	724
JUN 21	5	7	4.2	117.3	22	4	3	3	2	2	1
	6	6	14.8	108.4	155	60	30	18	17	16	10
	7	5	26.0	99.7	216	123	92	77	59	41	14
	8	4	37.4	90.7	246	182	159	142	121	97	16
	9	3	48.8	80.2	263	233	219	202	179	151	47
	10	2	59.8	65.8	272	272	266	248	224	194	74
	11	1	69.2	41.9	277	296	296	278	253	221	92
	12		73.5	0.0	279	304	306	289	263	230	98
	SURFACE DAILY TOTALS				3180	2648	2434	2224	1974	1670	610
JUL 21	5	7	2.3	115.2	2	0	0	0	0	0	0
	6	6	13.1	106.1	138	50	26	17	15	14	9
	7	5	24.3	97.2	208	114	89	75	60	44	14
	8	4	35.8	87.8	241	174	157	142	124	102	24
	9	3	47.2	76.7	259	225	218	203	182	157	58
	10	2	57.9	61.7	269	265	266	251	229	200	86
	11	1	66.7	37.9	275	290	296	281	258	228	104
	12		70.6	0.0	276	298	307	292	269	238	111
	SURFACE DAILY TOTALS				3062	2534	2409	2230	2006	1728	702
AUG 21	6	6	7.9	99.5	81	21	12	9	8	7	5
	7	5	19.3	90.0	191	87	76	69	60	49	12
	8	4	30.7	79.9	237	150	150	141	129	113	50
	9	3	41.8	67.9	260	205	216	207	193	173	89
	10	2	51.7	52.1	272	246	267	259	244	221	120
	11	1	59.3	29.7	278	273	300	292	276	252	140
	12		62.3	0.0	280	282	311	303	287	262	147
	SURFACE DAILY TOTALS				2916	2244	2354	2258	2104	1894	978
SEP 21	7	5	11.4	80.2	149	43	51	51	49	47	32
	8	4	22.5	69.6	230	109	133	134	131	124	84
	9	3	32.8	57.3	263	167	206	208	203	193	132
	10	2	41.6	41.9	280	211	262	265	260	247	168
	11	1	47.7	22.6	287	239	298	301	295	281	192
	12		50.0	0.0	290	249	310	313	307	292	200
	SURFACE DAILY TOTALS				2708	1788	2210	2228	2182	2074	1416
OCT 21	7	5	4.5	72.3	48	7	14	15	17	17	16
	8	4	15.0	61.9	204	68	106	113	117	118	100
	9	3	24.5	49.8	257	126	185	195	200	198	160
	10	2	32.4	35.6	280	170	245	257	261	257	203
	11	1	37.6	18.7	291	199	283	295	299	294	229
	12		39.5	0.0	294	208	295	308	312	306	238
	SURFACE DAILY TOTALS				2454	1348	1962	2060	2098	2074	1654
NOV 21	8	4	8.2	55.4	136	28	63	72	78	82	81
	9	3	17.0	44.1	232	82	152	167	178	183	167
	10	2	24.0	31.0	268	126	215	233	245	249	219
	11	1	28.6	16.1	283	153	254	273	285	288	248
	12		30.2	0.0	288	163	267	287	298	301	258
	SURFACE DAILY TOTALS				2128	942	1636	1778	1870	1908	1686
DEC	8	4	5.5	53.0	89	14	39	45	50	54	56
	9	3	14.0	41.9	217	65	135	152	164	171	163
	10	2	20.7	29.4	261	107	200	221	235	242	221
	11	1	25.0	15.2	280	134	239	262	276	283	252
	12		26.6	0.0	285	143	253	275	290	296	263
	SURFACE DAILY TOTALS				1978	782	1480	1634	1740	1796	1646

NOTE:

1) BASED ON DATA IN TABLE 1, P. 387 IN REF. [3]; 0% GROUND REFLECTANCE; 1.0 CLEARNESS FACTOR.
2) SEE FIG. 4, P. 394 IN [3] FOR TYPICAL REGIONAL CLEARNESS FACTORS.
3) GROUND REFLECTION NOT INCLUDED ON NORMAL OR HORIZONTAL SURFACES.

1 BTUH/SQ. FT. = 3.152 W/m^2

TABLE A4 ... SOLAR POSITION AND INSOLATION VALUES FOR 48 DEGREES NORTH LATITUDE

DATE	SOLAR TIME		SOLAR POSITION		BTUH/SQ. FT. TOTAL INSOLATION ON SURFACES						
	AM	PM	ALT	AZM			SOUTH FACING SURFACE ANGLE WITH HORIZ.				
					NORMAL	HORIZ.	38	48	58	68	90
JAN 21	8	4	3.5	54.6	37	4	17	19	21	22	22
	9	3	11.0	42.6	185	46	120	132	140	145	139
	10	2	16.9	29.4	239	83	190	206	216	220	206
	11	1	20.7	15.1	261	107	231	249	260	263	243
	12		22.0	0.0	267	115	245	264	275	278	255
	SURFACE DAILY TOTALS				1710	596	1360	1478	1550	1578	1478
FEB 21	7	5	2.4	72.2	12	1	3	4	4	4	4
	8	4	11.6	60.5	188	49	95	102	105	106	96
	9	3	19.7	47.7	251	100	178	187	191	190	167
	10	2	26.2	33.3	278	139	240	251	255	251	217
	11	1	30.5	17.2	290	165	278	290	294	288	247
	12		32.0	0.0	293	173	291	304	307	301	258
	SURFACE DAILY TOTALS				2330	1080	1880	1972	2024	1978	1720
MAR 21	7	5	10.0	78.7	153	37	49	49	47	45	35
	8	4	19.5	66.8	236	96	131	132	129	122	96
	9	3	28.2	53.4	270	147	205	207	203	193	152
	10	2	35.4	37.8	287	187	263	266	261	248	195
	11	1	40.3	19.8	295	212	300	303	297	283	223
	12		42.0	0.0	298	220	312	315	309	294	232
	SURFACE DAILY TOTALS				2780	1578	2208	2228	2182	2074	1632
APR 21	6	6	8.6	97.8	108	27	13	9	8	7	5
	7	5	18.6	86.7	205	85	76	69	59	48	21
	8	4	28.5	74.9	247	142	149	141	129	113	69
	9	3	37.8	61.2	268	191	216	208	194	174	115
	10	2	45.8	44.6	280	228	268	260	245	223	152
	11	1	51.5	24.0	286	252	301	294	278	254	177
	12		53.6	0.0	288	260	313	305	289	264	185
	SURFACE DAILY TOTALS				3076	2106	2358	2266	2114	1902	1262
MAY 21	5	7	5.2	114.3	41	9	4	4	4	3	2
	6	6	14.7	103.7	162	61	27	16	15	13	10
	7	5	24.6	93.0	219	118	89	75	60	43	13
	8	4	34.7	81.6	248	171	156	142	123	101	45
	9	3	44.3	68.3	264	217	217	202	182	156	86
	10	2	53.0	51.3	274	252	265	251	229	200	120
	11	1	59.5	28.6	279	274	296	281	258	228	141
	12		62.0	0.0	280	281	306	292	269	238	149
	SURFACE DAILY TOTALS				3254	2482	2418	2234	2010	1728	982
JUN 21	5	7	7.9	116.5	77	21	9	9	8	7	5
	6	6	17.2	106.2	172	74	33	19	18	16	12
	7	5	27.0	95.8	220	129	93	77	59	39	15
	8	4	37.1	84.6	246	181	157	140	119	95	35
	9	3	46.9	71.6	261	225	216	198	175	147	74
	10	2	55.8	54.8	269	259	262	244	220	189	105
	11	1	62.7	31.2	274	280	291	273	248	216	126
	12		65.5	0.0	275	287	301	283	258	225	133
	SURFACE DAILY TOTALS				3312	2626	2420	2204	1950	1644	874
JUL 21	5	7	5.7	114.7	43	10	5	5	4	4	3
	6	6	15.2	104.1	156	62	28	18	16	15	11
	7	5	25.1	93.5	211	118	89	75	59	42	14
	8	4	35.1	82.1	240	171	154	140	121	99	43
	9	3	44.8	68.8	256	215	214	199	178	153	83
	10	2	53.5	51.9	266	250	261	246	224	195	116
	11	1	60.1	29.0	271	272	291	276	253	223	137
	12		62.6	0.0	272	279	301	286	263	232	144
	SURFACE DAILY TOTALS				3158	2474	2386	2200	1974	1694	956
AUG 21	6	6	9.1	98.3	99	28	14	10	9	8	6
	7	5	19.1	87.2	190	85	75	67	58	47	20
	8	4	29.0	75.4	232	141	145	137	125	109	65
	9	3	38.4	61.8	254	189	210	201	187	168	110
	10	2	46.4	45.1	266	225	260	252	237	214	146
	11	1	52.2	24.3	272	248	293	285	268	244	169
	12		54.3	0.0	274	256	304	296	279	255	177
	SURFACE DAILY TOTALS				2898	2086	2300	2200	2046	1836	1208
SEP 21	7	5	10.0	78.7	131	35	44	44	43	40	31
	8	4	19.5	66.8	215	92	124	124	121	115	90
	9	3	28.2	53.4	251	142	196	197	193	183	143
	10	2	35.4	37.8	269	181	251	254	248	236	185
	11	1	40.3	19.8	278	205	287	289	284	269	212
	12		42.0	0.0	280	213	299	302	296	281	221
	SURFACE DAILY TOTALS				2568	1522	2102	2118	2070	1966	1546
OCT 21	7	5	2.0	71.9	4	0	1	1	1	1	1
	8	4	11.2	60.2	165	44	86	91	95	95	87
	9	3	19.3	47.4	233	94	167	176	180	178	157
	10	2	25.7	33.1	262	133	228	239	242	239	207
	11	1	30.0	17.1	274	157	266	277	281	276	237
	12		31.5	0.0	278	166	279	291	294	288	247
	SURFACE DAILY TOTALS				2154	1022	1774	1860	1890	1866	1626
NOV 21	8	4	3.6	54.7	36	5	17	19	21	22	22
	9	3	11.2	42.7	179	46	117	129	137	141	135
	10	2	17.1	29.5	233	83	186	202	212	215	201
	11	1	20.9	15.1	255	107	227	245	255	258	238
	12		22.2	0.0	261	115	241	259	270	272	250
	SURFACE DAILY TOTALS				1668	596	1336	1448	1518	1544	1442
DEC 21	9	3	8.0	40.9	140	27	87	98	105	110	109
	10	2	13.6	28.2	214	63	164	180	192	197	190
	11	1	17.3	14.4	242	86	207	226	239	244	231
	12		18.6	0.0	250	94	222	241	254	260	244
	SURFACE DAILY TOTALS				1444	446	1136	1250	1326	1364	1304

NOTE: 1) BASED ON DATA IN TABLE 1, P. 387 IN REF. [3]; 0% GROUND REFLECTANCE; 1.0 CLEARNESS FACTOR.

2) SEE FIG. 4, P. 394 IN [3] FOR TYPICAL REGIONAL CLEARNESS FACTORS.

3) GROUND REFLECTION NOT INCLUDED ON NORMAL OR HORIZONTAL SURFACES.

1 BTUH/SQ. FT. = 3.152 W/m^2

TABLE A5 ... SOLAR POSITION AND INSOLATION VALUES FOR 56 DEGREES NORTH LATITUDE

DATE	SOLAR TIME AM	SOLAR TIME PM	SOLAR POSITION ALT	SOLAR POSITION AZM	BTUH/SQ. FT. TOTAL INSOLATION ON SURFACES NORMAL	HORIZ.	SOUTH FACING SURFACE ANGLE WITH HORIZ. 46	56	66	76	90
JAN 21	9	3	5.0	41.8	78	11	50	55	59	60	60
	10	2	9.9	28.5	170	39	135	146	154	156	153
	11	1	12.9	14.5	207	58	183	197	206	208	201
	12		14.0	0.0	217	65	198	214	222	225	217
	SURFACE DAILY TOTALS				1126	282	934	1010	1058	1074	1044
FEB 21	8	4	7.6	59.4	129	25	65	69	72	72	69
	9	3	14.2	45.9	214	65	151	159	162	161	151
	10	2	19.4	31.5	250	98	215	225	228	224	208
	11	1	22.8	16.1	266	119	254	265	268	263	243
	12		24.0	0.0	270	126	268	279	282	276	255
	SURFACE DAILY TOTALS				1986	740	1640	1716	1742	1716	1598
MAR 21	7	5	8.3	77.5	128	28	40	40	39	37	32
	8	4	16.2	64.4	215	75	119	120	117	111	97
	9	3	23.3	50.3	253	118	192	193	189	180	154
	10	2	29.0	34.9	272	151	249	251	246	234	205
	11	1	32.7	17.9	282	172	285	288	282	268	236
	12		34.0	0.0	284	179	297	300	294	280	246
	SURFACE DAILY TOTALS				2586	1268	2066	2084	2040	1938	1700
APR 21	5	7	1.4	108.8	0	0	0	0	0	0	0
	6	6	9.6	96.5	122	32	14	9	8	7	6
	7	5	18.0	84.1	201	81	74	66	57	46	29
	8	4	26.1	70.9	239	129	143	135	123	108	82
	9	3	33.6	56.3	260	169	208	200	186	167	133
	10	2	39.9	39.7	272	201	259	251	236	214	174
	11	1	44.1	20.7	278	220	292	284	268	245	200
	12		45.6	0.0	280	227	303	295	279	255	209
	SURFACE DAILY TOTALS				3024	1892	2282	2186	2038	1830	1458
MAY 21	4	8	1.2	125.5	0	0	0	0	0	0	0
	5	7	8.5	113.4	93	25	10	9	8	7	6
	6	6	16.5	101.5	175	71	28	17	15	13	11
	7	5	24.8	89.3	219	119	88	74	58	41	16
	8	4	33.1	76.3	244	163	153	138	119	98	63
	9	3	40.9	61.6	259	201	212	197	176	151	109
	10	2	47.6	44.2	268	231	259	244	222	194	146
	11	1	52.3	23.4	273	249	288	274	251	222	170
	12		54.0	0.0	275	255	299	284	261	231	178
	SURFACE DAILY TOTALS				3340	2374	2374	2188	1962	1682	1218
JUN 21	4	8	4.2	127.2	21	4	2	2	2	2	1
	5	7	11.4	115.3	122	40	14	13	11	10	8
	6	6	19.3	103.6	185	86	34	19	17	15	12
	7	5	27.6	91.7	222	132	92	76	57	38	15
	8	4	35.9	78.8	243	175	154	137	116	92	55
	9	3	43.8	64.1	257	212	211	193	170	143	98
	10	2	50.7	46.4	265	240	255	238	214	184	133
	11	1	55.6	24.9	269	258	284	267	242	210	156
	12		57.5	0.0	271	264	294	276	251	219	164
	SURFACE DAILY TOTALS				3438	2562	2388	2166	1910	1606	1120
JUL 21	4	8	1.7	125.8	0	0	0	0	0	0	[illegible]
	5	7	9.0	113.7	91	27	11	10	9	8	[illegible]
	6	6	17.0	101.9	169	72	30	18	16	14	11
	7	5	25.3	89.7	212	119	88	74	58	41	15
	8	4	33.6	76.7	237	163	151	136	117	96	51
	9	3	41.4	62.0	252	201	208	193	173	147	[illegible]
	10	2	48.2	44.6	261	230	254	239	217	189	142
	11	1	52.9	23.7	265	248	283	268	245	216	165
	12		54.6	0.0	267	254	293	278	255	225	173
	SURFACE DAILY TOTALS				3240	2372	2342	2152	1926	1646	1186
AUG 21	5	7	2.0	109.2	1	0	0	0	0	0	0
	6	6	10.2	97.0	112	34	16	11	10	9	7
	7	5	18.5	84.5	187	82	73	65	56	45	28
	8	4	26.7	71.3	225	128	140	131	119	104	78
	9	3	34.3	56.7	246	168	202	193	179	160	126
	10	2	40.5	40.0	258	199	251	242	227	206	166
	11	1	44.8	20.9	264	218	282	274	258	235	191
	12		46.3	0.0	266	225	293	285	269	245	200
	SURFACE DAILY TOTALS				2850	1884	2218	2118	1966	1760	1392
SEP 21	7	5	8.3	77.5	107	25	36	36	34	32	28
	8	4	16.2	64.4	194	72	111	111	108	102	89
	9	3	23.3	50.3	233	114	181	182	178	168	147
	10	2	29.0	34.9	253	146	236	237	232	221	193
	11	1	32.7	17.9	263	166	271	273	267	254	223
	12		34.0	0.0	266	173	283	285	279	265	233
	SURFACE DAILY TOTALS				2368	1220	1950	1962	1918	1820	1594
OCT 21	8	4	7.1	59.1	104	20	53	57	59	59	57
	9	3	13.8	45.7	193	60	138	145	148	147	138
	10	2	19.0	31.3	231	92	201	210	213	210	195
	11	1	22.3	16.0	248	112	240	250	253	248	230
	12		23.5	0.0	253	119	253	263	266	261	241
	SURFACE DAILY TOTALS				1804	688	1516	1586	1612	1588	1480
NOV 21	9	3	5.2	41.9	76	12	49	54	57	59	58
	10	2	10.0	28.5	165	39	132	143	149	152	148
	11	1	13.1	14.5	201	58	179	193	201	203	196
	12		14.2	0.0	211	65	194	209	217	219	211
	SURFACE DAILY TOTALS				1094	284	914	986	1032	1046	1016
DEC 21	9	3	1.9	40.5	5	0	3	4	4	4	4
	10	2	6.6	27.5	113	19	86	95	101	104	103
	11	1	9.5	13.9	166	37	141	154	163	167	164
	12		10.6	0.0	180	43	159	173	182	186	182
	SURFACE DAILY TOTALS				748	156	620	678	716	734	722

NOTE:
1) BASED ON DATA IN TABLE 1, P. 387 IN REF. [3]; 0% GROUND REFLECTANCE; 1.0 CLEARNESS FACTOR.
2) SEE FIG. 4, P. 394 in [3] FOR TYPICAL REGIONAL CLEARNESS FACTORS.
3) GROUND REFLECTION NOT INCLUDED ON NORMAL OR HORIZONTAL SURFACES.

1 BTUH/SQ. FT. = 3.152 W/m^2

TABLE A6 ... SOLAR POSITION AND INSOLATION VALUES FOR 64 DEGREES NORTH LATITUDE

DATE	SOLAR TIME AM	SOLAR TIME PM	SOLAR POSITION ALT	SOLAR POSITION AZM	BTUH/SQ. FT. TOTAL INSOLATION ON SURFACES NORMAL	HORIZ.	SOUTH FACING SURFACE ANGLE WITH HORIZ. 54	64	74	84	90
JAN 21	10	2	2.8	28.1	22	2	17	19	20	20	20
	11	1	5.2	14.1	81	12	72	77	80	81	81
	12		6.0	0.0	100	16	91	98	102	103	103
	SURFACE DAILY TOTALS				306	45	268	290	302	306	304
FEB 21	8	4	3.4	58.7	35	4	17	19	19	19	19
	9	3	8.6	44.8	147	31	103	108	111	110	107
	10	2	12.6	30.3	199	55	170	178	181	178	173
	11	1	15.1	15.3	222	71	212	220	223	219	213
	12		16.0	0.0	228	77	225	235	237	232	226
	SURFACE DAILY TOTALS				1432	400	1230	1286	1302	1282	1252
MAR 21	7	5	6.5	76.5	95	18	30	29	29	27	25
	8	4	20.7	62.6	185	54	101	102	99	94	89
	9	3	18.1	48.1	227	87	171	172	169	160	153
	10	2	22.3	32.7	249	112	227	229	224	213	203
	11	1	25.1	16.6	260	129	262	265	259	246	235
	12		26.0	0.0	263	134	274	277	271	258	246
	SURFACE DAILY TOTALS				2296	932	1856	1870	1830	1736	1656
APR 21	5	7	4.0	108.5	27	5	2	2	2	1	1
	6	6	10.4	95.1	133	37	15	9	8	7	6
	7	5	17.0	81.6	194	76	70	63	54	43	37
	8	4	23.3	67.5	228	112	136	128	116	102	91
	9	3	29.0	52.3	248	144	197	189	176	158	145
	10	2	33.5	36.0	260	169	246	239	224	203	188
	11	1	36.5	18.4	266	184	278	270	255	233	216
	12		97.6	0.0	268	190	289	281	266	243	225
	SURFACE DAILY TOTALS				2982	1644	2176	2082	1936	1736	1594
MAY 21	4	8	5.8	125.1	51	11	5	4	4	3	3
	5	7	11.6	112.1	132	42	13	11	10	9	8
	6	6	17.9	99.1	185	79	29	16	14	12	11
	7	5	24.5	85.7	218	117	86	72	56	39	28
	8	4	30.9	71.5	239	152	148	133	115	94	80
	9	3	36.8	56.1	252	182	204	190	170	145	128
	10	2	41.6	38.9	261	205	249	235	213	186	167
	11	1	44.9	20.1	265	219	278	264	242	213	193
	12		46.0	0.0	267	224	288	274	251	222	201
	SURFACE DAILY TOTALS				3470	2236	2312	2124	1898	1624	1436
JUN 21	3	9	4.2	139.4	21	4	2	2	2	2	1
	4	8	9.0	126.4	93	27	10	9	8	7	6
	5	7	14.7	113.6	154	60	16	15	13	11	10
	6	6	21.0	100.8	194	96	34	19	17	14	13
	7	5	27.5	87.5	221	132	91	74	55	36	23
	8	4	34.0	73.3	239	166	150	133	112	88	73
	9	3	39.9	57.8	251	195	204	187	164	137	119
	10	2	44.9	40.4	258	217	247	230	206	177	157
	11	1	48.3	20.9	262	231	275	258	233	202	181
	12		49.5	0.0	263	235	284	267	242	211	189
	SURFACE DAILY TOTALS				3650	2488	2342	2118	1862	1558	1356
JUL 21	4	8	6.4	125.3	53	13	6	5	5	4	4
	5	7	12.1	112.4	128	44	14	13	11	10	9
	6	6	18.4	99.4	179	81	30	17	16	13	12
	7	5	25.0	86.0	211	118	86	72	56	38	28
	8	4	31.4	71.8	231	152	146	131	113	91	77
	9	3	37.3	56.3	245	182	201	186	166	141	124
	10	2	42.2	39.2	253	204	245	230	208	181	162
	11	1	45.4	20.2	257	218	273	258	236	207	187
	12		46.6	0.0	259	223	282	267	245	216	195
	SURFACE DAILY TOTALS				3372	2248	2280	2090	1864	1588	1400
AUG 21	5	7	4.6	108.8	29	6	3	3	2	2	2
	6	6	11.0	95.5	123	39	16	11	10	8	7
	7	5	17.6	81.9	181	77	69	61	52	42	35
	8	4	23.9	67.8	214	113	132	123	112	97	87
	9	3	29.6	52.6	234	144	190	182	169	150	138
	10	2	34.2	36.2	246	168	237	229	215	194	179
	11	1	37.2	18.5	252	183	268	260	244	222	205
	12		38.3	0.0	254	188	278	270	255	232	215
	SURFACE DAILY TOTALS				2808	1646	2108	1008	1860	1662	1522
SEP 21	7	5	6.5	76.5	77	16	25	25	24	23	21
	8	4	12.7	72.6	163	51	92	92	90	85	81
	9	3	18.1	48.1	206	83	159	159	156	147	141
	10	2	22.3	32.7	229	108	212	213	209	198	189
	11	1	25.1	16.6	240	124	246	248	243	230	220
	12		26.0	0.0	244	129	258	260	254	241	230
	SURFACE DAILY TOTALS				2074	892	1726	1736	1696	1608	1532
OCT 21	8	4	3.0	58.5	17	2	9	9	10	10	10
	9	3	8.1	44.6	122	26	86	91	93	92	90
	10	2	12.1	30.2	176	50	152	159	161	159	155
	11	1	14.6	15.2	201	65	193	201	203	200	295
	12		15.5	0.0	208	71	207	215	217	213	208
	SURFACE DAILY TOTALS				1238	358	1088	1136	1152	1134	1106
NOV 21	10	2	3.0	28.1	23	3	18	20	21	21	21
	11	1	5.4	14.2	79	12	70	76	79	80	79
	12		6.2	0.0	97	17	89	96	100	101	100
	SURFACE DAILY TOTALS				302	46	266	286	298	302	300
DEC 21	11	1	1.8	13.7	4	0	3	4	4	4	4
	12		2.6	0.0	16	2	14	15	16	17	17
	SURFACE DAILY TOTALS				24	2	20	22	24	24	24

NOTE: 1) BASED ON DATA IN TABLE 1, P. 387 IN REF. [3]; 0% GROUND REFLECTANCE; 1.0 CLEARNESS FACTOR.

2) SEE FIG. 4, P. 394 IN [3] FOR TYPICAL REGIONAL CLEARNESS FACTORS.

3) GROUND REFLECTION NOT INCLUDED ON NORMAL OR HORIZONTAL SURFACES.

1 BTUH/SQ. FT. = 3.152 W/m^2

TABLE A7 LATITUDE 24°N. INCIDENT ANGLES FOR HORIZONTAL AND SOUTH-FACING TILTED SURFACES

Dates: (Decl.)
Dec. 21 (-23.45)

		Horiz.	L - 10	Lat.	Lat. + 10	Lat. + 20	Vert.
7	5	86.8	80.5	76.3	72.4	68.9	62.6
8	4	75.1	67.5	62.7	58.6	55.4	56.6
9	3	64.5	55.3	49.6	44.9	41.8	51.1
10	2	55.7	44.5	37.4	31.6	28.0	46.6
11	1	49.6	36.5	27.6	19.6	14.3	43.6
12		47.4	33.4	23.5	13.5	3.4	42.5

Jan. 21 (-19.9)
Nov. 21 (-19.9)

		Horiz.	L - 10	Lat.	Lat. + 10	Lat. + 20	Vert.
7	5	85.2	79.6	75.9	72.6	69.8	65.7
8	4	73.1	66.2	62.0	58.5	56.0	59.8
9	3	62.1	53.5	48.4	44.5	42.2	54.4
10	2	52.8	42.1	35.5	30.6	28.2	50.0
11	1	46.4	33.4	24.8	17.6	14.1	47.0
12		44.0	30.0	20.0	10.0	0.0	46.0

Feb. 21 (-10.6)
Oct. 21 (-10.7)

		Horiz.	L - 10	Lat.	Lat. + 10	Lat. + 20	Vert.
7	5	80.7	77.2	75.2	73.7	72.6	74.8
8	4	67.7	62.9	60.5	59.0	58.5	69.0
9	3	55.6	49.0	45.9	44.3	44.5	63.8
10	2	43.9	35.9	31.5	29.5	30.6	59.6
11	1	37.0	25.0	18.0	14.8	17.6	56.9
12		34.0	20.0	10.0	0.0	10.0	56.0

Mar. 21 (0.0)
Sep. 21 (0.0)

		Horiz.	L - 10	Lat.	Lat. + 10	Lat. + 20	Vert.
7	5	76.3	75.2	75.0	75.2	75.9	84.0
8	4	62.8	60.5	60.0	60.5	62.0	78.3
9	3	49.8	45.9	45.0	45.9	48.4	73.3
10	2	37.7	31.5	30.0	31.5	35.5	69.4
11	1	28.1	18.0	15.0	18.0	24.8	66.9
12		24.0	10.0	0.0	10.0	20.0	66.0

Apr. 21 (+11.9)
Aug. 21 (+12.1)

		Horiz.	L - 10	Lat.	Lat. + 10	Lat. + 20	Vert.
6	6	85.3	88.0	90.0	92.0	93.9	100.6
7	5	71.7	73.5	75.3	77.6	80.2	94.6
8	4	58.0	58.9	60.7	63.4	67.0	89.1
9	3	44.4	44.2	46.2	49.7	54.4	84.4
10	2	31.0	29.5	32.0	36.8	43.2	80.7
11	1	18.9	14.8	18.9	26.2	34.9	78.4
12		12.4	1.6	11.6	21.6	31.6	77.6

May 21 (+20.3)
Jul 21 (+20.5)

		Horiz.	L - 10	Lat.	Lat. + 10	Lat. + 20	Vert.
6	6	82.0	86.0	90.0	93.4	96.7	108.2
7	5	68.8	72.6	75.9	79.6	83.6	102.3
8	4	55.4	58.5	62.0	66.2	71.1	97.0
9	3	41.7	44.5	48.4	53.5	59.5	92.4
10	2	28.0	30.6	35.5	42.1	49.6	88.9
11	1	14.5	17.6	24.8	33.4	42.6	86.7
12		4.0	10.0	20.0	30.0	40.0	86.0

Jun. 21 (+23.45)

		Horiz.	L - 10	Lat.	Lat. + 10	Lat. + 20	Vert.
6	6	80.7	86.0	90.0	94.0	97.8	111.3
7	5	67.7	72.4	76.3	80.5	85.0	105.5
8	4	54.5	58.6	62.7	67.5	72.8	100.2
9	3	41.0	44.9	49.6	55.8	61.7	95.7
10	2	27.4	31.6	37.4	44.5	52.4	92.3
11	1	13.7	19.7	27.6	36.5	45.9	90.2
12		0.6	13.4	23.4	33.4	43.4	89.4

TABLE A8 LATITUDE 32°N. INCIDENT ANGLES FOR HORIZONTAL AND SOUTH-FACING TILTED SURFACES

Dates (Decl.)			Horiz.	L - 10	Lat.	Lat. + 10	Lat. + 20	Vert.
Dec. 21 (-23.45	8	4	79.7	67.5	62.7	58.6	55.4	54.5
	9	3	70.2	55.3	49.6	44.9	41.8	47.1
	10	2	62.4	44.5	37.4	31.6	28.0	40.7
	11	1	57.3	36.5	27.6	19.6	14.3	36.2
	12		55.4	33.4	23.4	13.5	3.5	34.5

			Horiz.	L - 10	Lat.	Lat. + 10	Lat. + 20	Vert.
Jan. 21 (-19.9) Nov. 21 (-19.9)	7	5	88.6	79.6	75.9	72.6	69.8	65.2
	8	4	77.5	66.2	62.0	58.5	56.0	57.4
	9	3	67.5	53.5	48.4	44.5	42.2	50.0
	10	2	59.4	42.1	35.5	30.6	28.2	43.8
	11	1	53.9	33.4	24.8	17.6	14.1	39.6
	12		52.0	30.0	20.0	10.0	0.0	38.0

			Horiz.	L - 10	Lat.	Lat. + 10	Lat. + 20	Vert.
Feb. 21 (-10.6) Oct. 21 (-10.7)	7	5	82.9	77.2	75.2	73.7	72.6	73.6
	8	4	71.0	62.9	60.5	59.0	58.5	65.9
	9	3	60.1	49.0	45.9	44.3	44.5	58.9
	10	2	50.9	35.9	31.5	29.5	30.6	53.2
	11	1	44.4	25.0	18.0	14.8	17.6	49.4
	12		42.0	20.0	10.0	0.0	10.0	48.0

			Horiz.	L - 10	Lat.	Lat. + 10	Lat. + 20	Vert.
Mar. 21 (0.0) Sep. 21 (0.0)	7	5	77.3	75.2	75.0	75.2	75.9	82.1
	8	4	64.9	60.5	60.0	60.5	62.0	74.6
	9	3	53.2	45.9	45.0	45.9	48.4	68.0
	10	2	42.7	31.5	30.0	31.5	35.5	62.7
	11	1	35.0	18.0	15.0	18.0	24.8	59.2
	12		32.0	10.0	0.0	10.0	20.0	58.0

			Horiz.	L - 10	Lat.	Lat. + 10	Lat. + 20	Vert.
Apr. 21 (+11.9) Aug. 21 (+12.1)	6	6	83.9	88.0	90.0	92.0	93.9	99.8
	7	5	71.2	73.5	75.3	77.6	80.2	92.1
	8	4	58.5	58.9	60.7	63.4	67.0	84.9
	9	3	46.1	44.2	46.2	49.7	54.4	78.7
	10	2	34.3	29.5	32.0	36.8	43.2	.3.8
	11	1	24.6	14.8	18.9	26.2	34.9	70.7
	12		20.4	1.6	11.6	21.6	31.6	69.6

			Horiz.	L - 10	Lat.	Lat. + 10	Lat. + 20	Vert.
May 21 (+20.3) Jul. 21 (+20.5)	6	6	79.6	86.6	90.0	93.4	96.7	106.9
	7	5	67.2	72.6	75.9	79.6	83.6	99.3
	8	4	54.6	58.5	62.0	66.2	71.1	92.4
	9	3	41.9	44.5	48.4	53.5	59.5	86.4
	10	2	29.4	30.6	35.5	42.1	49.6	81.9
	11	1	18.0	17.6	24.8	33.4	42.6	79.0
	12		12.0	10.0	20.0	30.0	40.0	78.0

			Horiz.	L - 10	Lat.	Lat. + 10	Lat. + 20	Vert.
Jun. 21 (+23.45)	6	6	77.8	86.0	90.0	94.0	97.8	109.7
	7	5	65.7	72.4	76.3	80.5	85.0	102.2
	8	4	53.1	58.6	62.7	67.5	72.8	95.4
	9	3	40.4	44.9	49.6	55.3	61.7	89.6
	10	2	27.8	31.6	37.4	44.5	52.4	85.2
	11	1	15.8	19.6	27.6	36.5	45.8	82.4
	12		8.6	13.4	23.4	33.4	43.4	81.4

TABLE A9 LATITUDE 40°N. INCIDENT ANGLES FOR HORIZONTAL AND SOUTH-FACING TILTED SURFACES

Date: (Decl.) Dec. 21 (-23.45)

		Horiz.	L - 10	Lat.	Lat. + 10	Lat. + 20	Vert.
8	4	84.5	67.5	62.7	58.6	55.4	53.2
9	3	76.0	55.3	49.6	44.9	41.8	43.8
10	2	69.3	44.5	37.4	31.6	28.0	35.4
11	1	65.0	36.5	27.6	19.6	14.3	29.0
12		63.4	33.4	23.4	13.5	3.5	26.6

Jan. 21 (-19.9) Nov. 21 (-19.9)

		Horiz.	L - 10	Lat.	Lat. + 10	Lat. + 20	Vert.
8	4	81.9	66.2	62.0	58.5	56.0	55.7
9	3	73.2	53.5	48.4	44.5	42.2	46.4
10	2	66.2	42.1	35.5	30.6	28.2	38.3
11	1	61.6	33.4	24.8	17.6	14.1	32.3
12		60.0	30.0	20.0	10.0	0.0	30.0

Feb. 21 (-10.6) Oct. 21 (-10.7)

		Horiz.	L - 10	Lat.	Lat. + 10	Lat. + 20	Vert.
7	5	85.2	77.2	75.2	73.7	72.6	72.7
8	4	74.6	62.9	60.5	59.0	58.5	63.3
9	3	65.0	49.0	45.9	44.3	44.5	59.5
10	2	57.2	35.9	31.5	29.5	30.6	47.1
11	1	51.9	25.0	18.0	14.8	17.6	41.9
12		50.0	20.0	10.0	0.0	10.0	40.0

Mar. 21 (0.0) Sep. 21 (0.0)

		Horiz.	L - 10	Lat.	Lat. + 10	Lat. + 20	Vert.
7	5	78.6	75.2	75.0	75.2	75.9	80.4
8	4	67.5	60.5	60.0	60.5	62.0	71.3
9	3	57.2	45.9	45.0	45.9	48.4	63.0
10	2	48.4	31.5	30.0	31.5	35.5	56.2
11	1	42.3	18.0	15.0	18.0	24.8	51.6
12		40.0	10.0	0.0	10.0	20.0	50.0

Apr. 21 (+11.9) Aug. 21 (+12.1)

		Horiz.	L - 10	Lat.	Lat. + 10	Lat. + 20	Vert.
6	6	82.6	88.0	90.0	92.0	93.9	98.9
7	5	71.1	73.5	75.3	77.6	80.2	89.5
8	4	59.7	58.9	60.7	63.4	67.0	80.7
9	3	48.7	44.2	46.2	49.7	54.4	73.1
10	2	38.8	29.5	32.0	36.8	43.2	67.0
11	1	31.3	14.8	18.9	26.2	34.9	63.0
12		28.4	1.6	11.6	21.6	31.6	61.6

May 21 (+20.3) Jul. 21 (+20.5)

		Horiz.	L - 10	Lat.	Lat. + 10	Lat. + 20	Vert.
5	7	88.1	100.4	104.1	107.4	110.2	114.7
6	6	77.3	86.6	90.0	93.4	96.7	105.2
7	5	66.0	72.6	75.9	79.6	83.6	96.1
8	4	54.6	58.5	62.0	66.2	71.1	87.7
9	3	43.2	44.5	48.4	53.5	59.5	80.5
10	2	32.5	30.6	35.5	42.1	49.6	74.9
11	1	23.8	17.6	24.8	33.4	42.6	71.2
12		20.0	10.0	20.0	30.0	40.0	70.0

Jun. 21 (+23.45)

		Horiz.	L - 10	Lat.	Lat. + 10	Lat. + 20	Vert.
5	7	85.8	99.5	103.7	107.6	111.1	117.2
6	6	75.2	86.0	90.0	94.0	97.8	107.7
7	5	64.0	72.4	76.3	80.5	85.0	98.8
8	4	52.6	58.6	62.7	67.5	72.8	90.6
9	3	41.2	44.9	49.6	55.3	61.7	83.6
10	2	30.2	31.6	37.4	44.5	52.4	78.1
11	1	20.8	19.6	27.6	36.5	45.8	74.6
12		16.6	13.4	23.4	33.4	43.4	73.4

TABLE A10 LATITUDE 48°N. INCIDENT ANGLES FOR HORIZONTAL AND SOUTH-FACING TILTED SURFACES

Date			Horiz.	L - 10	Lat.	Lat. + 10	Lat. + 20	Vert.
Dec. 21 (-23.45)	9	3	82.0	55.3	49.6	44.9	41.8	41.6
	10	2	76.4	44.5	37.4	31.6	28.0	31.1
	11	1	72.7	36.5	27.6	19.6	14.3	22.4
	12		71.4	33.4	23.4	13.5	3.5	18.5

Date			Horiz.	L - 10	Lat.	Lat. + 10	Lat. + 20	Vert.
Jan. 21 (-19.9) Nov. 21 (-19.9)	8	4	86.5	66.2	62.0	58.5	56.0	54.7
	9	3	79.0	53.5	49.4	44.5	42.2	43.7
	10	2	73.1	42.1	35.5	30.6	28.2	33.5
	11	1	69.3	33.4	24.8	17.6	14.1	25.4
	12		68.0	30.0	20.0	10.0	0.0	22.0

Date			Horiz.	L - 10	Lat.	Lat. + 10	Lat. + 20	Vert.
Feb. 21 (-10.6) Oct. 21 (-10.7)	7	5	87.6	77.2	75.2	73.7	72.6	72.2
	8	4	78.4	62.9	60.5	59.0	58.5	61.2
	9	3	70.3	49.0	45.9	44.3	44.5	50.7
	10	2	63.8	35.9	31.5	29.5	30.6	41.4
	11	1	59.5	25.0	18.0	14.8	17.6	34.6
	12		58.0	20.0	10.0	0.0	10.0	32.0

Date			Horiz.	L - 10	Lat.	Lat. + 10	Lat. + 20	Vert.
Mar. 21 (0.0) Sep. 21 (0.0)	7	5	80.0	75.2	75.0	75.2	75.9	78.9
	8	4	70.5	60.5	60.0	60.5	62.0	68.2
	9	3	61.8	45.9	45.0	45.9	48.4	58.3
	10	2	54.6	31.5	30.0	31.5	35.5	49.9
	11	1	49.7	18.0	15.0	18.0	24.8	44.1
	12		48.0	10.0	0.0	10.0	20.0	42.0

Date			Horiz.	L - 10	Lat.	Lat. + 10	Lat. + 20	Vert.
Apr. 21 (+11.9) Aug. 21 (+12.1)	6	6	81.4	88.0	90.0	92.0	93.9	97.7
	7	5	71.4	73.5	75.3	77.6	80.2	86.9
	8	4	61.5	58.9	60.7	63.4	67.0	76.7
	9	3	52.2	44.2	46.2	49.7	54.4	67.7
	10	2	44.2	29.5	32.0	36.8	43.2	60.3
	11	1	38.5	14.8	18.9	26.2	34.9	55.3
	12		36.4	1.6	11.6	21.6	31.6	53.6

Date			Horiz.	L - 10	Lat.	Lat. + 10	Lat. + 20	Vert.
May 21 (+20.3) Jul. 21 (+20.5)	5	7	84.8	100.4	104.1	107.4	110.2	114.2
	6	6	75.3	66.6	90.0	93.4	96.7	103.2
	7	5	65.4	72.6	75.9	79.6	83.6	92.8
	8	4	55.4	58.5	62.0	66.2	71.1	83.1
	9	3	45.7	44.5	48.4	53.5	59.5	74.6
	10	2	37.0	30.6	35.5	42.1	49.6	67.9
	11	1	30.5	17.6	24.8	33.4	42.6	63.5
	12		28.0	10.0	20.0	30.0	40.0	62.0

Date			Horiz.	L - 10	Lat.	Lat. + 10	Lat. + 20	Vert.
Jun. 21 (+23.45)	5	7	82.1	99.5	103.7	107.6	111.1	116.3
	6	6	72.8	86.0	90.0	94.0	97.8	105.4
	7	5	63.0	72.4	76.3	80.5	85.0	95.2
	8	4	52.9	58.6	62.7	67.5	72.8	85.7
	9	3	43.1	44.9	49.6	55.3	61.7	77.5
	10	2	34.2	31.6	37.4	44.5	52.4	71.1
	11	1	27.3	19.6	27.6	36.5	45.8	66.9
	12		24.6	13.4	23.4	33.4	43.3	65.4

TABLE A11 LATITUDE 56°N. INCIDENT ANGLES FOR HORIZONTAL AND SOUTH-FACING TILTED SURFACES

			Horiz.	L - 10	Lat.	Lat. + 10	Lat. + 20	Vert.
Dec. 21 (-23.45)	9	3	83.1	55.3	49.6	44.9	41.8	40.5
	10	2	83.4	44.5	37.4	31.6	28.0	28.2
	11	1	80.5	36.5	27.6	19.6	14.3	16.8
	12		79.4	33.4	23.4	13.5	3.4	10.5

			Horiz.	L - 10	Lat.	Lat. + 10	Lat. + 20	Vert.
Jan. 21 (-19.9) Nov. 21 (-19.9)	9	3	85.0	53.5	48.4	44.5	42.2	42.1
	10	2	80.1	42.1	35.5	30.6	28.2	30.0
	11	1	77.1	33.4	24.8	17.6	14.1	19.3
	12		76.0	30.0	20.0	10.0	0.0	14.0

			Horiz.	L - 10	Lat.	Lat. + 10	Lat. + 20	Vert.
Feb. 21 (-10.6) Oct. 21 (-10.7)	8	4	82.5	62.9	60.5	59.0	58.5	59.6
	9	3	75.8	49.0	45.9	44.3	44.5	47.6
	10	2	70.6	35.9	31.5	29.5	30.6	36.5
	11	1	67.2	25.0	18.0	14.8	17.6	27.7
	12		66.0	20.0	10.0	0.0	10.0	24.0

			Horiz.	L - 10	Lat.	Lat. + 10	Lat. + 20	Vert.
Mar. 21 (0.0) Sep. 21 (0.0)	7	5	81.7	75.2	75.0	75.2	75.9	77.6
	8	4	73.9	60.5	60.0	60.5	62.0	65.0
	9	3	66.7	45.9	45.0	45.9	48.4	54.1
	10	2	61.0	31.5	30.0	31.5	35.5	44.1
	11	1	57.3	18.0	15.0	18.0	24.8	36.8
	12		56.0	10.0	0.0	10.0	20.0	34.0

			Horiz.	L - 10	Lat.	Lat. + 10	Lat. + 20	Vert.
Apr. 21 (+11.9) Aug. 21 (+12.1)	5	7	88.6	102.4	104.7	106.5	107.9	108.8
	6	6	80.4	88.0	90.0	92.0	93.9	96.5
	7	5	72.0	73.5	75.3	77.6	80.2	84.4
	8	4	63.9	58.9	60.7	63.4	67.0	72.9
	9	3	56.4	44.2	46.2	49.7	54.4	62.5
	10	2	50.1	29.5	32.0	36.8	43.2	53.8
	11	1	45.9	14.8	18.9	26.2	34.9	47.8
	12		44.4	1.6	11.6	21.6	31.6	45.6

			Horiz.	L - 10	Lat.	Lat. + 10	Lat. + 20	Vert.
May 21 (+20.3) Jul. 21 (+20.5)	4	8	88.8	113.8	118.0	121.5	124.0	125.5
	5	7	81.5	100.4	104.1	107.4	110.2	113.1
	6	6	73.5	86.6	90.0	93.4	96.7	101.0
	7	5	65.2	72.6	75.9	79.6	83.6	89.4
	8	4	56.9	58.5	62.0	66.2	71.1	78.6
	9	3	49.1	44.5	48.4	53.5	59.5	68.9
	10	2	42.4	30.6	35.5	42.1	49.6	61.1
	11	1	37.7	17.6	24.8	33.4	42.6	55.9
	12		36.0	10.0	20.0	30.0	40.0	54.0

			Horiz.	L - 10	Lat.	Lat. + 10	Lat. + 20	Vert.
Jun. 21 (+23.45)	4	8	85.8	112.5	117.3	121.4	124.6	127.1
	5	7	78.6	99.5	103.7	107.6	111.1	114.8
	6	6	70.7	86.0	90.0	94.0	97.8	102.9
	7	5	62.4	72.4	76.3	80.5	85.0	91.5
	8	4	54.1	58.6	62.7	67.5	72.8	80.9
	9	3	46.2	44.9	49.6	55.3	61.7	71.6
	10	2	39.3	31.6	37.4	44.5	52.4	64.1
	11	1	34.4	19.6	27.6	36.5	45.8	59.2
	12		32.6	13.4	23.4	33.4	43.4	57.4

TABLE A12 LATITUDE 64°N. INCIDENT ANGLES FOR HORIZONTAL AND SOUTH-FACING TILTED SURFACES

			Horiz.	L - 10	Lat.	Lat. + 10	Lat. + 20	Vert.
Dec. 21 (-23.45)	11	1	88.2	36.5	27.6	19.6	14.3	13.9
	12		87.4	33.4	23.4	13.5	3.4	2.5

			Horiz.	L - 10	Lat.	Lat. + 10	Lat. + 20	Vert.
Jan. 21 (-19.9) Nov. 21 (-19.9)	10	2	87.2	42.1	35.5	30.6	28.2	28.2
	11	1	84.8	33.4	24.8	17.6	14.1	15.0
	12		84.0	30.0	20.0	10.0	0.0	6.0

			Horiz.	L - 10	Lat.	Lat. + 10	Lat. + 20	Vert.
Feb. 21 (-10.6) Oct. 21 (-10.7)	8	4	86.6	62.9	60.5	59.0	58.5	58.8
	9	3	81.4	49.0	45.9	44.3	44.5	45.4
	10	2	77.4	35.9	31.5	29.5	30.6	32.6
	11	1	74.9	25.0	18.0	14.8	17.6	21.4
	12		74.0	20.0	10.0	0.0	10.0	16.0

			Horiz.	L - 10	Lat.	Lat. + 10	Lat. + 20	Vert.
Mar. 21 (0.0) Sep. 21 (0.0)	7	5	83.5	75.2	75.0	75.2	75.9	76.5
	8	4	77.3	60.5	60.0	60.5	62.0	63.3
	9	3	71.9	45.9	45.0	45.9	48.4	50.5
	10	2	67.7	31.5	30.0	31.5	35.5	38.9
	11	1	64.9	18.0	15.0	18.0	24.8	29.8
	12		64.0	10.0	0.0	10.0	20.0	26.0

			Horiz.	L - 10	Lat.	Lat. + 10	Lat. + 20	Vert.
Apr. 21 (+11.9) Aug. 21 (+12.1)	5	7	86.0	102.4	104.7	106.5	107.9	108.4
	6	6	79.6	88.0	90.0	92.0	93.9	95.1
	7	5	73.0	73.5	75.3	77.6	80.2	82.0
	8	4	66.7	58.9	60.7	63.4	67.0	69.4
	9	3	61.0	44.2	46.2	49.7	54.4	57.7
	10	2	56.5	29.5	32.0	36.8	43.2	47.6
	11	1	53.5	14.8	18.9	26.2	34.9	40.3
	12		52.4	1.6	11.6	21.6	31.6	37.6

			Horiz.	L - 10	Lat.	Lat. + 10	Lat. + 20	Vert.
May 21 (+20.3) Jul. 21 (+20.5)	4	8	84.2	113.8	118.0	121.5	124.0	124.9
	5	7	78.4	100.4	104.1	107.4	110.2	111.6
	6	6	72.1	86.6	90.0	93.4	96.7	98.6
	7	5	65.5	72.6	75.9	79.6	83.6	86.1
	8	4	59.1	58.5	62.0	66.2	71.1	74.2
	9	3	53.2	44.5	48.4	53.5	59.5	63.4
	10	2	48.4	30.6	35.5	42.1	49.6	54.4
	11	1	45.1	17.6	24.8	33.4	42.6	48.3
	12		44.0	10.0	20.0	30.0	40.0	46.0

			Horiz.	L - 10	Lat.	Lat. + 10	Lat. + 20	Vert.
Jun. 21 (+23.45)	3	9	85.8	124.7	130.4	135.1	138.2	139.2
	4	8	81.0	112.5	117.3	121.4	124.6	125.9
	5	7	75.3	99.5	103.7	107.6	111.1	112.8
	6	6	69.0	86.0	90.0	94.0	97.8	100.0
	7	5	62.5	72.4	76.3	80.5	85.0	87.8
	8	4	56.0	58.6	62.7	67.5	72.8	76.2
	9	3	50.1	44.9	49.6	55.6	61.7	65.9
	10	2	45.1	31.6	37.4	44.5	52.4	57.3
	11	1	41.7	19.6	27.6	36.5	45.8	51.5
	12		40.6	13.5	23.4	33.4	43.4	49.4

Table A13 Test Data to be Recorded

Item	Test Involving Air as the Transfer Fluid	Test Involving a Liquid as the Transfer Fluid
Date	X	X
Observer(s)	X	X
Equipment name plate data	X	X
Collector tilt angle	X	X
Collector azimuth angle (as a function of time if movable)	X	X
Collector aperture area or frontal transparent area	X	X
Local standard time, at the beginning of collector warm-up and at the beginning and end of each 15 minute test period	X	X
Barometric pressure	X	
Ambient air temperature (at the beginning and end of each 15 minute test period)	X	X
$\Delta t = t_{f,e} - t_{f,i}$ across solar collector (either as a continuous function of time or as a 15 minute integrated quantity)	X	X
Inlet temperature, $t_{f,i}$ (as a continuous function of time	X	X
Outlet temperature, $t_{f,e}$ (as a continuous function of time	X	X

Table A13 - continued

Item	Test Involving Air as the Transfer Fluid	Test Involving a Liquid as the Transfer Fluid
Liquid flow rate		X
Gauge pressure at solar collector inlet		X
Gauge pressure at nozzle throat	X	
Nozzle throat diameter	X	
Velocity pressure at nozzle throat or static pressure difference across nozzle	X	
Dry bulb temperature at nozzle throat	X	
Wet bulb temperature at nozzle throat	X	
Pressure drop across solar collector	X	X
Height of the collector outlet above the collector inlet	X	X
Wind velocity near the collector surface or aperture (15 minute average)	X	X
I, the incident solar radiation onto the collector (as a continuous function of time and as a 15 minute integrated quantity if desired)	X	X
I_d, the diffuse component of the solar radiation onto the collector (at the beginning of the 15 minute period and after the completion of the 15 minute period)	X	X

Table A14 Data to be Reported

General Information

Manufacturer or Project Name . . . .
Collector Model No. . . . .
Construction details of the collector

- gross dimensions and area . . . .
- area of absorbing surface . . . .
- cover plate*, dimensions, materials, optical properties (if known) . .
- reflector*, dimensions and shape, materials, optical properties (if known) . . . .
- absorber plate, dimensional layout and configuration of flow path, absorptivity to short wave radiation (if known), emissivity for long wave radiation (if known), description of coating (including maximum allowable temperature if known) . . . .
- air space(s)*, thickness and description of contained gas or construction . . . .
- insulation*, material, thickness, thermal properties . . . .

Transfer fluid used and its properties . . . .

Weight of collector per m^2 of gross cross-sectional area . . . .

Volumetric capacity of the collector per m^2 of gross cross-sectional area if designed to operate with a liquid as the transfer fluid . . .

Normal operating temperature range . . . .

Minimum transfer fluid flow rate . . . .

Maximum transfer fluid flow rate . . . .

Maximum operating pressure . . . .

Description of apparatus, including flow configuration and instrumentation used in testing (include photographs) . . . .

Description of the mounting of the collector for testing . . . .

Location of tests (longitude, latitude, and elevation above see level)

Efficiency Tests

A plot of the efficiency versus $\left(\frac{t_{f,i} + t_{f,e}}{2} - t_a\right)/I$ . . . .

* if applicable

An equation for the efficiency curve . . . .

For each "data point"

$\dot{m}$ . . . .

c_p . . . .

$\int_{\tau_1}^{\tau_2} (t_{f,e} - t_{f,i})\, d\tau$ . . . .

$\int_{\tau_1}^{\tau_2} I\, d\tau$ . . . .

pressure drop across the solar collector . . . .
collector tilt angle . . . .
collector azimuth angle (as a function of time if movable) . . . . . .
incident angle . . . .
inlet fluid temperature, $t_{f,i}$ . . . .
percentage of incident radiation that is diffuse . . . .
wind speed near the collector surface or aperture . . . .

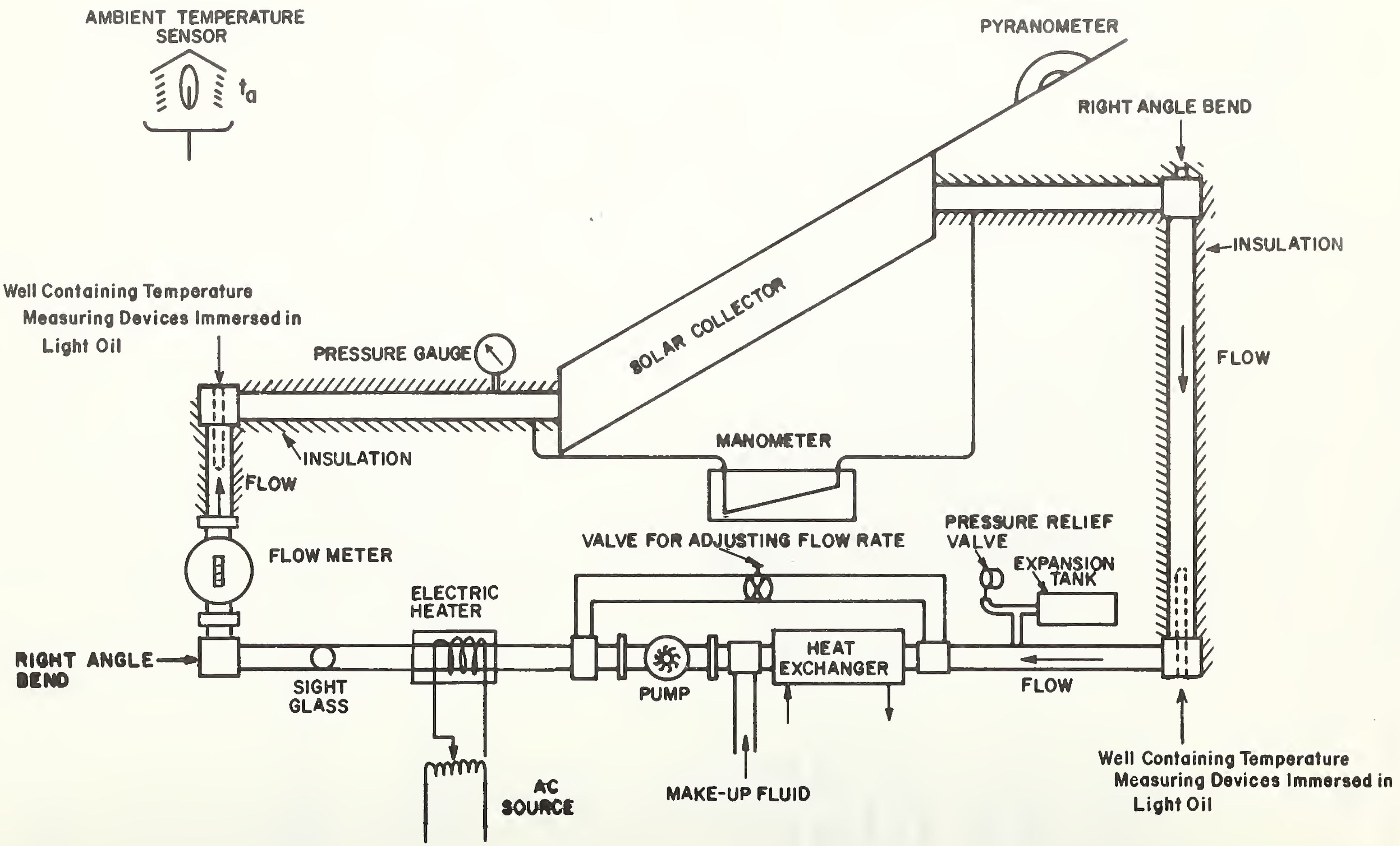


Figure A1 Testing Configuration for the Solar Collector When the Transfer Fluid is a Liquid

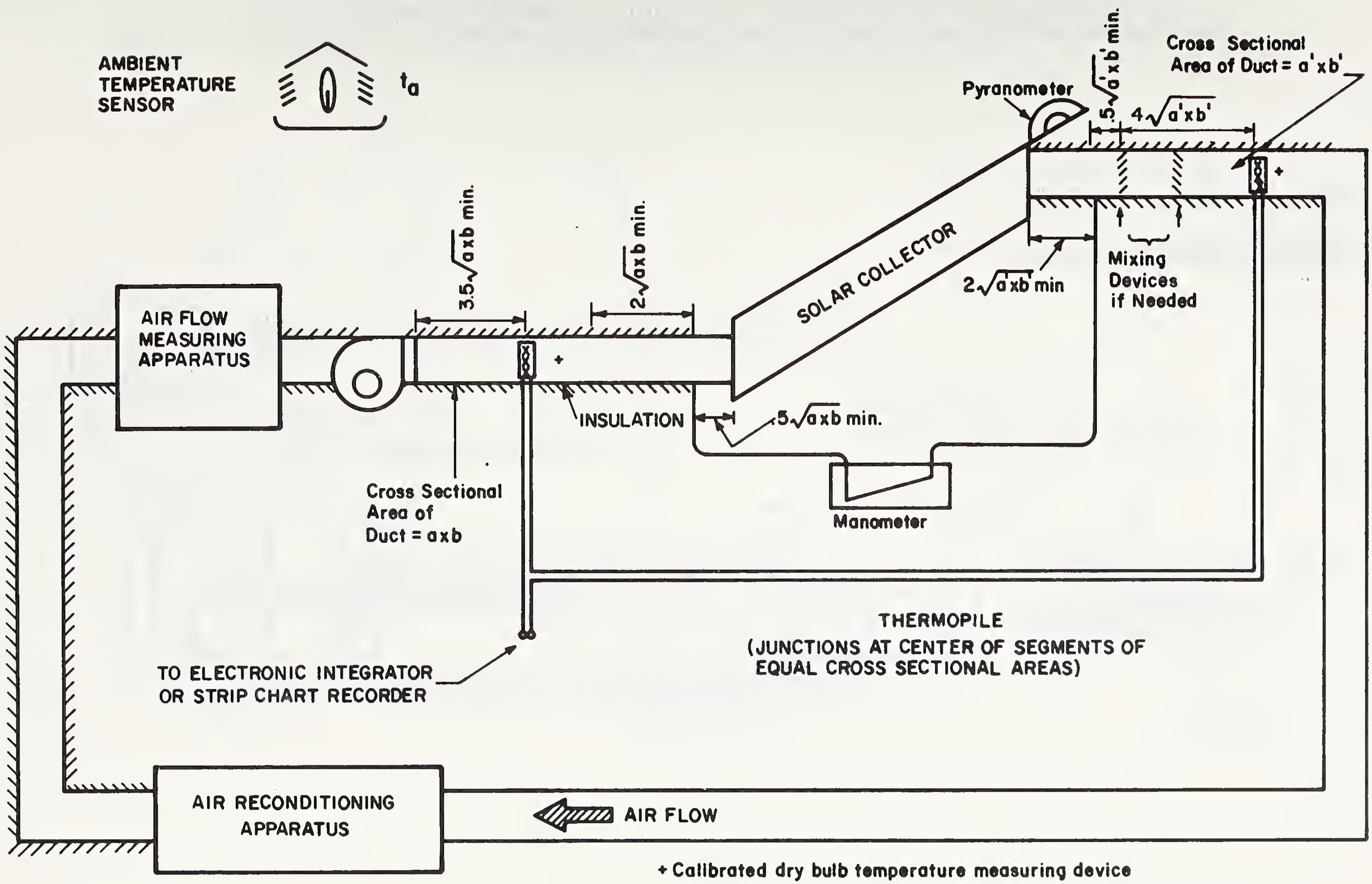


Figure A2 Testing Configuration for the Solar Collector When the Transfer Fluid is Air

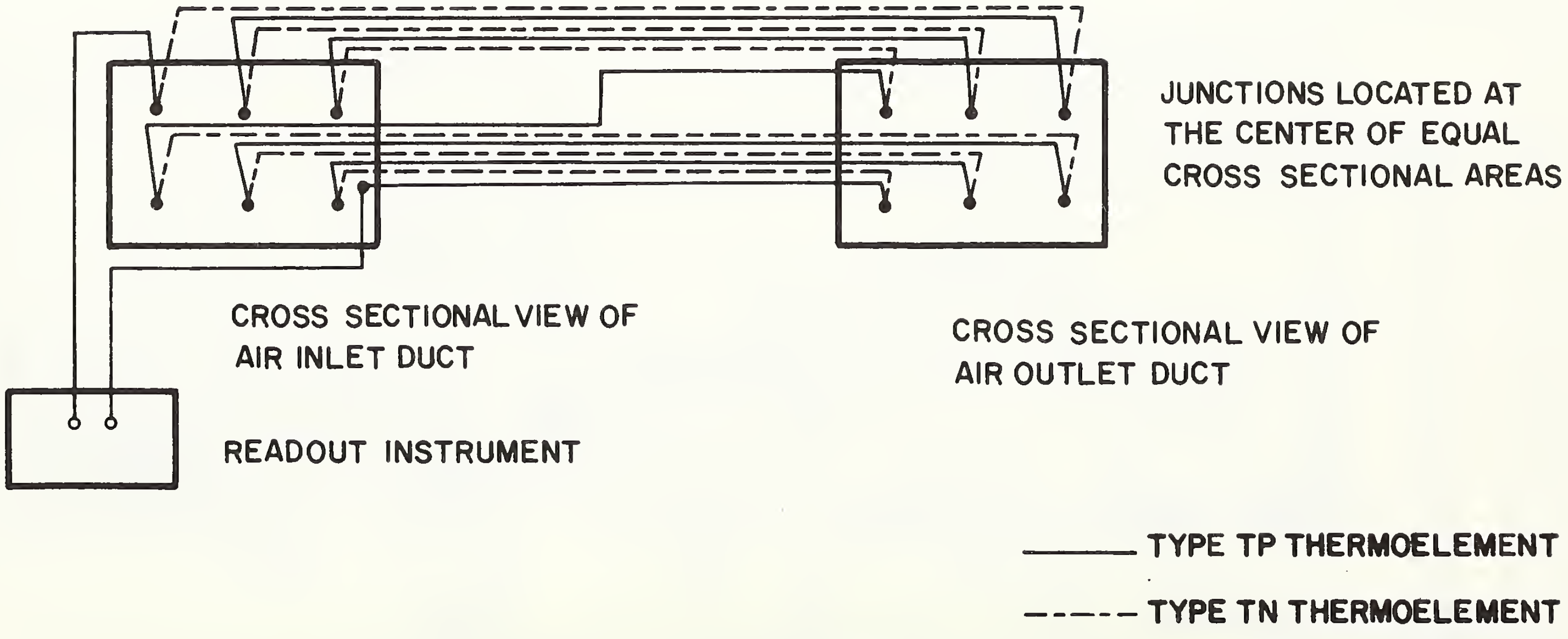


Figure A3 Schematic of the Thermopile Arrangement Used to Measure the Temperature Difference Across the Solar Collector

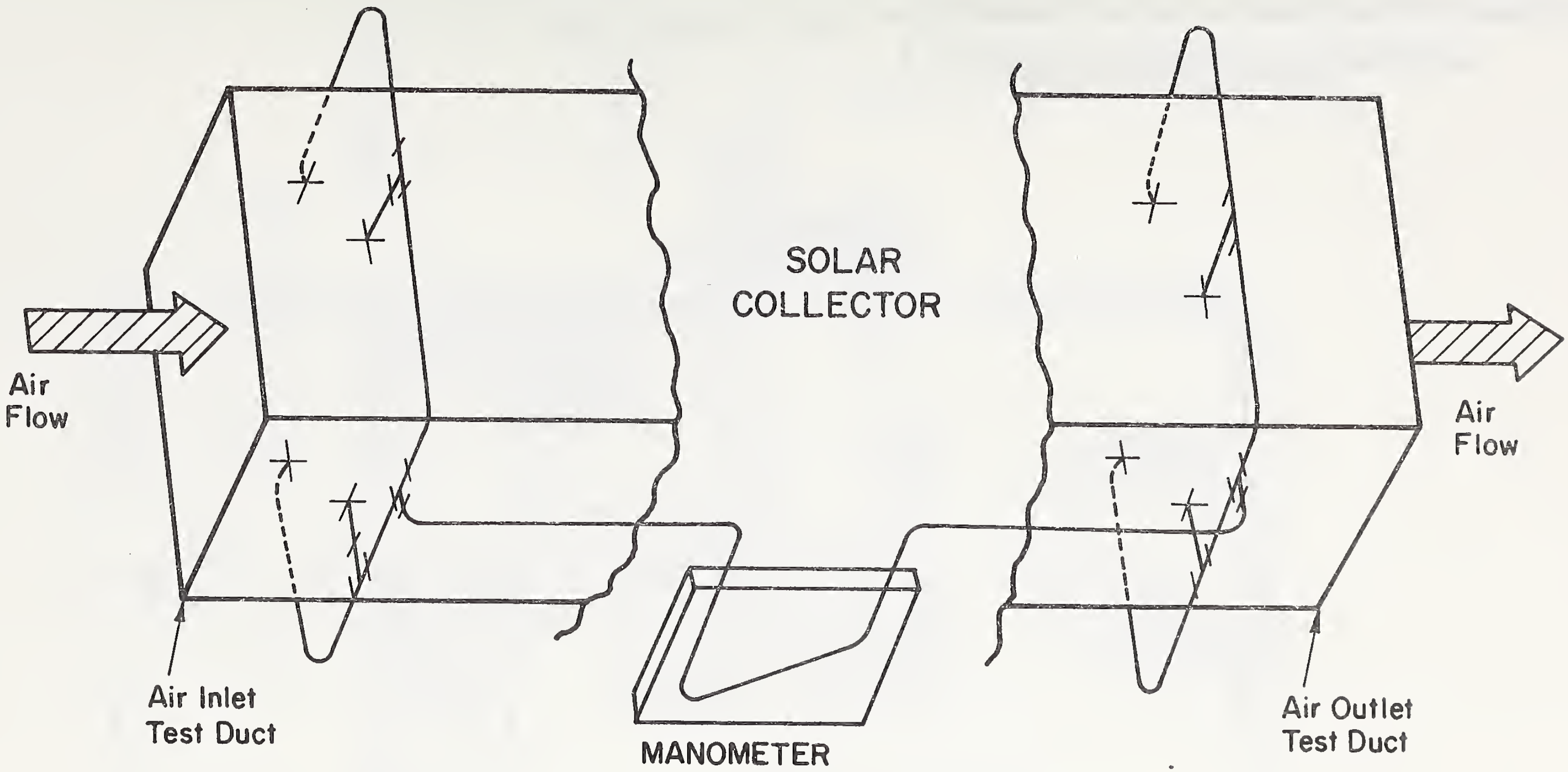
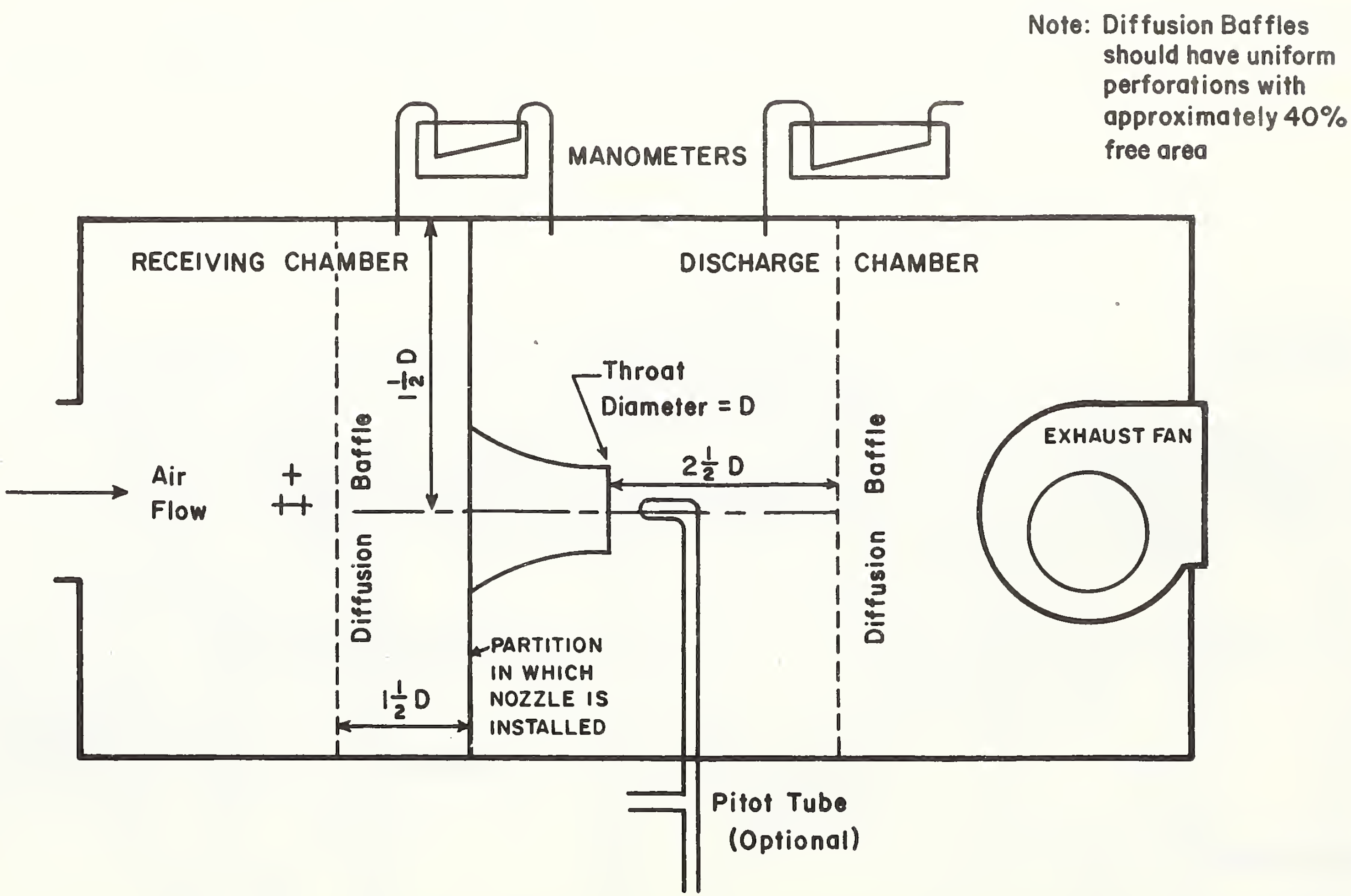


Figure A4 Schematic Representation of the Measurement of Pressure Drop Across the Solar Collector When Air is the Transfer Fluid



+ CALIBRATED THERMOCOUPLE OR THERMISTOR

++ CALIBRATED WET BULB TEMPERATURE MEASURING DEVICE

Figure A5 Nozzle Apparatus for Measuring Air Flow Rate

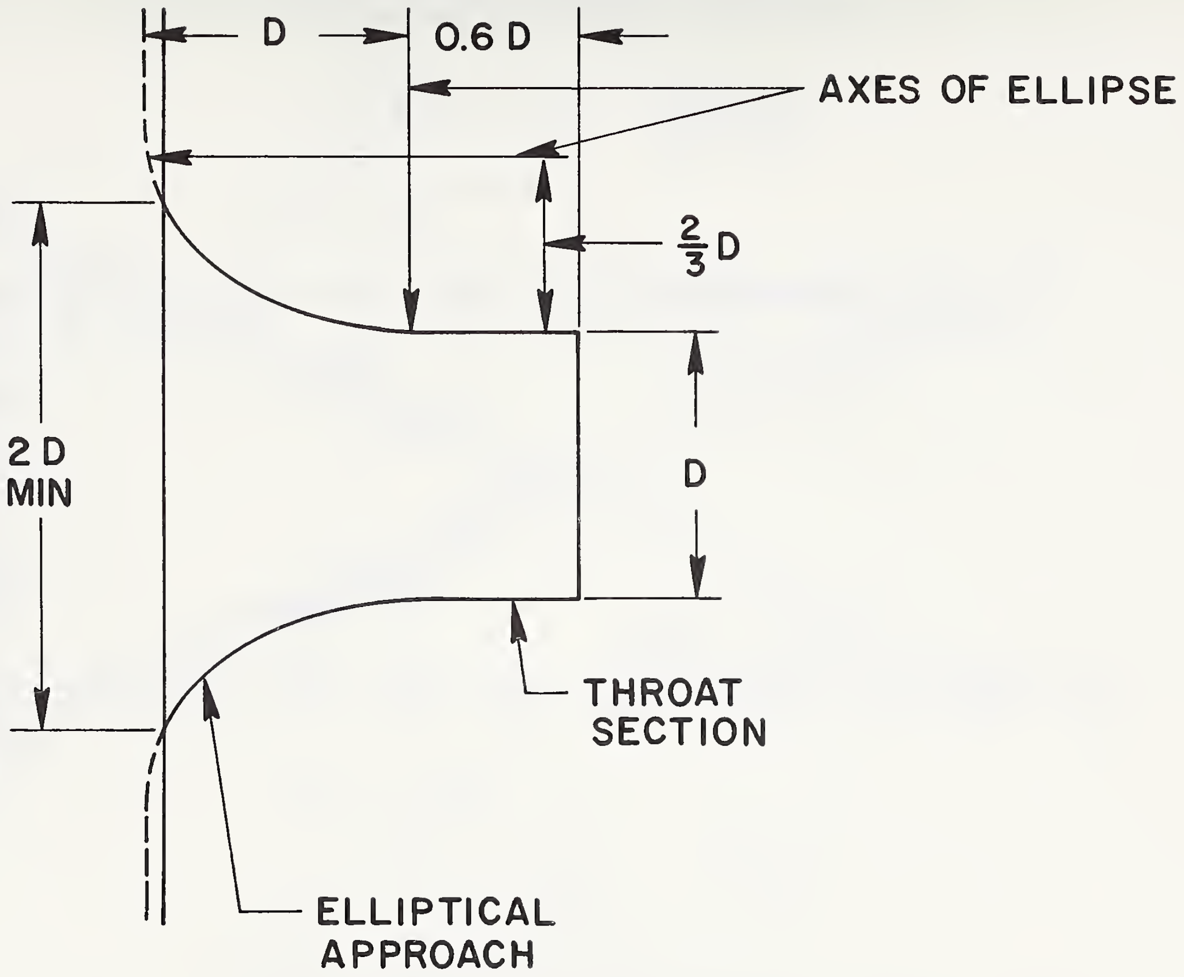


Figure A6 Air Flow Measuring Nozzle

1.23 m by 0.76 m Air Heaters
single glass cover plate
.15 m glass wool edge insulation
.05 m glass wool back insulation
o corrugated galvanized iron absorber surface, carbon black paint
● corrugated aluminum absorber surface, commercial chimney paint

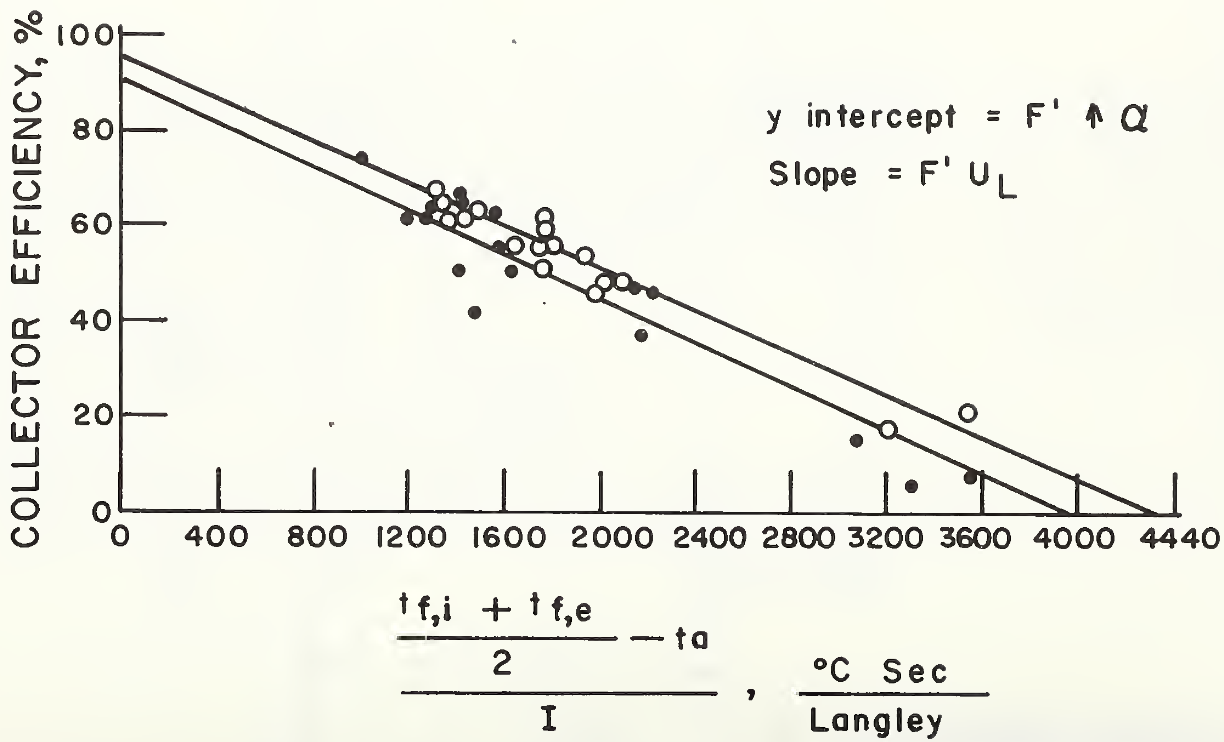


Figure A7 Efficiency Curves for Two Flat-Plate Collectors Using Air as the Transfer Fluid (reference [24])

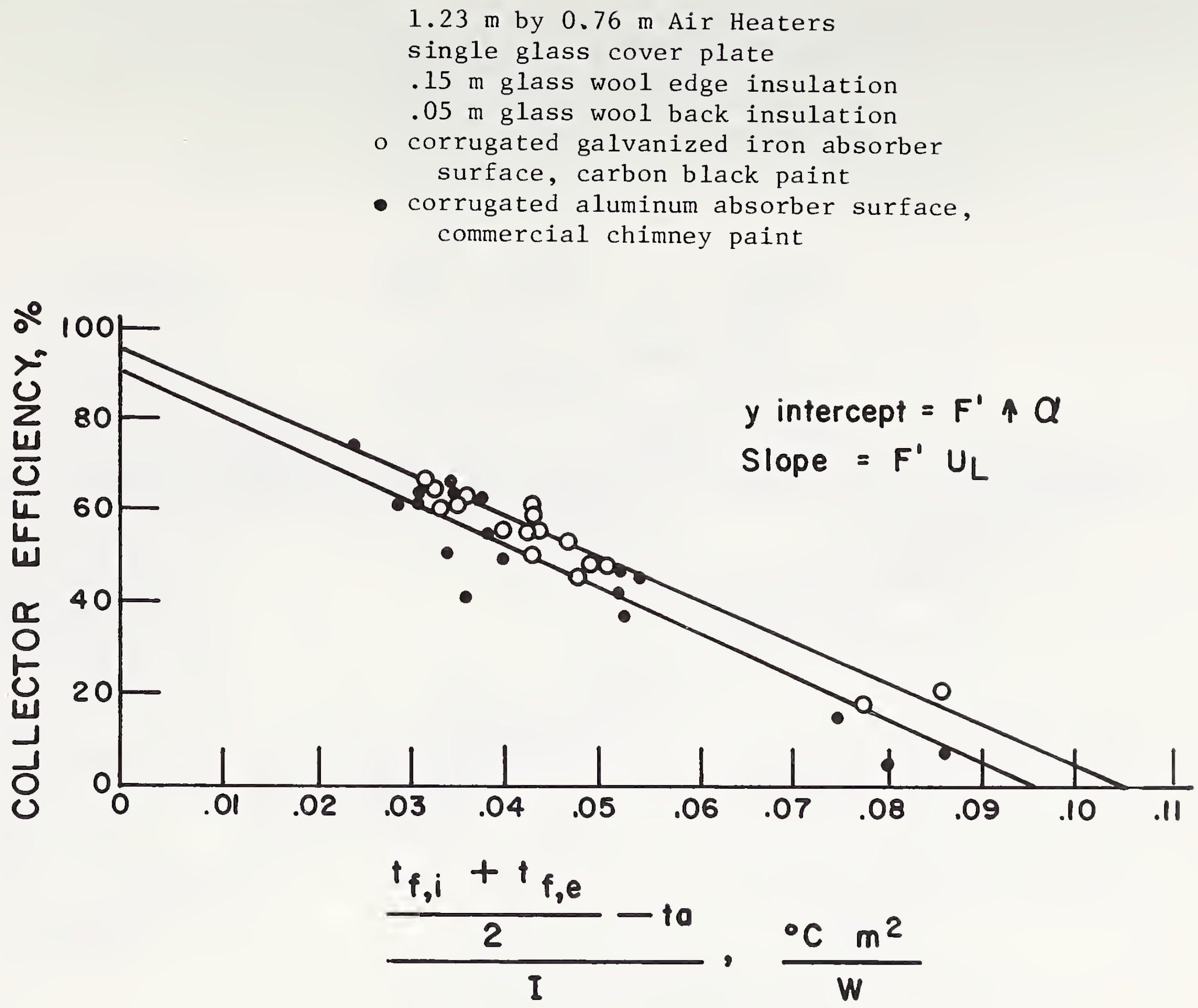
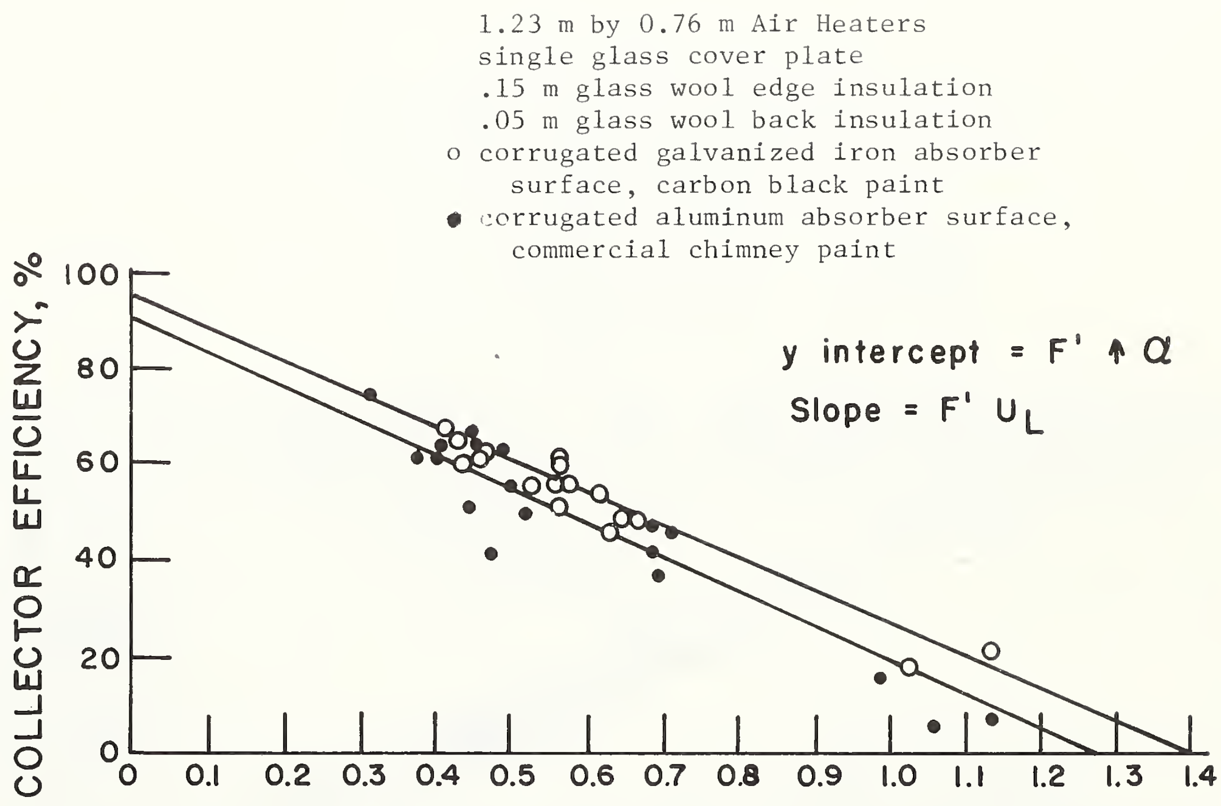


Figure A8 Efficiency Curves for Two Flat-Plate Collectors Using Air as the Transfer Fluid (reference [24])



$$\frac{\frac{t_{f,i} + t_{f,e}}{2} - t_a}{t_{bp} - t_{fp}} \bigg/ \frac{I}{I_{sc}}$$

Figure A9 Efficiency Curves for Two Flat-Plate Collectors Using Air as the Transfer Fluid (reference [24])

.03 m by 0.3 m Flat-Plate Collector
single glass cover plate
.15 m styrofoam edge insulation
.15 m styrofoam back insulation
copper tube on copper plate absorber surface, carbon black-silicon dioxide paint

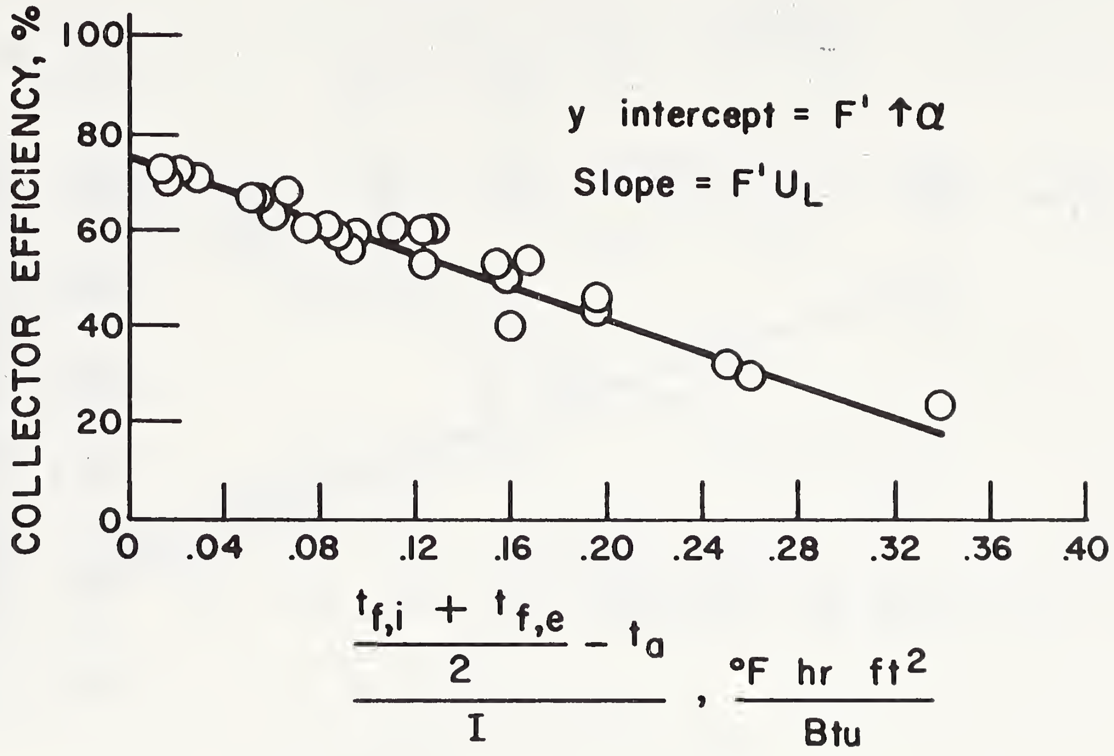


Figure A10 Efficiency Curve for a Flat-Plate Collector Using Water as the Transfer Fluid (reference [25])

.03 m by 0.3 m Flat-Plate Collector
single glass cover plate
.15 m styrofoam edge insulation
.15 m styrofoam back insulation
copper tube on copper plate absorber surface, carbon black-silicon dioxide paint

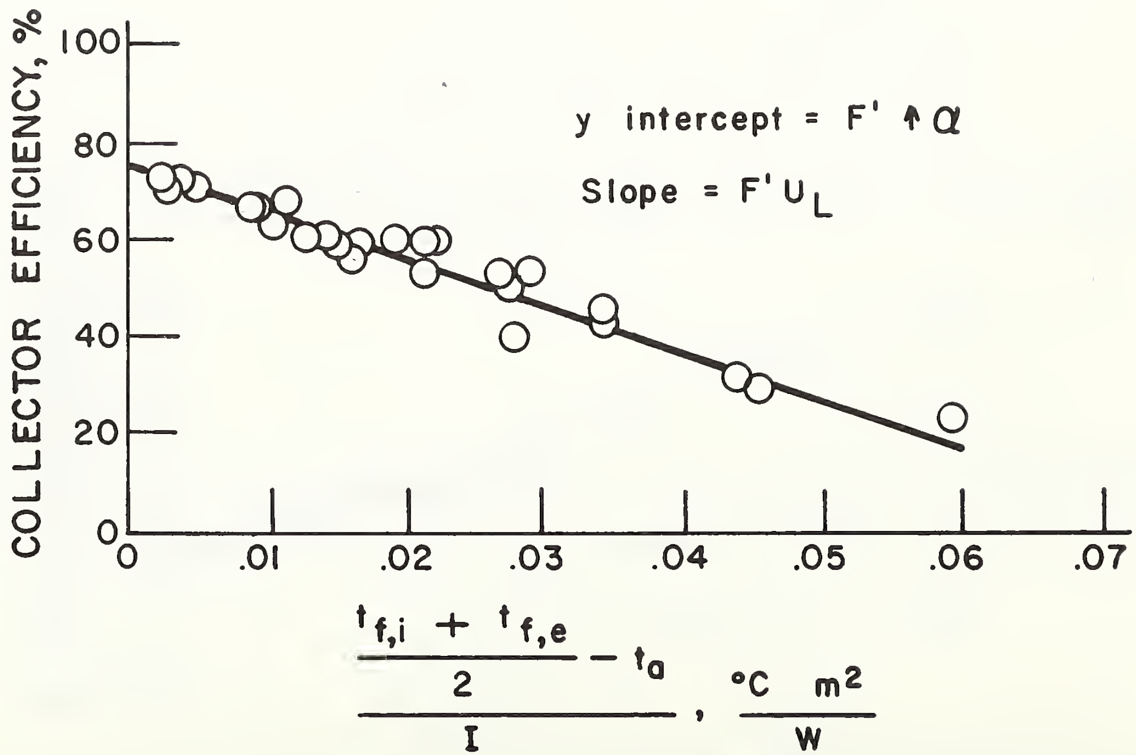


Figure A11 Efficiency Curve for a Flat-Plate Collector Using Water as the Transfer Fluid (reference [25])

.03 m by 0.3 m Flat-Plate Collector
single glass cover plate
.15 m styrofoam edge insulation
.15 m styrofoam back insulation
copper tube on copper plate absorber
surface, carbon black-silicon dioxide
paint

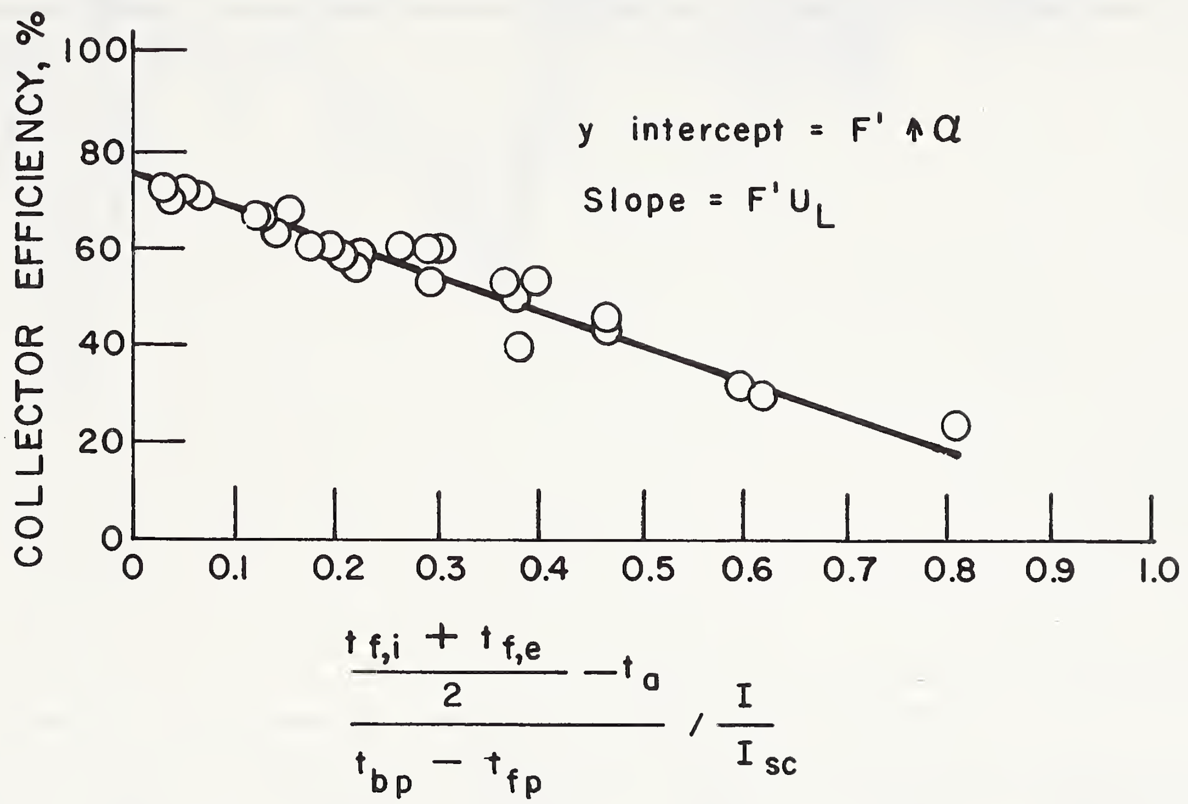


Figure A12 Efficiency Curve for a Flat-Plate Collector Using Water as the Transfer Fluid (reference [25])

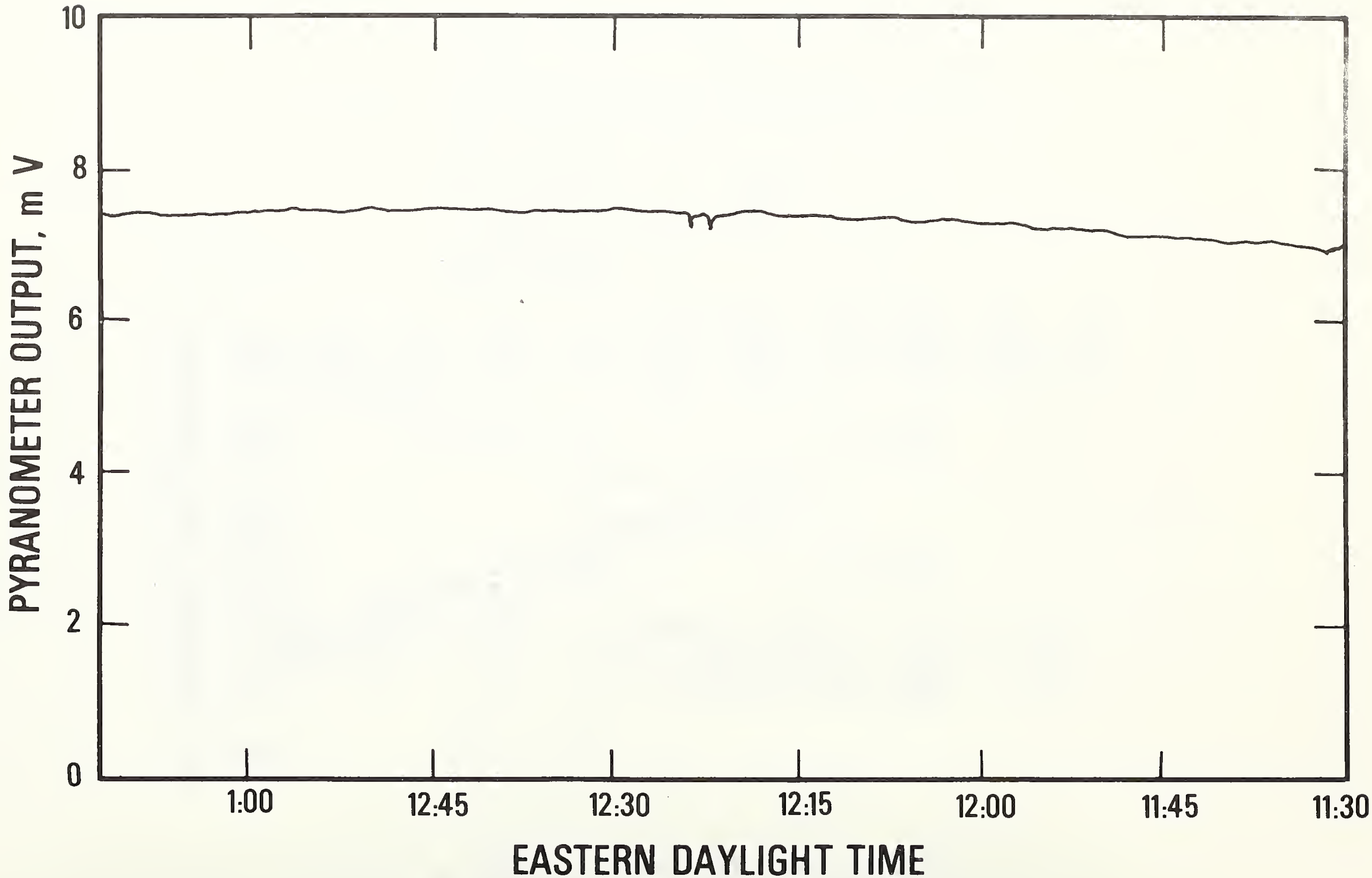


Figure A13 Incident Solar Radiation on a Horizontal Surface at the National Bureau of Standards Site in Gaithersburg, Maryland, March 13, 1974

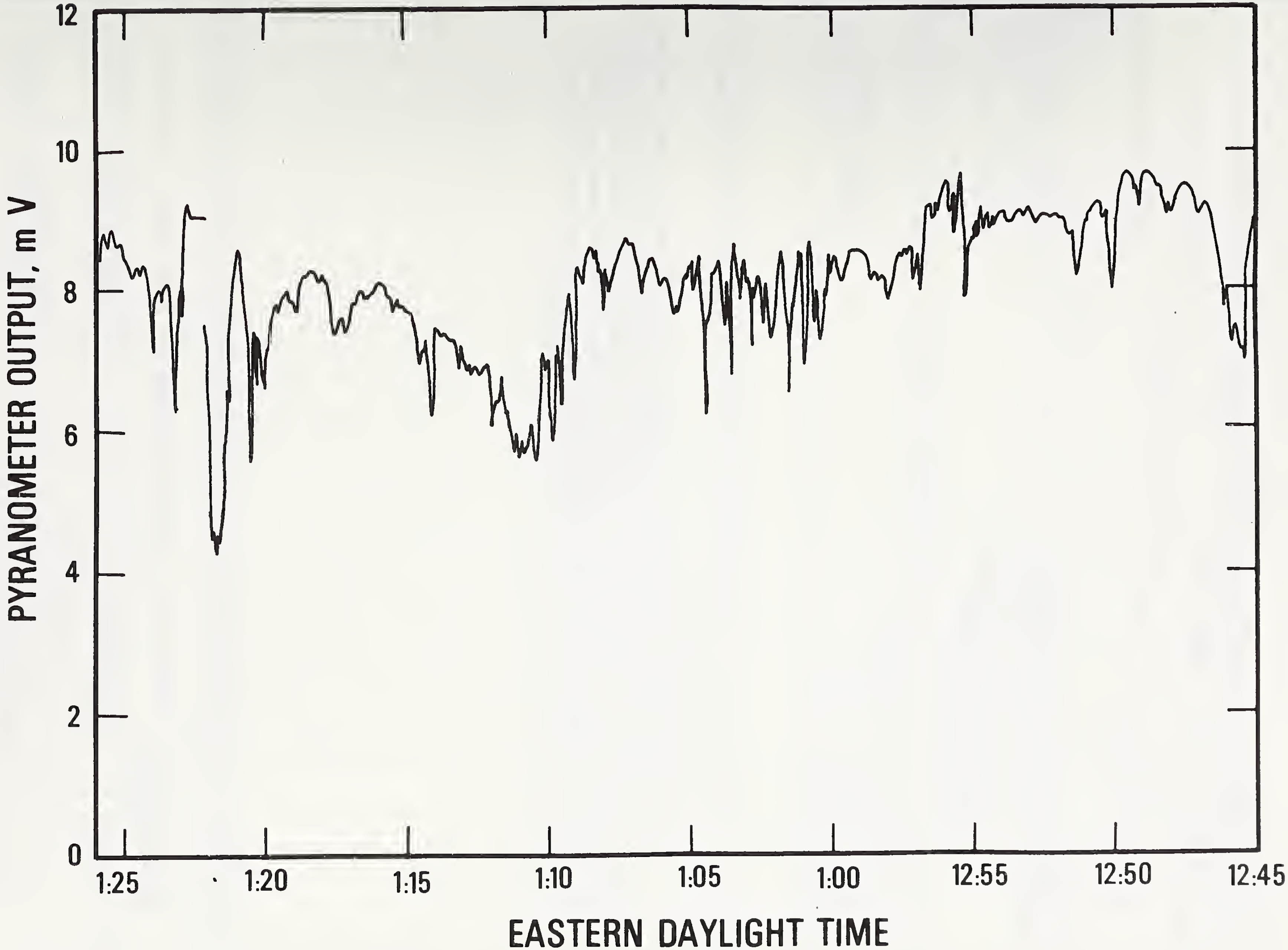


Figure A14 Incident Solar Radiation on a Horizontal Surface at the National Bureau of Standards Site in Gaithersburg, Maryland, March 11, 1974

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15. SUPPLEMENTARY NOTES

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

The National Bureau of Standards has made a study of the different techniques that could be used for testing solar collectors and rating them on the basis of thermal performance. This document outlines a standard test procedure based on that study. It is written in the format of a standard of the American Society of Heating, Refrigerating, and Air Conditioning Engineers and specifies the recommended apparatus, instrumentation, and test procedure.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Solar collector; standard test; thermal performance; solar energy; standard; solar radiation.

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