ANSI/ASHRAE Standard 96-1980(RA89) (W)

Intent to Withdraw

Methods of Testing to Determine the Thermal Performance of Unglazed Flat-Plate Liquid-Type Solar Collectors

First Withdrawal Review (October 2024)

This standard will be submitted to the American National Standards Institute Board of Standards Review (BSR) with a notice of Intent-to-Withdraw.

This intent-to-withdraw draft has been recommended for public review by the cognizant technical committee and approved by a subcommittee of the Standards Committee. To submit a comment on this proposed withdrawal, go to the ASHRAE website at http://www.ashrae.org/technology/page/331 and access the online comment database. The draft is subject to modification until it is approved for publication by the ASHRAE Board of Directors and ANSI. Until this time, the current edition of the standard (as modified by any published addenda on the ASHRAE Web site) remains in effect. The current edition of any standard may be purchased from the ASHRAE Bookstore at www.ashrae.org or by calling 404-636-8400 or 1-800-527-4723 (for orders in the U.S. or Canada).

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NOTE

Approved addenda, errata, or interpretations for this standard can be downloaded free of charge from the ASHRAE Web site at www.ashrae.org/technology.

This Foreword is not part of this Standard but is provided for information purposes only.

FOREWORD

This Standard describes tests for determining the thermal performance of unglazed collectors used in low temperature applications such as heating of swimming pools and with heat pumps. Glazed and/or concentrating collectors used in these same applications are intended to be tested for thermal performance in accordance with ASHRAE Standard 93-1986.

It should be recognized that the thermal performance of a single collector may not be indicative of the performance of a collector array consisting of a number of modules of the same collector.

The 1980 Standard was recommended for reaffirmation with minor editorial changes by the Standards Committee on June 28, 1987. Since the ASHRAE Journal intent-to-reaffirm notice elicited no negative comments, the Board of Directors approved the reaffirmation with minor editorial changes on February 2, 1989.

1.0 PURPOSE

1.1 The purpose of this Standard is to provide test methods for determining the thermal performance of unglazed flat-plate liquid-type solar energy collector modules (hereinafter called solar collectors) which heat a liquid for low temperature applications.

2.0 SCOPE

2.1 Application. This Standard applies to unglazed flat-plate liquid-type solar collectors to be used in low temperature applications and in which a liquid enters the collector through a single inlet and leaves the collector through a single outlet.

2.1.1 Collectors containing more than one inlet and more than one outlet may be tested according to this Standard provided that the external piping can be connected so as to provide effectively a single inlet and a single outlet.

2.1.2 Collectors, other than unglazed flat-plate liquid-type, which are intended for low temperature applications should be tested in accordance with ASHRAE Standard 93-1986 modified in accordance with the requirements of Section 8.3 of this Standard.

2.2 Outdoor and Indoor Testing. This Standard contains methods for conducting tests outdoors under natural solar irradiation and for conducting tests indoors under simulated solar irradiation.

2.3 Test Methods and Calculation Procedures. This Standard provides test methods and calculations procedures for determining steady-state and quasi-steady-state thermal performance, and angular response characteristics of the solar collectors.

NOMENCLATURE

a,b = constants used in incident angle modifier equation, dimensionless
A_a = transparent frontal area or aperture area for a flat-plate collector, m^2 (ft^2)
A_g = gross collector area, m^2 (ft^2)
b_o = constant used in incident angle modifier equation, dimensionless
c_p = specific heat of the transfer fluid, J/(kg · °C) [Btu/ (lb · °F)]
F_R = solar collector heat removal factor, dimensionless
I_{DN} = direct normal solar irradiation, W/m^2 [Btu/(h · ft^2)]
I_d = diffuse solar irradiation incident upon the aperture plane of collector, W/m^2 [Btu/(h · ft^2)]
I_{sc} = solar constant, 1353 W/m^2 [429.2 Btu/(h · ft^2)]
I_t = total solar irradiation incident upon the aperture plane of collector, W/m^2 [Btu/(h · ft^2)]
$K_{\alpha\tau}$ = incident angle modifier, dimensionless
LST = local standard time, decimal hours
LSTM = local standard time meridian, deg
AST = apparent solar time, decimal hours
$\dot{m}$ = mass flow rate of the transfer fluid, kg/s (lb/h)
P_{th} = theoretical power required to move the transfer fluid through the collector, W (hp)
Δp = pressure drop across the collector, Pa (lb/in.^{2})
q_u = rate of useful energy extraction from the collector, W(Btu/h)
t_a = ambient air temperature, °C (°F)
$t_{f,e}$ = temperature of the transfer fluid leaving the collector, °C (°F)
$t_{f,i}$ = temperature of the transfer fluid entering the collector, °C (°F)
t_p = average temperature of the absorber surface for a flat-plate collector, °C (°F)
Δt = temperature difference, °C (°F)
U_L = solar collector heat transfer loss coefficient, W/(m^2 · °C) [Btu/(h · ft^2 · °F)]
w = density, kg/m^3 (lb/ft^3)
α = absorptance of the collector absorber surface for solar radiation, dimensionless
θ = angle of incidence between direct solar rays and the normal to the collector surface or to the aperture, deg
n_g = collector efficiency based on gross collector area, %
λ = wavelength, μm
τ = transmittance of the solar collector cover plate, dimensionless (if no cover plate is used, τ = 1.0)
$(\tau\alpha)_e$ = effective transmittance-absorptance product, dimensionless
$(\tau\alpha)_{e,n}$ = effective transmittance-absorptance product at normal incidence, dimensionless
T_1,T_2 = time at the beginning and end of a test period, decimal hours

3.0 DEFINITIONS

absorber: that part of the solar collector which receives the incident radiant energy and transforms it into thermal energy. It may possess a surface through which energy is transmitted to the transfer liquid; however, the transfer liquid itself can be the absorber.

absorber area: the total heat transfer area through which the absorbed solar irradiation heats the transfer liquid or of the absorber media if both transfer liquid and solid surfaces jointly perform the absorbing function.

air mass: the ratio of the mass of atmosphere in the actual earth-sun path to the mass which would exist if the sun were directly overhead at sea level.

angle of incidence: the angle between the direct solar beam and the normal to the aperture plane.

aperture area: the maximum projected area of a solar collector through which the unconcentrated solar radiant energy is admitted.

area, gross collector: the maximum projected area of the complete collector module exclusive of integral mounting means and liquid connectors. For assemblies of collectors, gross area includes the entire area of the assembly.

collector, unglazed: a solar collector in which the absorbing surface is directly exposed to the atmosphere.

collector, flat-plate: a non-concentrating solar collector in which the absorbing surface is essentialy planar.

collimation angle: the angle within which the radiation beams from the source depart from the line drawn from the source to the receiver.

insolation: see Irradiation, Instantaneous.

irradiation, instantaneous: the total quantity of solar radiation incident on a unit surface area in unit time, measured in W/m^2 ($Btu/(h \cdot ft^2)$).

instantaneous efficiency: the amount of energy removed by the transfer liquid per unit of gross collector area during the specified time period divided by the total solar radiation incident on the collector per unit area during the same time period, under steady-state or quasi-steady-state conditions.

pyranometer: a radiometer used to measure the total solar radiation incident upon a surface per unit time per unit area. This energy includes the direct radiation, the diffuse sky radiation, and the solar radiation reflected from the foreground.

pyrheliometer: a radiometer used to measure the direct radiation on a surface normal to the sun's rays.

quasi-steady-state: describes the state of the solar collector test when the flow rate and temperature of the liquid entering the collector are constant but the exit fluid temperature changes gradually due to the normal change in irradiation that occurs with time for clear sky conditions.

solar collector: a device designed to absorb incident solar radiation and to transfer the energy to a liquid passing through it.

temperature, ambient air: the temperature of the air surrounding the solar collector being tested.

transfer liquid, heat: the medium which passes through the solar collector and carries the absorbed thermal energy away from the collector.

4.0 CLASSIFICATIONS

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

4.1.1 Collecting Characteristics. An unglazed flat-plate collector is one in which the absorbing surface is directly exposed to the atmosphere, where the absorbing surface is essentially flat, and in which the aperture and the absorber are similar in area and geometry. Other types include glazed (single or multiple) and/or concentrating collectors.

4.1.2 Mounting. A solar collector may be mounted in a stationary position with a fixed azimuth and tilt angle (measured from the horizontal) or it may be adjustable as to tilt angle to follow the annual changes in solar declination.

4.1.3 Type of Liquid. In low temperature applications, collectors normally employ water circulated directly through the passages in the collector. They may however, employ a heat transfer liquid and a heat exchanger to heat the water.

4.1.4 Flow Direction. The liquid may flow in any manner through the collector. Figures 1, 2 and 3 show flow from bottom to top.

5.0 REQUIREMENTS

5.1 General. Unglazed flat-plate liquid-type solar collectors shall be tested in accordance with the provisions set forth in this Section and in Section 8.

5.1.1 Preconditioning. The collector whose thermal performance is to be tested in accordance with this document shall be preconditioned prior to initiation of the test. Preconditioning shall consist of stagnation heating in a non-operational mode in a dry condition for not less than three days (not necessarily successive) in which the cumulative mean incident solar radiation measured in the plane of the collector shall be not less than 17,000 $kJ/(m^2 \cdot day)$ (1500 $Btu/(ft^2 \cdot day)$). The exposure angle shall be the angle of test specified herein.

5.1.2 Size of Test Sample. Testing of full scale modules is preferred. The size of the collector to be 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. If special liquid connectors are furnished or required by the manufacturer of the collector, they shall be used for introducing the fluid during testing. If the manufacturer recommends or furnishes a special panel inter-connection means, a stub-off unit shall be installed on the panel during testing.

5.1.3 Collector Mounting. If the collector module is designed with no back insulation, for test it shall be mounted on a rigid insulating board having an insulating value of $R = 0.88\ m^2 \cdot °C/W$ ($5.0\ ft^2 \cdot h \cdot °F/Btu$).

5.1.4 Avoidance of Reflected Radiation. For tests conducted outdoors to determine thermal efficiency and incident angle modifier, 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 requirement will be satisfied if the ground and immediately adjacent foreground surfaces are diffuse reflectors with a reflectance of less than 0.20. If significant reflection can 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 no shadow will be cast onto the collector by any obstruction at any time during the test period.

5.1.5 Weather Conditions. For tests conducted outdoors to determine thermal efficiency, the tests shall be conducted at times having weather conditions such that the integrated average irradiation measured in the plane of the collector or aperture, reported, and used for the computation of instantaneous efficiency values shall be not less than 630 W/m^2 [200 Btu/(h·ft^2)]. Specific irradiation values that can be expected for clear sky conditions are shown in Tables B1 through B6 taken from Ref. 1. More accurate estimates can be made using the tables in conjunction with Clearance Numbers (see Ref. 2, pg. 27.3, Fig. 3).

5.1.6 Orientation. For tests conducted to determine thermal efficiency at near normal incidence conditions, 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 30° during the period in which test data are being taken. Angle of incidence may be estimated from Tables B7 through B12 taken from Ref. 3. More accurate estimates can be made using the procedures outlined in Refs. 2, pg. 27.3; and 4, Chapter 58.

5.1.7 Collector Surface Air Speed. For tests conducted to determine thermal efficiency and incident angle modifier, the average air speed across the collector surface shall be measured and recorded for each data point. Measurements shall be made in the immediate vicinity of the collector, at a height not greater than 15.3 cm (6 in.) above the surface of the collector and at locations where the wind speed sensor is not shielded from the wind and the sensor does not significantly cast a shadow on the collector during the tests. Average wind speed for each data point shall not exceed 1.3 m/s (3.0 mph).

5.1.8 Ambient Temperature Range. For tests conducted outdoors to determine collector thermal efficiency, the range of ambient temperatures for all reported test points comprising the efficiency curve shall be less than 10 °C (18 °F) and in the range of 15 to 38 °C (60 to 100 °F).

5.1.9 Transfer Liquid Specific Heat and Density. The transfer liquid used in the solar collector shall have known specific heat which varies by less than 0.5% in the temperature range of the liquid during a particular test period. The density of the transfer liquid shall also be known and it shall not vary by more than 0.5% over a particular test period.

6.0 INSTRUMENTATION

6.1 Solar Radiation Measurement.

6.1.1 Total Irradiation Measurement. A pyranometer shall be used to measure the total short wave radiation from both the sun and the sky. A pyrheliometer may be used to measure the direct normal radiation. The instruments shall have the following minimum characteristics, which are consistent with current practice or requirements of a first class pyranometer (or pyrheliometer if used) as classified by the World Meteorological Organization (WMO)[5-7]:

6.1.1.1 Change of Response Due to Variation in Ambient Temperature. The instruments shall be equipped with a built-in temperature compensation circuit and have a temperature sensitivity of less than ±1% over the range 15 to 38 °C (60 to 100 °F).

6.1.1.2 Variation in Spectral Response. Pyranometer and pyrheliometer errors caused by a departure from the required spectral response of the sensor shall not exceed ±2% over the range of interest. The WMO specification for a first class pyranometer is ±1%.

6.1.1.3 Nonlinearity of Response. Unless the pyranometer was supplied with a calibration curve relating the output to the irradiation, its response shall not depart more than ±1% from being linear over the range of irradiation existing during the tests.

6.1.1.4 Time Response of Pyranometer and Pyrheliometer. The time constant of the pyranometer, defined as the time required for the instrument to achieve a reading of $(1-1/e) = 63.2\%$ of its final reading after a step change in irradiation, shall be less than 5 seconds. The time constant for the pyrheliometer (if used) shall be less than 25 seconds.

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

6.1.1.6 Precautions for Effects of Humidity and Moisture. The pyranometer shall be provided with a means of preventing accumulation of moisture that may condense on surfaces within the instrument and affect its reading. An instrument with a desiccator that can be inspected is required. The ambient relative humidity and condition of the desicator should be observed prior to and following any daily measurement sequence.

6.1.2 Calibration. The pyranometer shall be calibrated for solar response within 12 months preceding the collector test(s) against another pyranometer whose calibration uncertainty relative to recognized measurement standards is known. Any change of more than ±1% over a year period shall require the use of more frequent calibration or replacement of the instrument. If the instrument is damaged in any significant manner, it shall be recalibrated or replaced.

6.1.3 Measurement of Direct Component of Irradiation. When a pyrheliometer is available, it may be used to determine the direct component of the irradiation incident on a tilted pyranometer. Alternately, the diffuse component may be determined by shading the tilted pyranometer from the direct irradiation. (See Section 8.3.1 and Ref. 7). At non-horizontal attitudes, ground features which can affect readings shall be noted and their effect on calibration shall be documented.

6.2 Temperature Measurements.

6.2.1 Standard Practice. Temperature measurements shall be made in accordance with ASHRAE Standard 41.1-1986[8].

6.2.2 Accuracy and Precision. The accuracy and precision of the instruments including their associated readout devices shall be within the limits as follows:

	Instrument Accuracy*	Instrument Precision**
Temperature	±0.5 °C (±0.9 °F)	±0.2 °C (±0.36 °F)
Temperature Difference	±0.01 °C (±0.018 °F)	±0.01 °C (±0.018 °F)

*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.

6.2.3 Temperature Difference Measurements Across the Solar Collector. The temperature difference of the transfer liquid across the solar collector may be measured with one of the following[8]:

a. A thermopile
b. Calibrated resistance thermometers connected in two arms of a bridge circuit.
c. Precision thermometers.
d. Calibrated thermistors.
e. Calibrated matched type-T thermocouples
f. Quartz thermometers.

6.2.4 Scale Divisions. In no case should the smallest scale division of the instrument or instrument system exceed 2 times the specified precision. For example, if the specified precision is ±0.1 °C (±0.18 °F), the smallest scale division should not exceed 0.2 °C (0.36 °F).

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

6.3 Dew Point Temperature. The dew point temperature of the ambient air shall be measured for each data point to an accuracy of ±1 °C (±1.8 °F).

6.4 Liquid Flow Measurements. The accuracy of the liquid flow rate measurement shall be equal to or better than ±1.0% of the measured value in mass units per unit time.

6.5 Integrators and Recorders.

6.5.1 Strip Chart Recorders. Strip chart recorders used shall have an accuracy equal to or better than ±0.5% of the full scale reading and have a time constant of 1 second or less. The peak signal indication shall be between 50 and 100% of full scale.

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

6.5.3 Input Impedance. The input impedance of the recorders shall be greater than 1000 times the impedance of the sensor.

6.6 Time and Mass Measurements. For calibration purposes, time measurements and mass measurements shall be made to an accuracy of ±0.20%[9].

6.7 Wind Speed. The wind speed shall be measured with an instrument and associated readout device that can determine the integrated average wind speed for each data point to an accuracy of ±0.2 m/s (±0.5 mph).

6.8 Pressure Drop Across Collector. The static pressure drop across the solar collector shall be measured with an instrument having an accuracy of ±5.0 Pa (±0.2 in. of water).

7.0 APPARATUS AND METHOD OF TESTING

7.1 Test Configuration. The test configurations for testing solar collectors are shown in Figs. 1, 2, and 3 and are representative rather than exact. They are not drawn to scale. Whichever configuration is used, the test conditions specified herein must be satisfied. When the circulating transfer liquid is susceptible to evaporation losses as in Fig. 2, care should be taken to minimize and to account for the evaporation losses.

7.1.1 Solar Collector. The solar collector shall be rigidly mounted to the test rack at the predetermined tilt angle with backing determined in accordance with the provisions of Section 5.1.3. It is essential that the test rack, whether fixed or movable, be unaffected by strong gusts of wind.

7.1.2 Ambient Temperature. The ambient temperature sensors 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 sensors 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.).[10]

7.1.3 Solar Radiation. Irradiation measurements shall be reported in terms of apparent solar time for the test site (see Appendix B).

A pyranometer for measuring the total radiation and a suitable method for determining the direct component shall be utilized for all collector tests. The pyranometer shall meet the requirements specified in 6.1.1 and shall be mounted such that its sensor is coplanar with the plane of the collector aperture. It shall not cast a shadow onto the collector aperture at any time during the test period. The pyranometer shall not be mounted so as to receive a percentage of terrestrial radiation that is disproportionate with that received by the collector. It is recommended that the pyranometer be mounted near the upper-half periphery of the collector, and in the upper center of the collector array. The pyranometer should be oriented so that the emerging leads of the connector are located north of the receiving surface (in the Northern Hemisphere), or are otherwise shaded to minimize solar heating of the electrical connections.

Care should also be taken to minimize reflected and reradiated energy from the solar collector onto the pyranometer. Some pyranometers are supplied with shields. Pyranometers not supplied with a shield may be susceptible to error due to reflections by radiation that originates below the plane of the sensor.

The direct and diffuse components of the solar radiation shall be determined for each data point. This measurement can be made utilizing the shading band or shading

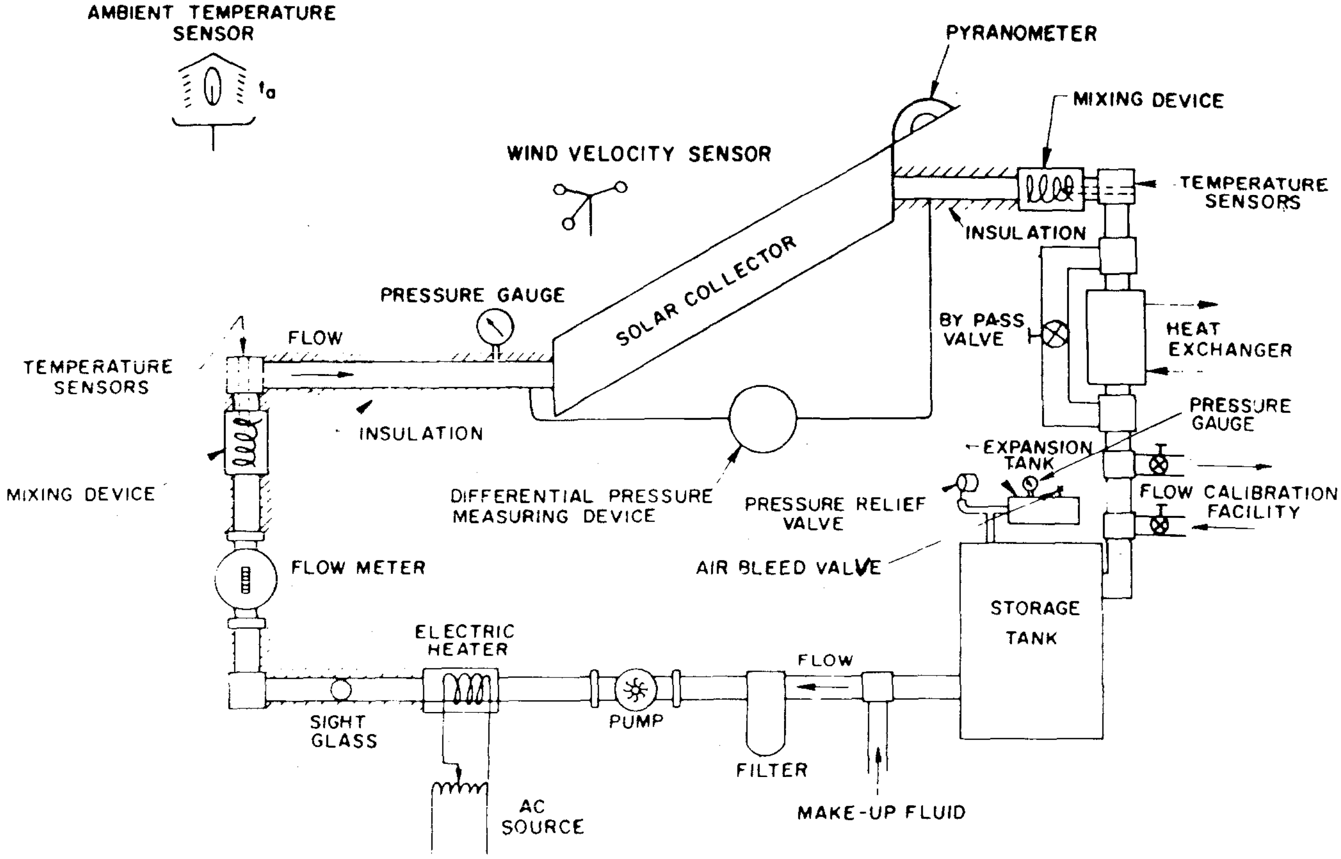


Figure 1. Closed-Loop Testing Configuration for the Solar Collector

disc method using a pyranometer (see 8.3.1) or by using a pyrheliometer.

7.1.4 Temperature Difference Measurements Across the Solar Collector. The temperature difference of the transfer liquid between entering and leaving the solar collector shall be measured in accordance with 6.2.2 and 6.2.3.

To minimize temperature measurement error, each probe shall be located as close as possible to the inlet or outlet of the solar collector and shall be inserted into a mixing device located as shown in Figs. 1, 2, and 3. In addition, the inlet and outlet piping between the mixing devices and the collector shall be insulated in such a manner that the calculated heat loss or gain from the ambient air will not cause a temperature change for any test of more than 0.01 °C (0.018 °F) between each mixing device and the collector. Both inlet and outlet piping shall be treated in like manner.

7.1.5 Additional Temperature Measurements. The temperature of the transfer liquid at each of the two positions cited above shall be measured by inserting appropriate sensors into the mixing devices (except for the case where precision thermometers are employed to determine temperature difference). Reference 8 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 an instrument such as a manometer or a differential pressure transducer. The edges of the holes on the inside surface of the pipe should be free of burrs. The holes should be as small as practical and should not exceed 1.6 mm (1/16 in.) in diameter. The thickness of the pipe wall should be at least 2.5 times the hole diameter. Provisions shall be made for determining the absolute pressure of the entering transfer liquid[11]. If the cross-sectional areas at the two sensing locations of the differential pressure measuring device are unequal, a correction for the difference in velocity pressure at the two locations shall be made.

7.1.7 Reconditioning Apparatus. As shown in Figure 1, the use of a closed-loop test facility requires that a heat exchanger be employed to cool the transfer liquid and an adjustable in-line electrical resistance heater be used to control the inlet temperature to the prescribed test values. This combination of equipment or its equivalent shall control the temperature of the liquid entering the collector to within ±0.1 °C (±0.18 °F) for each data point.

A heat exchanger is also recommended when employing an open-loop test facility similar to Fig. 2 to cool the outlet liquid to minimize evaporation losses and thus minimize weighing errors in the gravimetric determination of mass flow rate. Figure 3 shows an open-loop system in which the liquid is not recirculated.

7.1.8 Additional Equipment. A pump and a means of adjusting the flow rate of the transfer liquid shall be provided at the relative locations shown in Figs. 1, 2, and 3. Depending upon the test apparatus design, an additional throttle valve may be required in the line just preceding the solar collector for proper control.

A storage tank, expansion tank, air vent, and a pressure relief valve should be installed in the closed-loop test con-

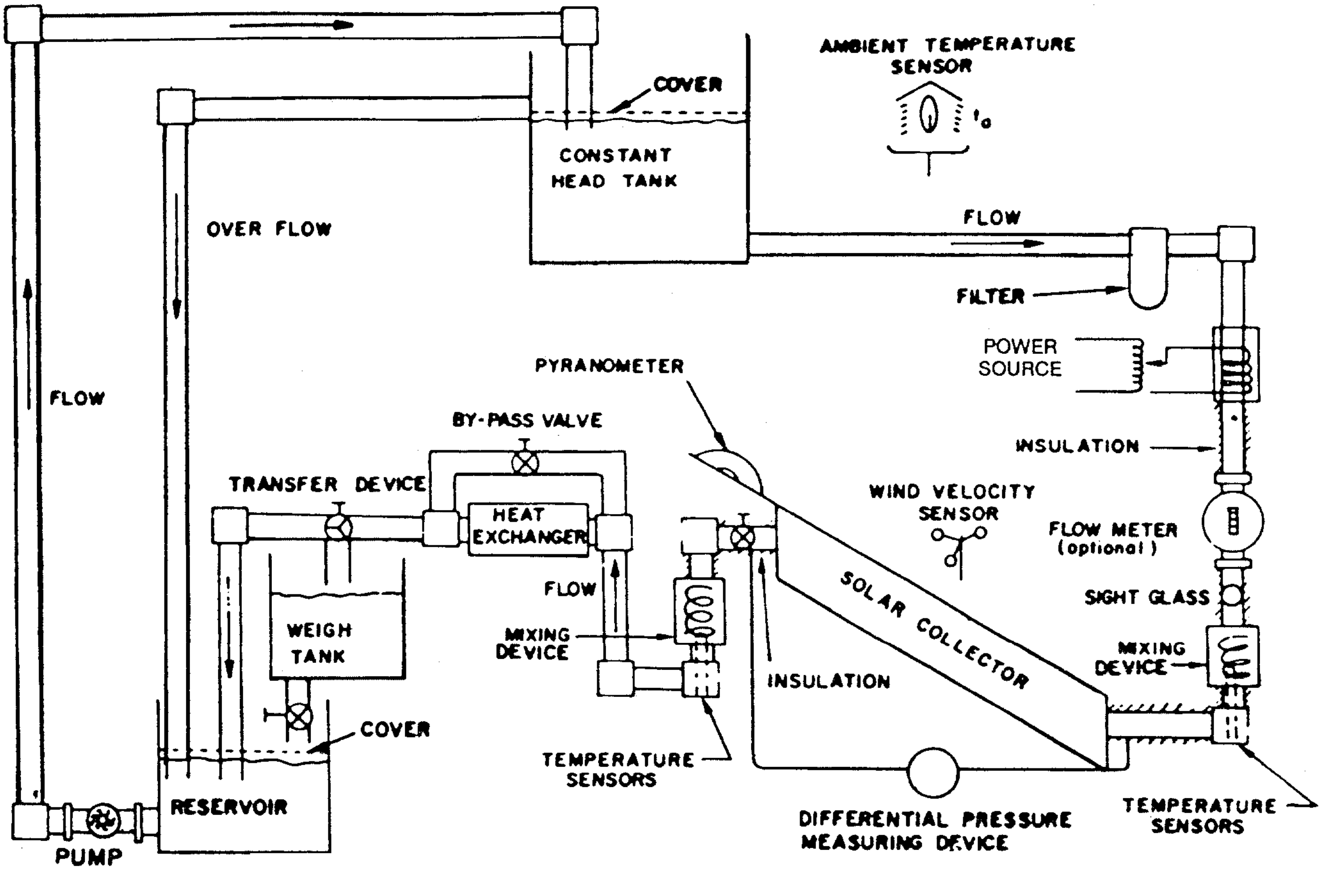


Figure 2. Open-Loop Testing Configuration for the Solar Collector

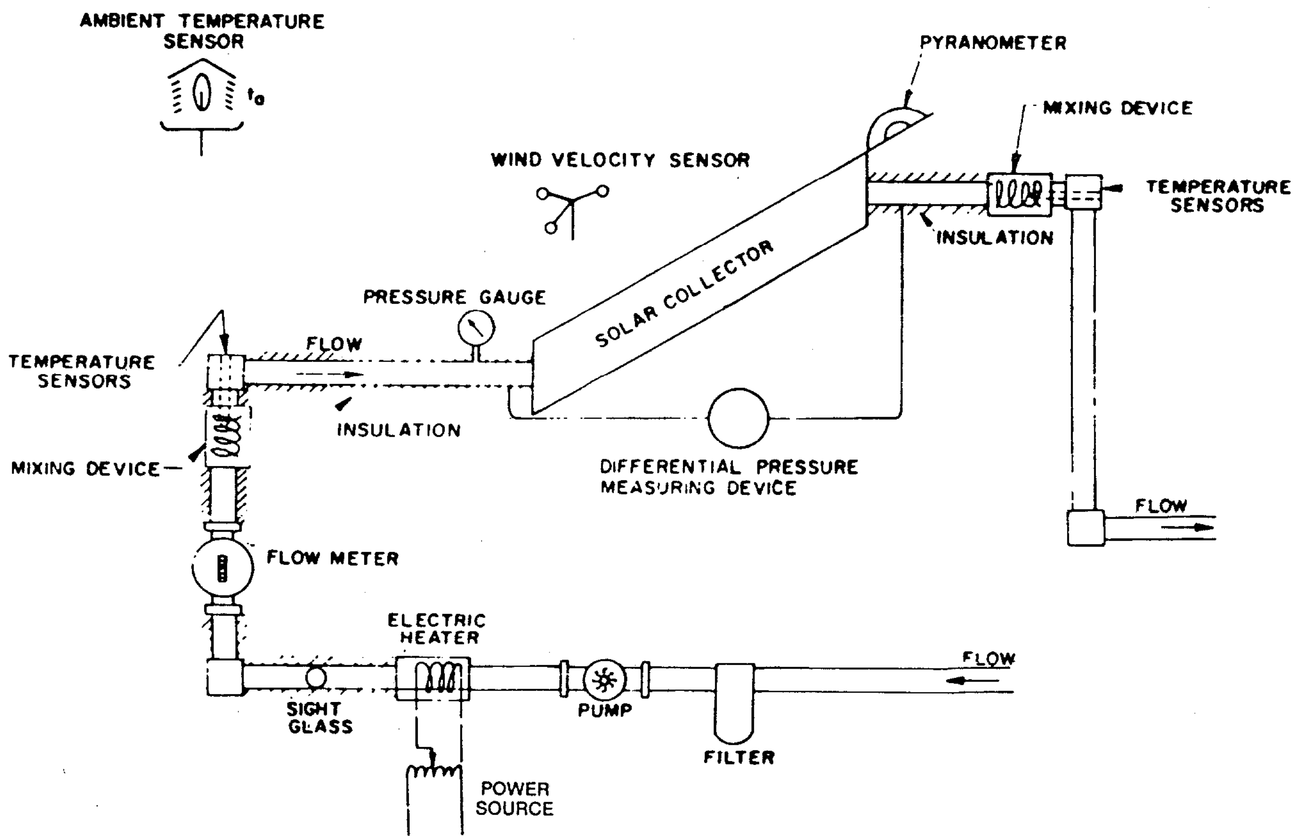


Figure 3. Open-Loop Testing Configuration for the Solar Collector for Use when Liquid is Supplied Continuously

figuration as shown in Fig. 1 to stabilize the flow and allow the transfer liquid to expand and contract freely in the system. Figure 1 should not be interpreted to mean that the relief valve and expansion tank must necessarily be located below the collector. Depending upon the design, an expansion tank and relief valve are sometimes inserted between the pump and the collector in an open-loop test facility.

Filters and a sight glass should be installed within the apparatus to ensure that the transfer liquid passing through the collector is free of contaminants, including air bubbles.

7.2 Indoor Testing With a Solar Simulator. A solar simulator may be used in lieu of outdoor testing to determine the steady-state thermal performance of the solar collectors under controlled conditions of wnd and ambient temperature. References 12, 13, and 14 describe typical simulators used for testing collectors. Solar simulators employed in the testing procedure shall have the following characteristics:

7.2.1 Spectral Qualities. The simulator shall duplicate the spectrum of average North American sunlight as closely as possible. This average is best represented by an air mass 2 solar spectrum.[12] The measured energy spectrum shall not deviate from the air mass 2 spectrum more than specified in the following table:

Band λ μm	Air Mass 2, Percent of Energy in Band	Maximum Deviation of Simulator
0.3-0.4	2.7	15%
0.4-0.7	44.4	9
0.7-1.0	28.6	3
1.0-∞	24.3	10

In addition, the calculated solar absorptance, α, of the spectrally selective surface described in Ref. 15 irradiated by the simulator shall not differ more than 1% from the value measured under air mass 2 sunlight.

There shall not be a significant change in the simulator's energy spectrum for variations in power output. The calculated solar absorptance of the above specific selective surface 15 irradiated by the simulator shall not change by more than 1% for a change in radiation flux from 0.45 to 0.75 of one Solar Constant.*

7.2.2 Uniformity. The departure from uniformity of the illumination of the solar simulator beam over the test plane (the plane of the collector aperture) shall be such that the high and low irradiation values of the illuminated plane shall not exceed ±10% of the average irradiation.

7.2.3 Collimation. The collimation shall be such that 95% of the energy output of the simulator is within a subtended angle of less than 12 degrees.

7.2.4 Simulator-to-Collector Configuration Factor. The collector configuration factor** between the solar simulator and the solar collector shall not exceed 0.05.

7.2.5 Air Flow Across Collector. A fan shall be provided to cause a substantially uniform air flow across the collector surface at a wind speed not in excess of 1.3 m/s (3.0 mph).

* 1353 W/m^2 [429.2 $Btu/(h \cdot ft^2)$].[16]

** Configuration factor, radiation exchange factor, or radiation shape factor are defined in most heat ransfer textbooks, for example, Ref. 17.

8.0 TEST PROCEDURES AND COMPUTATIONS

8.1 General. The thermal performance of unglazed flat-plate liquid-type collectors is determined in part by obtaining values of instantaneous efficiency for a combination of values of incident radiation and ambient temperature, while inlet liquid temperature is both above and below ambient. 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 liquid as it passes through the collector, all under steady-state or quasi-steady-state conditions. In addition, tests are performed to determine how the steady-state thermal efficiency varies with the incident angle between the direct solar beam and the collector.

8.2 Basic Performance Equations.

8.2.1 Collector Thermal Efficiency. It has been shown and discussed by a number of investigators[18-21] that the performance of a flat-plate solar collector operating under steady-state conditions can be successfully described by the following relationship:

$$\frac{q_u}{A_a} = I_t(\tau\alpha)_e - U_L(t_p - t_a) = \frac{\dot{m}}{A_a} c_p(t_{f,e} - t_{f,i}) \qquad (8.1)$$

To assist in obtaining detailed information about the performance of flat-plate collectors and to preclude the necessity for determining the average temperature of the absorber surface, it has been convenient to introduce a parameter F_R where:

$$F_R = \frac{\text{actual useful energy collector by a flat-plate collector}}{\text{useful energy collector if the entire flat-plate collector surface were at the inlet fluid temperature}}$$

Introducing this factor into Equation (8.1) results in

$$\frac{q_u}{A_a} = F_R[I_t(\tau\alpha)_e - U_L(t_{f,i} - t_a)] = \frac{\dot{m}}{A_a} c_p(t_{f,e} - t_{f,i}) \qquad (8.2)$$

If the solar collector efficiency is defined as

$$n_g = \frac{\text{actual useful energy collected}}{\text{solar energy incident upon or intercepted by the collector}} = \frac{q_u/A_g}{I_t} \qquad (8.3)$$

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

$$n_g = (A_a/A_g)F_R[(\tau\alpha)_e - U_L \frac{(t_{f,i} - t_a)}{I_t}] = \frac{\dot{m}c_p(t_{f,e} - t_{f,i})}{A_g I_t} \qquad (8.4)$$

$t_{f,i}$ and $t_{f,e}$ may be either greater or less than t_a for collectors used in low temperature applications.

Equation (8.4) indicates that if the efficiency, n_g, is plotted against $(t_{f,i} - t_a)/I_t$, a straight line will result where the slope is equal to $(A_a/A_g) F_R U_L$ and the y intercept is equal to $(A_a/A_g) F_R(\tau\alpha)_e$. 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 $(\tau\alpha)$ varies with the incident angle between the solar beam and the collector. However, in the range of values of parameter $(t_{f,i} - t_a)/I_t$ of interest in low temperature applications, -0.020 to $+0.030$ (°C·m²)/W, $(A_a/A_g)F_R\,U_L$ is essentially constant and the efficiency plot will be nearly a straight line within that range.

The procedures outlined in this document are intended to control the test conditions so that a well defined efficiency curve can be obtained with a minimum of scatter. Figure 4 shows a typical result of tests conducted under near-normal-incidence conditions on an unglazed collector.

Although a straight-line representation of the efficiency curve will suffice for almost all low temperature applications, some collectors may require the use of a higher order fit, i.e., a second order polynominal, due to variation of U_L with collector temperature.

8.2.2 Collector Incident Angle Modifier. The effective transmittance absorptance factor, $(\tau\alpha)_e$, can be replaced in the general equations (8.1), (8.2), and (8.4) by the value at normal incidence, $(\tau\alpha)_{e,n}$, $K_{\alpha\tau}$, is introduced.[22] Equation (8.4) then becomes:

$$\eta_g = (A_a/A_g)F_R\left[K_{\alpha\tau}(\tau\alpha)_{e,n} - U_L\frac{(t_{f,i} - t_a)}{I_t}\right] = \frac{\dot{m}c_p}{a_g I_t}(t_{f,e} - t_{f,i}) \quad (8.5)$$

It can be shown for a wide variety of solar collectors, $(\tau\alpha)_e$ should vary with incident angle according to the general expression:

$$(\tau\alpha)_e = a - (b/\cos\Phi) \quad (8.6)$$

Comparing equations (8.5) and (8.6)

$$K_{\alpha\tau}(\tau\alpha)_{e,n} = a - \frac{b}{\cos\Phi} \quad (8.7)$$

Solving the equation for $K_{\alpha\tau}$ and recognizing that $(\tau\alpha)_{e,n} = a - b$;

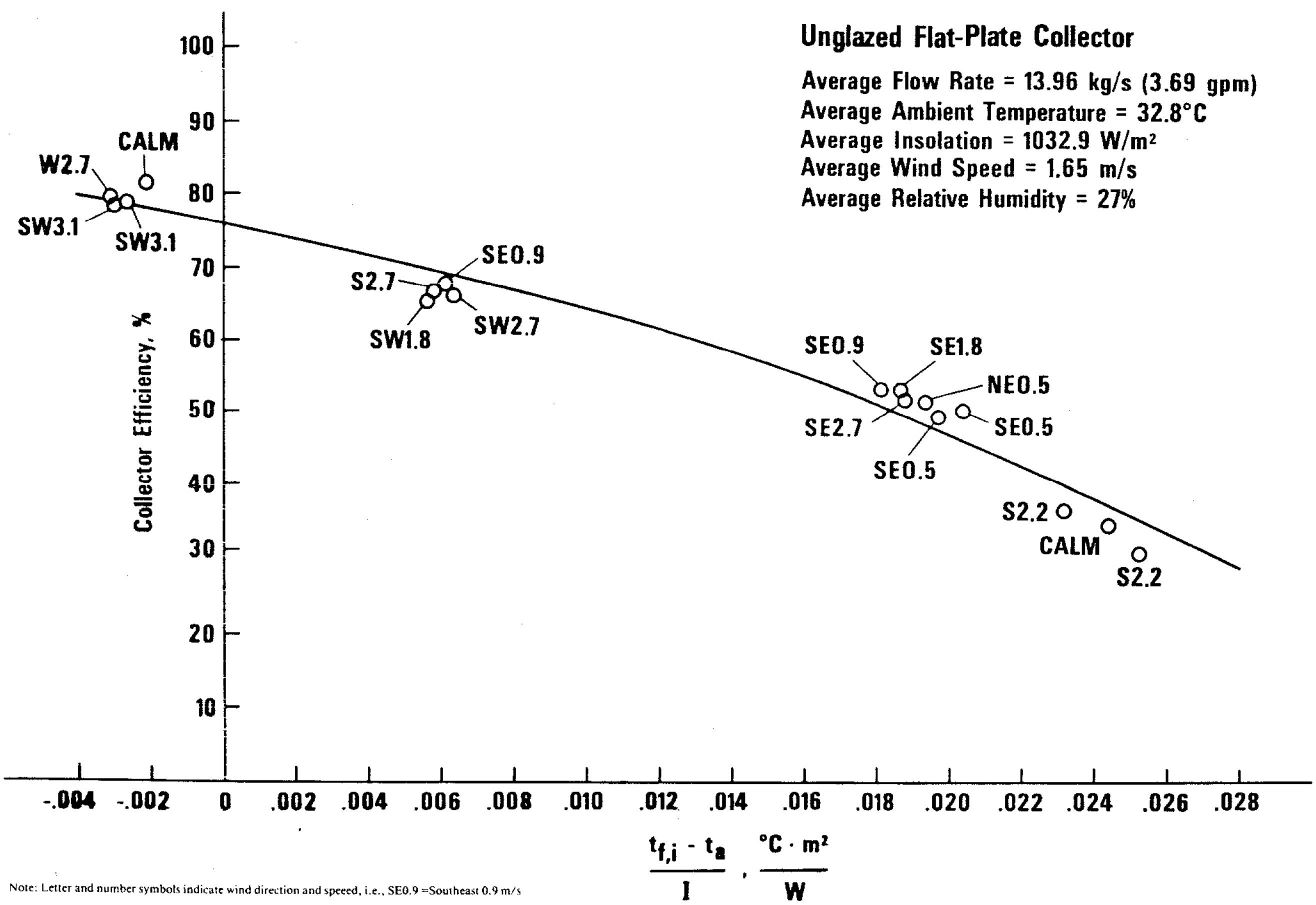
$$K_{\alpha\tau} = 1 - \frac{b}{a-b}\left(\frac{1}{\cos\Phi} - 1\right) \quad (8.8)$$

In terms of one constant, the incident angle modifier $K_{\alpha\tau}$ is:

$$K_{\alpha\tau} = 1 - b_o\left(\frac{1}{\cos\Phi} - 1\right) \quad (8.9)$$

Figure 5 shows the variation of $K_{\alpha\tau}$ with incident angle for a typical unglazed collector.

The significance of the incident angle modifier to the test procedures outlined herein is that the thermal efficiency values are determined for the collector at or near normal incidence conditions. Therefore, the y intercept of the efficiency curve is equal to $(A_a/A_g)F_R\,(\tau\alpha)_{e,n}$. A separate test is conducted to determine the value of b_o and hence $K_{\alpha\tau}$ so that the performance of the collector can be predicted



Note: Letter and number symbols indicate wind direction and speeed, i.e., SE0.9 =Southeast 0.9 m/s

Figure 4. Hottel-Whillier-Newton Plot of Thermal Efficiency for an Unglazed Flat-Plate Liquid-Type Solar Collector Using Water as the Transfer Liquid

under a wide range of conditions and/or time of day using Equation (8.5).

It is recognized that some collector designs require tests in two different incident angle planes to account for non-symmetrical response to irradiation as solar azimuth and altitude change throughout the day. In such cases, both incident angle modifiers should be determined in the different planes.

8.3 Test Procedure. The first performance tests to be conducted are a series of thermal efficiency tests as explained in 8.3.1. The value of the collector incident angle modifier is then determined in accordance with 8.3.2. The incident angle modifier test is not required for those collectors for which the angular response characteristics are known.

8.3.1 Experimental Determination of the Collector Thermal Efficiency. The testing of the solar collector to determine its thermal efficiency shall be conducted in such a way that a governing efficiency curve for near-normal-incidence is determined under test conditions described in Section 5 and this section. At least four different values of inlet liquid temperature shall be used to obtain the values of $\Delta t/I_t$. At least one value of $\Delta t/I_t$ shall be in the negative range of approximately -0.02 to $-0.15°$ (°C ·m²)/W. The remaining values shall be in the positive range of $+0.01$ to $+0.030$ (°C ·m²)/W.

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. The requirement for obtaining data points equally divided between morning and afternoon does not apply when testing with an altazimuth mount. 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 efficiency values determined by integrating over five minutes. The integrated value of incident solar radiation will be divided into the integrated value of energy obtained from the collector to obtain the efficiency value for that test period.

When an indoor solar simulator is employed and true steady-state conditions can be obtained, the time interval specified above is not applicable. In this case, data may be considered as steady-state when the collector outlet temperature does not change (within the limits of measurement) in a five minute time period. Instantaneous data may then be used to determine instantaneous efficiency.

In conducting outdoor tests, care should be taken to ensure that the incident solar energy is steady for each time interval 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/h (12 in./h) or greater must always be used to monitor the output of the pyranometer to ensure that the incident radiation has remained steady during the test period. Figures 6 and 7 show strip chart recordings of incident solar radiation on a horizontal surface. Whereas the conditions of Fig. 6 would be perfectly acceptable for obtaining efficiency values, those of Fig. 7 would not be.*

The surface of the exposed envelopes of the pyranometer(s) and pyrheliometer (if used) 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 since such abrasive action can appreciably alter the original transmission properties of the enclosing envelope.

The pyranometer(s) 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 steady-state or quasi-steady-state conditions for the solar collection process, the transfer, liquid should be circulated through the collector

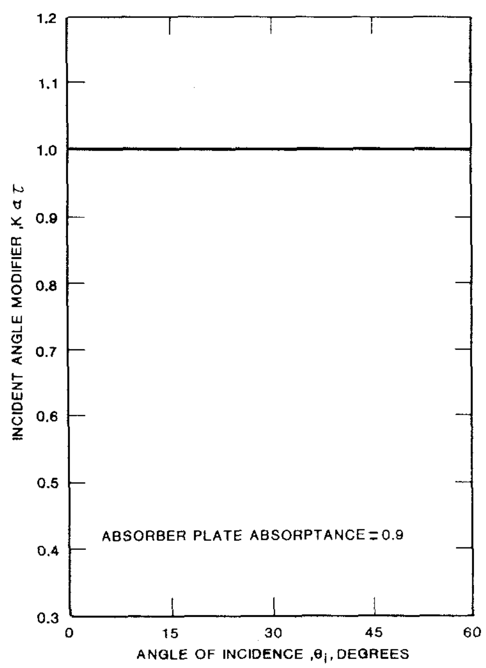


Figure 5. Example of Incident Angle Modifier for an Unglazed Flat-Plate Solar Collector with a Non-Selective Surface

* One or two "blips" of 10 s or less occurring the test period such as at 12.18 in Figure 6 are acceptable.

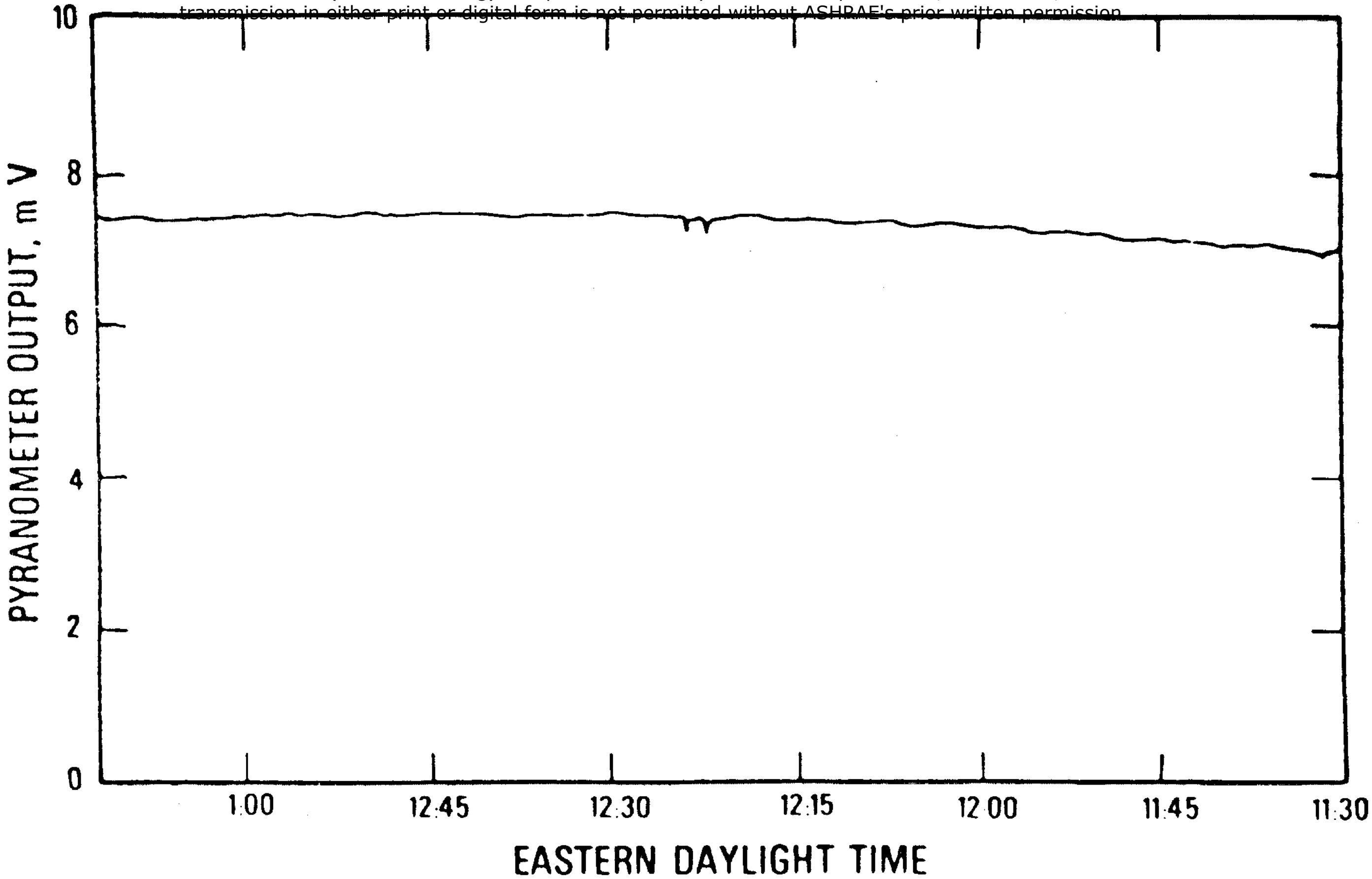


Figure 6. Incident Solar Radiation on a Horizontal Surface in Gaithersburg, Md, March 13, 1974.

at the appropriate inlet temperature level until the temperature has remained constant for 15 min prior to the period in which data will be taken to calculate the efficiency values.

When using an indoor simulator, the following starting procedure has been found satisfactory. The transfer liquid is circulated through the collector at the inlet temperature chosen for the test. After equilibrium is established for the chosen inlet temperature, the simulator is turned on and the desired radiant flux obtained by adjusting the lamp voltage. A check should be made to ensure that the flow rate of the transfer liquid does not vary by more than ±1% and that the incident radiation is steady as described above.

The flow rate of heat transfer liquid through the collector shall be standardized for all data points. The recommended value of flow rate per unit area (transparent frontal or aperture) for standard tests is 0.07 kg/s $\cdot m^2$ (51.5 lb/(h $\cdot$ ft^2)). It is recognized that in some cases the manufacturer of a collector will recommend a design flow rate different from that specified above. In such cases the recommended design flow rate should be used.

The fraction of the incident solar radiation which is diffuse must be determined and reported for each efficiency data point. In the absence of a normal incidence pyrheliometer, two pyranometers may be used, one of which uses a shading band[7] or if only a single pyranometer is used, its sensing element shall be shaded from the direct beam of sun just prior to and just following each test for a short period and the value of the incident diffuse radiation determined. This shall be accomplished by using a small disc attached to a slender rod held in a direct line between the pyranometer and the sun. The disc should be just large enough to shade the sensing element alone. As an example, see [5].

The steady wind speed across the collector as measured per 5.1.7 and 6.7 shall be less than 1.3 m/s (3.0 mph). Average wind speed shall be recorded for each data point on the efficiency curve.

8.3.2 Experimental Determination of Collector Incident Angle Modifier for Stationary Collectors. The testing of the solar collector to determine its incident angle modifier can be done by either of two methods.

Method (1): This method is applicable for testing indoors using a solar simulator or outdoors using a movable test rack so that the orientation of the collector can be arbitrarily adjusted with respect to the direction of the direct solar beam. Four separate efficiency values are determined in general accordance with the method described in 8.3.1. For each data point, the inlet temperature of the transfer liquid is controlled as close as possible to within ±1°C (±1.8°F) of the ambient air temperature. The collector is oriented so that the average incident angles between it and the direct solar beam for the four test conditions are respectively, approximately 0, 30, 45 and 60 degrees ±3°.The foregoing values are appropriate for most unglazed collectors.

Method (2): This method is applicable for testing outside using a permanent test rack where the collector orientation cannot be arbitrarily adjusted with respect to the direction of the incident solar radiation (except for adjustments in tilt). Six separate efficiency values are determined in general accordance with the method described in 8.3.1. For each data point the inlet temperature of the transfer liquid is

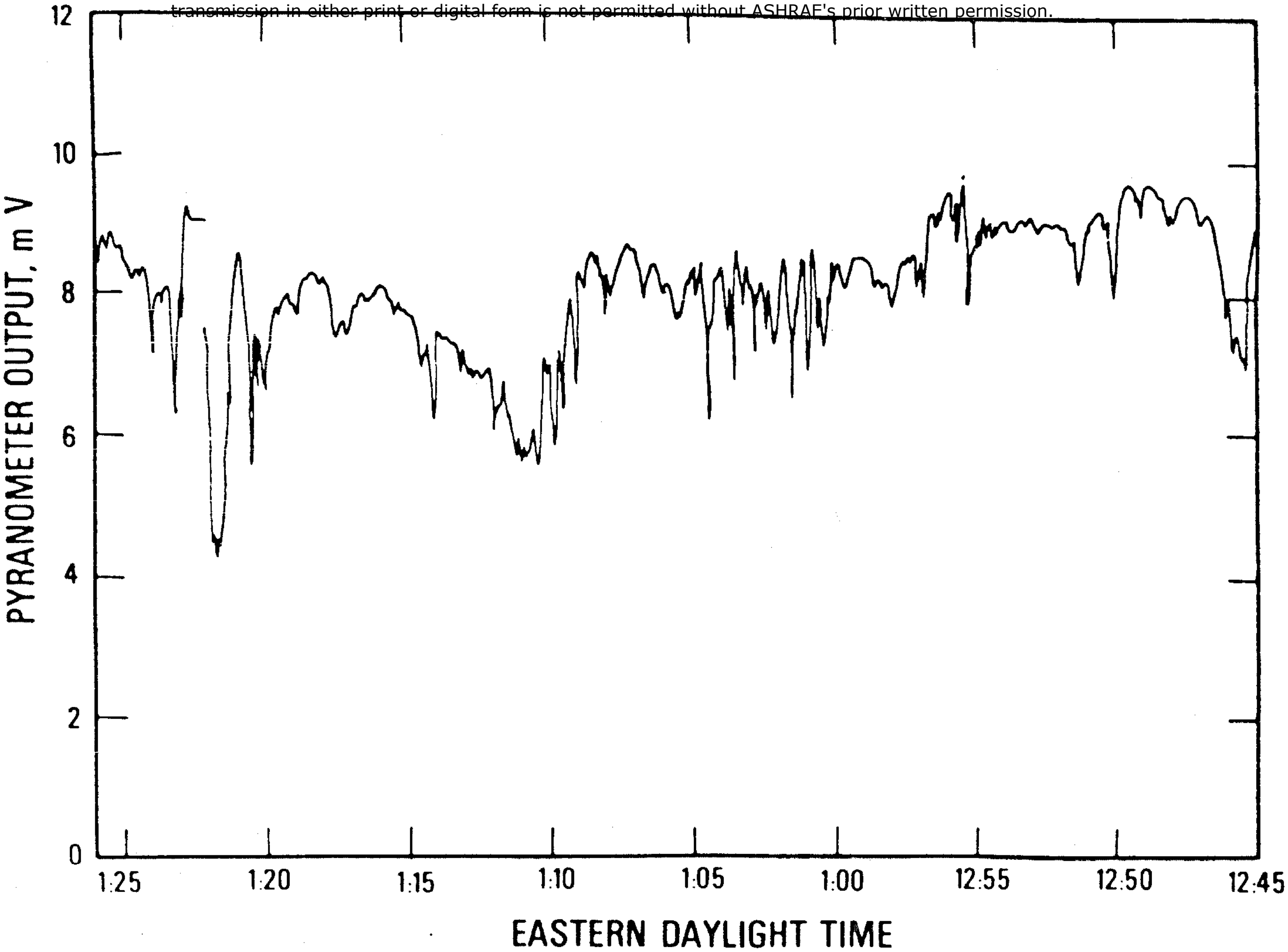


Figure 7. Incident Solar Radiation on a Horizontal Surface in Gaithersburg, Md, March 11, 1974

controlled as close as possible to within ±1 °C (±1.8 °F) of the ambient air temperature. The efficiency values are determined in three pairs where each pair includes a value of efficiency early in the day and a second value late in the day. The average incident angle between the collector and the direct solar beam for both data points is the same. The efficiency of the collector for the specific incident angle shall be considered equal to the average of the two values. As with Method (1), data should be collected for average incident angles of 0, 30, 45 and 60 degrees, ±3 °.

8.4 Computation of Collector Thermal Efficiency. For the test interval for each efficiency data point, the efficiency value is calculated using the equation:

$$\eta_g = \frac{\dot{m} c_p \int_{T_1}^{T_2} (t_{f,e} - t_{f,i}) dT}{A_g \int_{T_1}^{T_2} I_t dT} \qquad (8.10)$$

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 gross collector area.

At least sixteen data points shall be obtained for the establishment of each efficiency curve and an equation for the curve shall be obtained using the standard technique of a least-square fit.* In most cases, a linear or second order fit will suffice. The curve should not be extrapolated beyond the limits of data.

8.5 Computation of Collector Incident Angle Modifier. Regardless of which experimental method in Section 8.3.2 is used, three different values of the thermal efficiency of the collector shall be determined corresponding to three different values of incident angle. Since the inlet collector temperature is held sufficiently close to the ambient air temperature, $(t_{f,i} - t_a) \sim 0$, the relationship between $K_{\alpha\tau}$ and the efficiency, according to Equation (8.5), is:

$$K_{\alpha\tau} = \frac{\eta_g}{(a_a/A_g) F_R (\tau\alpha)_{e,n}} \qquad (8.11)$$

Since $(A_a/A_g)F_R(\tau\alpha)_{e,n}$ will have already been obtained as the intercept of the efficiency curve determined in accordance with Sections 8.3.1 and 8.4, three different values of $K_{\alpha\tau}$ can be computed for the different incident angles using Equation (8.11). The value of b_o may be determined using Equation (8.9) and the standard technique of a least-squares fit to a first-order polynominal. Other methods of correlation may be used to describe an equation for the incident angle modifier.

* One should consult any standard text discussing analysis of experimental data for presentation of this technique (e.g. Refs. 23 and 24).

If the inlet liquid temperature cannot be controlled to equal the ambient air temperature [within ±1.0°C (±1.8°F)], an estimate of the $(A_a/A_g)F_R U_L$ product should be made for the collector for the conditions of the test and each value of $K_{\alpha\tau}$ computed as:

$$K_{\alpha\tau} = \frac{\eta_g + (A_a/A_g)F_R U_L(t_{f,i} - t_a)/I}{(A_a/A_g)F_R(\tau\alpha)_{e,n}} \qquad (8.12)$$

Alternatively, each data point can be plotted on the same plot with the efficiency curve determined in accordance with 8.3.1 and 8.4 and a curve drawn through each point parallel to the efficiency curve and made to intersect the y axis. The values of the y intercept are the efficiency values that would have resulted had the inlet liquid temperature been controlled to equal the ambient air temperature. Therefore, those values can be used in conjunction with equation (8.11) to compute the different values of $K_{\alpha\tau}$.

8.6 Computation of Theoretical Power Requirements. In order to calculate theoretical power required to move the transfer liquid through the solar collector, the following equation shall be used.

$$P_{th} = \dot{m} \cdot \Delta p/w \qquad (8.13)$$

9.0 DATA TO BE RECORDED AND TEST REPORT

9.1 Test Data. Table 1 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 2 specifies the data and information that shall be reported in testing the solar collector.

Table 1 Measurements to be Made and Test Data and Information to be Recorded

Data
Observer(s)
Equipment name plate data
Collector tilt angle, deg.
Collector azimuth angle, deg. from South
Collector aperture area or frontal acceptance area, m^2 (ft^2)
Gross collector area, m^2 (ft^2)
Local Standard Time at the beginning of the collector warm-up and at the beginning and end of each test period
Apparent solar time, as required above
Ambient air temperature at the beginning and end of each test period, °C (°F)
$\Delta t = t_{f,e} - t_{f,i}$ across solar collector (either as a continuous function of time or as a data point integrated quantity), °C (°F)
Inlet temperature, $t_{f,i}$ °C (°F)
Outlet temperature $t_{f,e}$, °C (°F)
Liquid flow rate, kg/s (lb/h)
Pressure drop across solar collector, Pa (lb/in.^{2})
Height of collector outlet above the collector inlet, m (ft)
Wind speed near the collector surface or aperture (data point average), m/s (mph)
I_t, the incident total solar irradiation onto the collector (as a continuous function of time, and as a data point integrated quantity if desired), W/m^2 ($Btu/(h \cdot ft^2)$) or J/m^2 (Btu/ft^2)
I_{DN}, direct beam component of solar irradiation onto the collector (as a continuous function of time and as a data point integrated quantity if measured) W/m^2 ($Btu/(h \cdot ft^2)$) or J/m^2 (Btu/ft^2)

or

I_d, the diffuse component of the solar irradiation onto the collector (at the beginning of the test period and after the completion of the test period) W/m^2 ($Btu/(h \cdot ft^2)$) or J/m^2 (Btu/ft^2)
Φ, incident angle (at the beginning of each test period), deg.
Dew-point temperature, °C (°F)

Table 2 Data and Information to be Reported

General Information

Manufacturer of project name ______________________________

Collector model no. ______________________________

Construction details of the collector:
aperture dimensions and area, m and m^2 (ft and ft^2) ______________________________
gross dimensions and area, m and m^2 (ft and ft^2) ______________________________
dimensions and area of absorbing surface, m and m^2 (ft and ft^2) ______________________________

Absorber area, dimension layout and configuration of flow path, absorptance to short wave radiation (if known), emittance for long wave radiation (if known), description of coating (including maximum allowable temperature (if known), °C (°F) ______________________________

____

____

*If applicable.

Table 2 - continued

Insulation*, material, thickness, m (ft), thermal properties ______________________

____

____

Transfer liquid used and its thermal and physical properties ______________________

____

Mass of collector, based on gross area, kg/m^2 (lb/ft^2) ______________________

Volume of transfer liquid contained in collector, based on gross area m^3/m^2(ft^3/ft^2) ______________________

Direction of flow ______________________

Normal operating temperature range, °C (°F)

Minimum transfer liquid flow rate, kg/s(lb/h)

Maximum transfer liquid flow rate, kg/s(lb/h)

Maximum operating pressure, Pa(lb/ft^2)

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

Description of mounting of the collector for testing

Location of tests (longitude, deg. latitude, deg. and elevation above sea level, m (ft)) ______________________

Collector Thermal Efficiency Tests

A plot of efficiency vs $\frac{t_{f,i} - t_a}{I_t}$ ______________________

For each data point:

- $\dot{m}$ ______________________ kg/s (lb/h)
- c_p ______________________ J/(kg · °C) (Btu/(lb · °F))
- inlet liquid temperature, $t_{f,i}$ ______________________ °C (°F)
- exit liquid temperature, $t_{f,e}$ ______________________ °C (°F)
- T_1, time of starting test, ______________________ LST (AST)
- T_2, time of ending test, ______________________ LST (AST)
- $\int_{T_1}^{T_2}(t_{f,e} - t_{f,i})dT$ ______________________ °C · s(°F · h)
- $\int_{T_1}^{T_2} I_t dT$ ______________________ J/m^2(Btu/ft^2)
- pressure drop across the solar collector ______________________ Pa($lb/in.^2$)
- collector tilt angle ______________________ deg.
- collector azimuth angle ______________________ deg.
- incident angle ______________________ deg.
- percentage of incident radiation that is diffuse ______________________ %
- wind speed near the collector surface ______________________ m/s (mph)

Collector Incident Angle Modifier Test

Method (1) or Method (2) ______________________

A plot of $K_{\alpha\tau}$ versus Φ ______________________

$(A_a/A_g)F_R(\tau\alpha)_{e,n}$ ______________________

For each data point:

- $\dot{m}$ ______________________ kg/s(lb/h)
- c_p ______________________ J/kg · °C) (Btu/(lb · °F))

*If applicable.

Table 2 - continued

inlet fluid temperature, $t_{f,i}$	°C (°F)
exit fluid temperature, $t_{f,e}$	°C (°F)
ambient temperature, t_a	°C (°F)
T_1, time of starting test	LST (AST)
T_2, time of ending test	LST (AST)
$\int_{T_1}^{T_2}(t_{f,e} - t_{f,i})dT$	°C·s(°F·h)
$\int_{T_1}^{T_2} I_t dT$	J/m² (Btu/ft²)
collector tilt angle	deg.
collector azimuth angle	deg.
incident angle	deg.
percentage of incident radiation that is diffuse	%
wind speed near the collector surface or aperture	m/s (mph)

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This Appendix is not part of this Standard but is included for information purposes only.

APPENDIX A
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This Appendix is not part of this Standard but is included for information purposes only.

APPENDIX B

Table B1

Solar Position Data for 1977 (values of declination and Equation of Time will vary slightly for specific dates in other years).

Month		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Date													
	Year Day	1	32	60	91	121	152	182	213	244	274	305	335
1	Declination	−23.0	−17.0	−7.4	+4.7	+15.2	+22.1	+23.1	+17.9	+8.2	−3.3	−14.6	−21.9
	Eq. of Time	−3.6	−13.7	−12.5	−4.0	+2.9	+2.4	−3.6	−6.2	+0.0	+10.2	+16.3	+11.0
	Year Day	6	37	65	96	126	157	187	218	249	279	310	340
6	Declination	−22.4	−15.5	−5.5	+6.6	+16.6	+22.7	+22.7	+16.6	+6.7	−5.3	−16.1	−22.5
	Eq. of Time	−5.9	−14.2	−11.4	−2.5	+3.5	+1.6	−4.5	−5.8	+1.6	+11.8	+16.3	+9.0
	Year Day	11	42	70	101	131	162	192	223	254	284	315	345
11	Declination	−21.7	−13.9	−3.5	+8.5	+17.9	+23.1	−22.1	+15.2	+4.4	−7.2	−17.5	−23.0
	Eq. of Time	−8.0	−14.4	−10.2	−1.1	+3.7	+0.6	−5.3	−5.1	+3.3	+13.1	+15.9	+6.3
	Year Day	16	47	75	106	136	167	197	228	259	289	320	350
16	Declination	−20.8	−12.2	−1.6	+10.3	+19.2	+23.3	+21.3	+13.6	+2.5	−8.7	−18.8	−23.3
	Eq. of Time	−9.8	−4.2	−8.8	+0.1	+3.8	−0.4	−5.9	−4.3	+5.0	+14.3	+15.2	+4.4
	Year Day	21	52	80	111	141	172	202	233	264	294	325	355
21	Declination	−19.6	−10.4	+0.4	+12.0	+20.3	+23.4	+20.6	+12.0	+0.5	−10.8	−20.0	−23.4
	Eq. of Time	−11.4	−13.8	−7.4	+1.2	+3.6	−1.5	−6.2	−3.1	+6.8	+15.3	+14.1	+2.0
	Year Day	26	57	85	116	146	177	207	238	269	299	330	360
26	Declination	−18.6	−8.6	+2.4	+13.6	+21.2	+23.3	+19.3	+10.3	−1.4	−12.6	−21.0	−23.4
	Eq. of Time	−12.6	−13.1	−5.8	+2.2	−3.2	−2.6	−6.4	−1.8	+8.6	+15.9	+12.7	−0.5

(Units for declination are angular degrees; units for Equation of Time are minutes of time.)

Apparent Solar Time (AST) = local Standard Time + Eq. of Time + 4 minutes × (Local Standard Time Meridian − Local Longitude).

Standard Time Meridians:
- EST, 75 deg W
- CST, 90 deg W
- MST, 105 deg W
- PST, 120 deg W
- YST, 135 deg W
- A-HST 150 deg W

To find solar altitude, β, when latitude L, declination δ and hour angle H are known:

$\sin\beta = \cos L \cos\delta \cos H + \sin L \sin\sigma$

To find solar azimuth,

$\sin\phi = \cos\delta \sin H / \cos\beta$

Table B2 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: Direct Normal	Horiz	South Facing Surface Angle with Horiz. 14	24	34	54	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	276
	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	488
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

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	54	90
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	[illegible]
	9	3	48.4	94.5	261	231	221	207	187	161	[illegible]
	10	2	62.1	89.0	272	278	270	256	235	206	[illegible]
	11	1	75.7	79.2	278	307	302	287	265	235	[illegible]
	12		86.6	0.0	280	317	312	298	275	245	[illegible]
	Surface Daily Totals				2932	2526	2412	2250	2036	1766	[illegible]
AUG 21	6	6	5.0	101.3	35	7	5	4	4	4	[illegible]
	7	5	18.5	95.6	186	82	76	69	62	50	[illegible]
	8	4	32.2	89.7	241	158	154	146	134	118	[illegible]
	9	3	45.9	82.9	265	223	222	214	200	181	[illegible]
	10	2	59.3	73.0	278	273	275	268	252	230	[illegible]
	11	1	71.6	53.2	284	304	309	301	285	261	[illegible]
	12		78.3	0.0	286	315	320	313	296	272	[illegible]
	Surface Daily Totals				2864	2408	2402	2316	2168	1958	476
SEP 21	7	5	13.7	83.8	173	57	60	60	59	56	[illegible]
	8	4	27.2	76.8	248	136	144	146	143	136	[illegible]
	9	3	40.2	67.9	278	205	218	221	217	206	[illegible]
	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	[illegible]
	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

$1\ Btu/(h \cdot ft^2) = 3.152\ W/m^2$

NOTE:

*In these tables "Insolation" denotes solar irradiation.

1. Based on data in Table 1, p. 27.2 in Ref 2; 0% ground reflectance; 1.0 clearness factor.
2. See Fig. 3, p. 27.3 in Ref 2 for typical regional clearness factors.

Table B3 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 DIRECT 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	[illegible]
	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

1 Btu/(h·ft²) = 3.152 W/m²

NOTE:
*In these tables "Insolation" denotes solar irradiation.
1. Based on data in Table 1, p. 27.2 in Ref 2; 0% ground reflectance; 1.0 clearness factor.
2. See Fig. 3, p. 27.3 in Ref 2 for typical regional clearness factors.

Table B4 Solar Position and Insolation* Values for 40 Degrees North Latitude

DATE	SOLAR TIME AM	SOLAR TIME PM	SOLAR POSITION ALT	SOLAR POSITION AZM	BTUH/SQ. FT. TOTAL INSOLATION ON SURFACES DIRECT 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 TOTALS				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	[illegible]
	6	6	13.1	106.1	138	50	26	17	15	14	[illegible]
	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	11[illegible]
	SURFACE DAILY TOTALS				3062	2534	2409	2230	2006	1728	702
AUG 21	6	6	7.9	99.5	81	21	12	9	8	7	[illegible]
	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	56
	9	3	41.8	67.9	260	205	216	207	193	173	8[illegible]
	10	2	51.7	52.1	272	246	267	259	244	221	12[illegible]
	11	1	59.3	29.7	278	273	300	292	276	252	140
	12		62.3	0.0	280	282	311	303	287	262	14[illegible]
	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	20[illegible]
	SURFACE DAILY TOTALS				2708	1788	2210	2228	2182	2074	1416
OCT 21	7	5	4.5	72.3	48	7	14	15	17	17	1[illegible]
	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	16[illegible]
	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	162
	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	16[illegible]
	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

1 Btu/(h · ft²) = 3.152 W/m²

NOTE:
*In these tables "Insolation" denotes solar irradiation.
1. Based on data in Table 1, p. 27.2 in Ref 2; 0% ground reflectance; 1.0 clearness factor.
2. See Fig. 3, p. 27.3 in Ref 2 for typical regional clearness factors.

Table B5 Solar Position and Insolation* Values for 48 Degrees North Latitude

DATE	SOLAR TIME AM	SOLAR TIME PM	SOLAR POSITION ALT	SOLAR POSITION AZM	BTUH/SQ. FT. TOTAL INSOLATION ON SURFACES: DIRECT NORMAL	HORIZ.	SOUTH FACING SURFACE ANGLE WITH 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	307	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

1 Btu/(h · ft²) = 3.152 W/m²

NOTE:
*In these tables "Insolation" denotes solar irradiation.
1. Based on data in Table 1, p. 27.2 in Ref 2; 0% ground reflectance; 1.0 clearness factor.
2. See Fig. 3, p. 27.3 in Ref 2 for typical regional clearness factors.

Table B6 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: Direct 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	C.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	0
	5	7	9.0	113.7	91	27	11	10	9	8	6
	6	6	17.0	101.9	169	72	30	18	16	14	12
	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	63
	9	3	41.4	62.0	252	201	208	193	173	147	106
	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:
*In these tables "Insolation" denotes solar irradiation.
1. Based on data in Table I, p. 27.2 in Ref 2; 0% ground reflectance; 1.0 clearness factor.
2. See Fig. 3, p. 27.3 in Ref 2 for typical regional clearness factors.

1 Btu/(h · ft²) = 3.152 W/m²

Table B7 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: Direct 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

$1\ Btu/(h \cdot ft^2) = 3.152\ W/m^2$

NOTE:
*In these tables "Insolation" denotes solar irradiation.
1. Based on data in Table 1, p. 27.2 in Ref 2; 0% ground reflectance; 1.0 clearness factor.
2. See Fig. 3, p. 27.3 in Ref 2 for typical regional clearness factors.

Table B8 Latitude 24 °N, Incident Angles for Horizontal and South-Facing Tilted Surfaces

Dates (Declination)	am	pm	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
Dec. 21 (−23.45)	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
	am	pm	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	59.5
Jan. 21 (−19.9)	9	3	62.1	53.5	48.4	44.5	42.2	54.4
Nov. 21 (−19.9)	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
	am	pm	Horiz.	L − 10	Lat.	Lat. + 10	Lat. + 20	Vert.
	7	5	80.7	77.2	75.2	73.7	72.6	74.8
Feb. 21 (−10.6)	8	4	67.7	62.9	60.5	59.0	58.5	69.0
Oct. 21 (−10.7)	9	3	55.6	49.0	45.9	44.3	44.5	63.8
	10	2	44.9	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
	am	pm	Horiz.	L − 10	Lat.	Lat. + 10	Lat. + 20	Vert.
	7	5	76.3	75.2	75.0	75.2	75.9	84.0
Mar. 21 (0.0)	8	4	62.8	60.5	60.0	60.5	62.0	78.3
Sep. 21 (0.0)	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
	am	pm	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
Apr. 21 (+11.9)	8	4	58.0	58.9	60.7	63.4	67.0	89.1
Aug. 21 (+12.1)	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
	am	pm	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
May 21 (+20.3)	8	4	55.4	58.5	62.0	66.2	71.1	97.0
Jul 21 (+20.5)	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
	am	pm	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
Jun. 21 (+23.45)	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 B9 Latitude 32 °N, Incident Angles for Horizontal and South-Facing Tilted Surfaces

Dates (Declination)	am	pm	Horiz.	L − 10	Lat.	Lat. + 10	Lat. + 20	Vert.
	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
Dec. 21 (−23.45)	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
	am	pm	Horiz.	L − 10	Lat.	Lat. + 10	Lat. + 20	Vert.
	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
Jan. 21 (−19.9)	9	3	67.5	53.5	48.4	44.5	42.2	50.0
Nov. 21 (−19.9)	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	6.0	38.0
	am	pm	Horiz.	L − 10	Lat.	Lat. + 10	Lat. + 20	Vert.
	7	5	82.9	77.2	75.2	73.7	72.6	73.6
Feb. 21 (−10.6)	8	4	71.0	62.9	60.5	59.0	58.5	65.9
Oct. 21 (−10.7)	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
	am	pm	Horiz.	L − 10	Lat.	Lat. + 10	Lat. + 20	Vert.
	7	5	77.3	75.2	75.0	75.2	75.9	82.1
Mar. 21 (0.0)	8	4	64.9	60.5	60.0	60.5	62.0	74.6
Sep. 21 (0.0)	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
	am	pm	Horiz.	L − 10	Lat.	Lat. + 10	Lat. + 20	Vert.
	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
Apr. 21 (+11.9)	8	4	58.5	58.9	60.7	63.4	67.0	84.9
Aug. 21 (+12.1)	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	73.8
	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
	am	pm	Horiz.	L − 10	Lat.	Lat. + 10	Lat. + 20	Vert.
	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
May 21 (+20.3)	8	4	54.6	58.5	62.0	66.2	71.1	92.4
Jul 21 (+20.5)	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
	am	pm	Horiz.	L − 10	Lat.	Lat. + 10	Lat. + 20	Vert.
	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
Jun. 21 (+23.45)	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 B10 Latitude 40 °N, Incident Angles for Horizontal and South-Facing Tilted Surfaces

Dates (Declination)	am	pm	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
Dec. 21 (−23.45)	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
	8	4	81.9	66.2	62.0	58.5	56.0	55.7
Jan. 21 (−19.9)	9	3	73.2	53.5	48.4	44.5	42.2	46.4
Nov. 21 (−19.9)	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
	7	5	85.2	77.2	75.2	73.7	72.6	72.7
Feb. 21 (−10.6)	8	4	74.6	62.9	60.5	59.0	58.5	63.3
Oct. 21 (−10.7)	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	49.9
	12		50.0	20.0	10.0	0.0	10.0	40.0
	7	5	78.6	75.2	75.0	75.2	75.9	80.4
Mar. 21 (0.0)	8	4	67.5	60.5	60.0	60.5	62.0	71.3
Sep. 21 (0.0)	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
	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
Apr. 21 (+11.9)	8	4	59.7	58.9	60.7	63.4	67.0	80.7
Aug. 21 (+12.1)	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
	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
May 21 (+20.3)	8	4	54.6	58.5	62.0	66.2	71.1	87.7
Jul 21 (+20.5)	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
	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
Jun. 21 (+23.45)	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 B11 Latitude 48 °N, Incident Angles for Horizontal and South-Facing Tilted Surfaces

Dates (Declination)	am	pm	Horiz.	L − 10	Lat.	Lat. + 10	Lat. + 20	Vert.
	9	3	82.0	55.3	49.6	44.9	41.8	41.6
Dec. 21 (−23.45)	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
	8	4	86.5	66.2	62.0	58.5	56.0	54.7
	9	3	79.0	53.5	48.4	44.5	42.2	43.7
Jan. 21 (−19.9)	10	2	73.1	42.1	35.5	30.6	28.2	33.5
Nov. 21 (−19.9)	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
	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
Feb. 21 (−10.6)	9	3	70.3	49.0	45.9	44.3	44.5	50.7
Oct. 21 (−10.7)	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
	7	5	80.0	75.2	75.0	73.2	75.9	78.9
	8	4	70.5	60.5	60.0	60.5	62.0	68.2
Mar. 21 (0.0)	9	3	61.8	45.9	45.0	45.9	48.4	58.3
Sep. 21 (0.0)	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
	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
Apr. 21 (+11.9)	9	3	52.2	44.2	46.2	49.7	54.4	67.7
Aug. 21 (+12.1)	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
	5	7	84.8	100.4	104.1	107.4	110.2	114.2
	6	6	75.3	86.6	90.0	93.4	96.7	103.2
May 21 (+20.3)	7	5	65.4	72.6	75.9	79.6	83.6	92.8
Jul 21 (+20.5)	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
	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
Jun. 21 (+23.45)	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	43.4	65.4

Table B12 Latitude 56 °N, Incident Angles for Horizontal and South-Facing Tilted Surfaces

Dates (Declination)	am	pm	Horiz.	L − 10	Lat.	Lat. + 10	Lat. + 20	Vert.
	9	3	88.1	55.3	49.6	44.9	41.8	40.5
Dec. 21 (−23.45)	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
	am	pm	Horiz.	L − 10	Lat.	Lat. + 10	Lat. + 20	Vert.
	9	3	85.0	53.5	48.4	44.5	42.2	42.1
Jan. 21 (−19.9)	10	2	80.1	42.1	35.5	30.6	28.2	30.0
Nov. 21 (−19.9)	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
	am	pm	Horiz.	L − 10	Lat.	Lat. + 10	Lat. + 20	Vert.
	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
Feb. 21 (−10.6)	10	2	70.6	35.9	31.5	29.5	30.6	36.5
Oct. 21 (−10.7)	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
	am	pm	Horiz.	L − 10	Lat.	Lat. + 10	Lat. + 20	Vert.
	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
Mar. 21 (0.0)	9	3	66.7	45.9	45.0	45.9	48.4	54.1
Sep. 21 (0.0)	10	2	61.0	31.5	30.0	31.5	35.5	44.1
	11	1	57.3	18.0	15.0	18.0	24.3	36.8
	12		56.0	10.0	0.0	10.0	20.0	34.0
	am	pm	Horiz.	L − 10	Lat.	Lat. + 10	Lat. + 20	Vert.
	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
Apr. 21 (+11.9)	7	5	72.0	73.5	75.3	77.6	80.2	84.4
Aug. 21 (+12.1)	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	36.3	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
	am	pm	Horiz.	L − 10	Lat.	Lat. + 10	Lat. + 20	Vert.
	4	8	88.3	113.8	118.0	121.5	124.0	125.5
	5	7	81.5	100.4	104.1	107.4	110.2	113.1
May 21 (+20.3)	6	6	73.5	86.6	90.0	93.4	96.7	101.0
Jul 21 (+20.5)	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
	am	pm	Horiz.	L − 10	Lat.	Lat. + 10	Lat. + 20	Vert.
	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
Jun. 21 (+23.45)	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 B13 Latitude 64 °N, Incident Angles for Horizontal and South-Facing Tilted Surfaces

Dates (Declination)	am	pm	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
	am	pm	Horiz.	L − 10	Lat.	Lat. + 10	Lat. + 20	Vert.
Jan. 21 (−19.9)	10	2	87.2	42.1	35.5	30.6	28.2	28.2
Nov. 21 (−19.9)	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
	am	pm	Horiz.	L − 10	Lat.	Lat. + 10	Lat. + 20	Vert.
	8	4	86.6	62.9	60.5	59.0	58.5	58.3
	9	3	81.4	49.0	45.9	44.3	44.5	45.4
Feb. 21 (−10.6)	10	2	77.4	35.9	31.5	29.5	30.6	32.6
Oct. 21 (−10.7)	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
	am	pm	Horiz.	L − 10	Lat.	Lat. + 10	Lat. + 20	Vert.
	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
Mar. 21 (0.0)	9	3	71.9	45.9	45.0	45.9	48.4	50.5
Sep. 21 (0.0)	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
	am	pm	Horiz.	L − 10	Lat.	Lat. + 10	Lat. + 20	Vert.
	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
Apr. 21 (+11.9)	7	5	73.0	73.5	75.3	77.6	80.2	82.0
Aug. 21 (+12.1)	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
	am	pm	Horiz.	L − 10	Lat.	Lat. + 10	Lat. + 20	Vert.
	4	8	84.2	113.3	118.0	121.5	124.0	124.9
	5	7	78.4	100.4	104.1	107.4	110.2	111.6
May 21 (+20.3)	6	6	72.1	86.6	90.0	93.4	96.7	98.6
Jul. 21 (+20.5)	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	24.3	33.4	42.6	48.3
	12		44.0	10.0	20.0	30.0	40.0	46.0
	am	pm	Horiz.	L − 10	Lat.	Lat. − 10	Lat. + 20	Vert.
	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
Jun 21 (+23.45)	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	35.6	61.7	63.9
	10	2	45.1	31.6	37.4	44.5	52.4	57.3
	11	1	41.7	19.6	27.6	36.5	45.3	51.5
	12		40.6	13.5	23.4	33.4	43.4	49.4

This Appendix is not part of this Standard but is included for information purposes only.

Appendix C

This appendix presents a sample calculation showing how the test results obtained in accordance with this Standard can be used to compute the daily performance of a collector which is used for heating swimming pool water.

The collector considered is unglazed, south-facing and tilted at 30° with respect to the horizontal, and its efficiency is assumed to be described by Figure 4 in the body of the Standard. Its incident angle modifier is assumed to be described by the curve in Figure 5. For this example, the ambient temperature is assumed to vary from 15 °C (59 °F) to 27 °C (81 °F) during the day and the pool to have a constant temperature of 29 °C (84 °F). The location is 40 °N latitude and the calculation is done for the 21st of September. Table C.1 shows the results of the calculation and each step is described as follows:

1. Inlet fluid temperature to the collector; this is assumed to be constant for all hours as described above.
2. Ambient air temperature; this assumed to vary as stated above and shown in Table C.1. If records of typical days are not available for the location of interest, a diurnal temperature profile can be calculated for the summer months based on Table 1, pg 24.4, and Table 3, pg 26.7 of reference 2.
3. Incident radiation on the collector plane; these values were taken for Table B4 for September 21, 30° tilt angle. Therefore this calculation is based on clear sky conditions. If only incident radiation on a horizontal surface is available for the location of interest, see reference 21, pp. 48-55 for procedures for converting the values to incident radiation on a tilted surface.
4. $(t_{f,i} - t_a)/I_t$; these values were computed using the data from lines 1, 2, and 3.
5. Collector thermal efficiency at normal incidence; based on the calculated values in line 4, the collector efficiency was determined using Figure C.1 (duplicate of Figure 4).
6. Incident angle between the direct solar beam and outward drawn normal to the collector plane; these values were taken from Table B10 for September 21, L-10. To compute the values in general, see refernce 21, pp. 14-18.
7. Incident angle modifier; although the incident angle modifier was only obtained for angles up to 60° as shown in Figure 5, for this example it was assumed to be constant and equal to 1.0 out to 75.° In reality, the incident angle modifier will drop off to values less than 1.0 between 60° and 75°; however, the collector efficiency is zero for the low radiation levels that occur at these angles. (Less than 5% of the daily total radiation falls at angles greater than 60.°)
8. Energy output from the collector; this is calculated using the equation shown. $F_R(\tau\alpha)_{e,n}$ is obtained from the ordinate (y) intercept of Figure C.1 (Figure 4). For this example, since $K_{\alpha\tau} \equiv 1$, the energy output for all hours is simply the collector efficiency (expressed as a fraction) at normal incidence multiplied by the incident solar radiation.
9. Collector thermal efficiency; this is calculated using the equation shown. The approximate daily collector efficiency is obtained by dividing the daily total in line 8 by that in line 3. Since the values in the table are only rates and not hourly totals, the exact daily collector efficiency is obtained by plotting the curves shown in Figure C.2 using the hourly rates, determining the area under each curve, and calculating the ratio of the two areas.

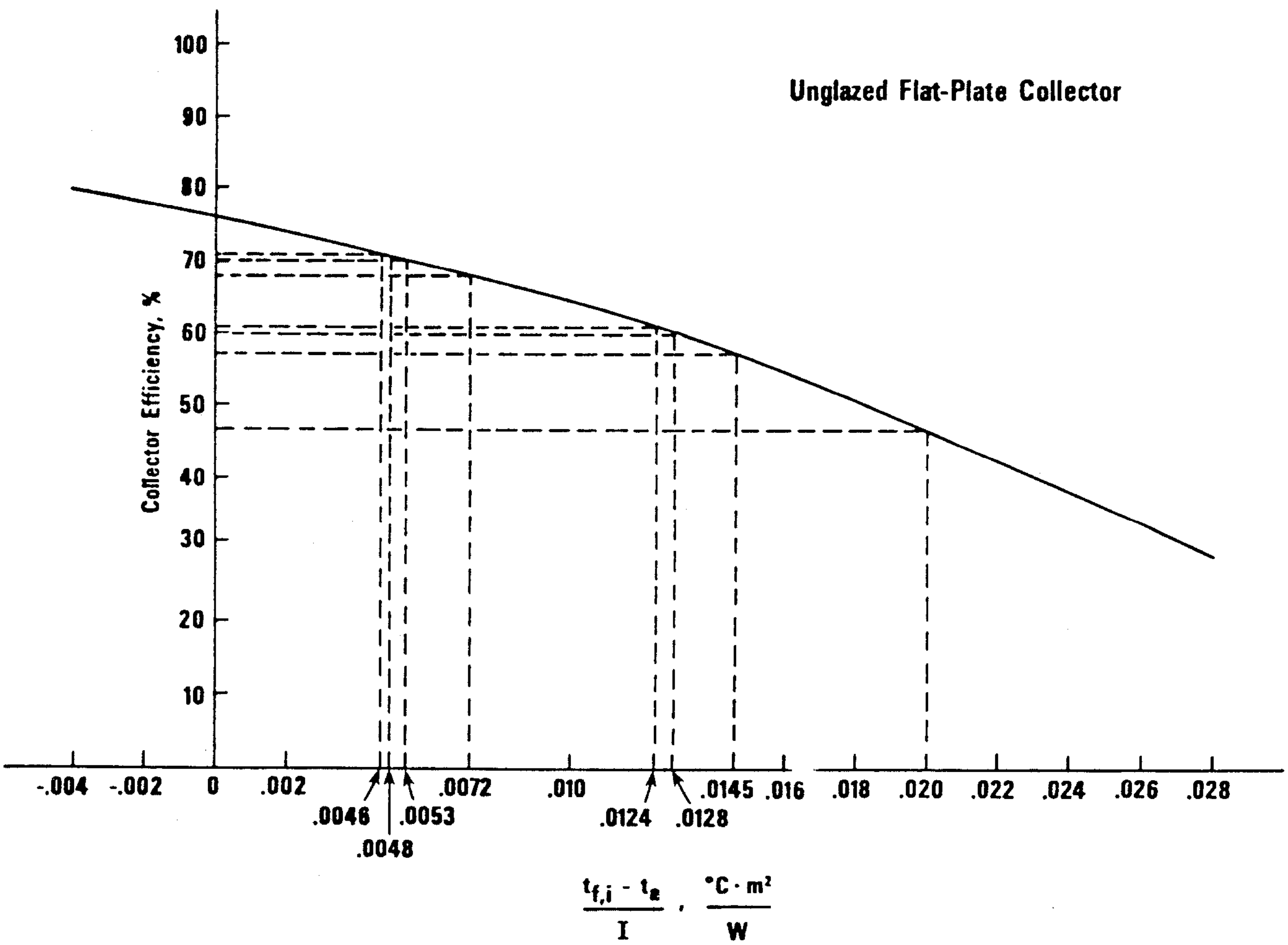

Figure C.1 Thermal Efficiency Curve Used in the Example Calculation

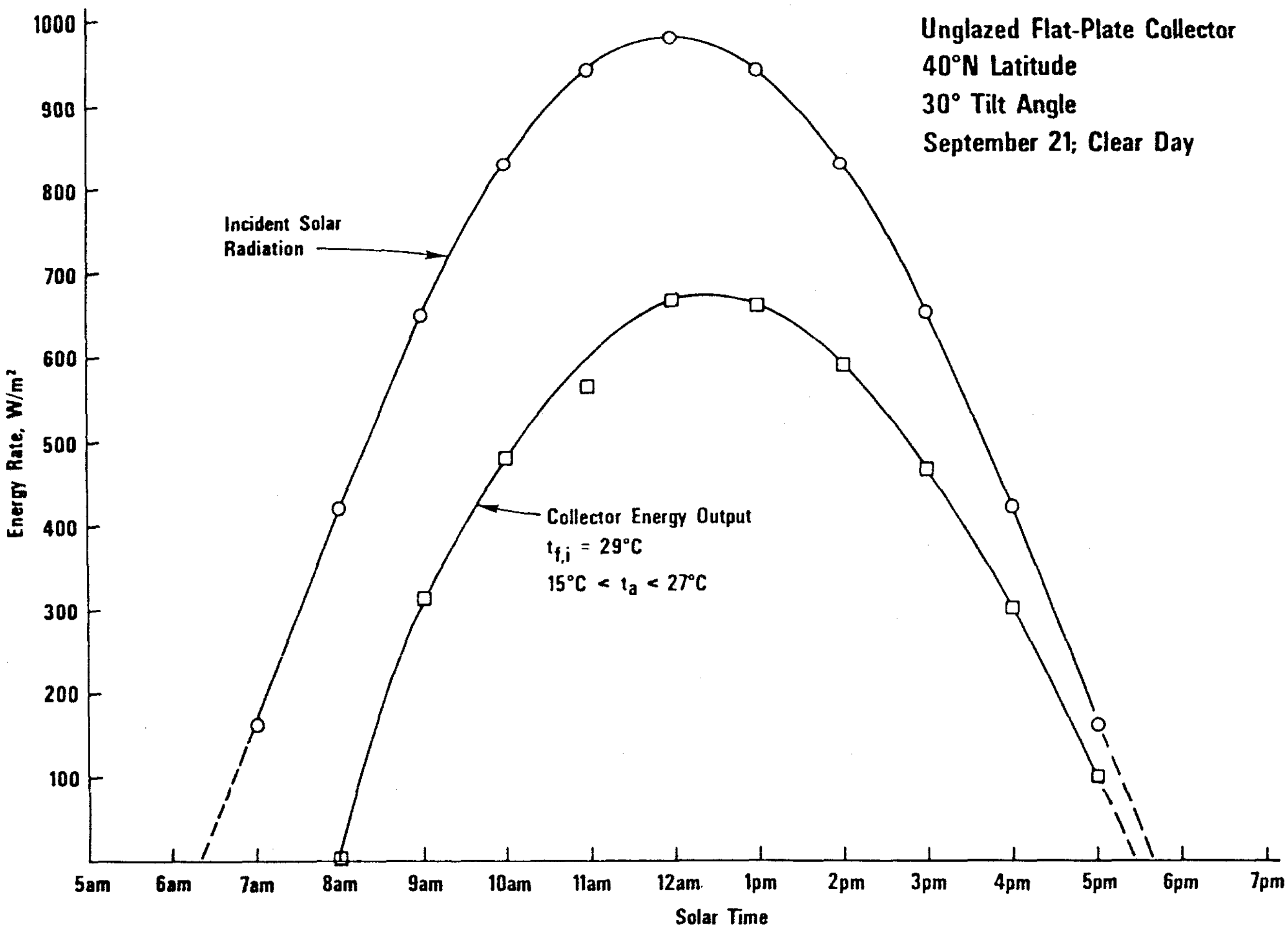

Figure C.2 Incident Solar Radiation and Solar Collector Output for the Example Calculation

Table B1 Solar Position and Insolation* Values for 24 Degrees North Latitude

	Solar Time, H											Daily
	7 am	8 am	9 am	10 am	11 am	12	1 pm	2 pm	3 pm	4 pm	5 pm	Total
1. Inlet fluid temperature to the collector, $t_{f,i}$, °C	29	29	29	29	29	29	29	29	29	29	29	—
2. Ambient air temperature, t_a, °C	15	15	16	17	17	22	24	25	26	27	27	—
3. Incident radiation on the collector plane, I_t, W/m²	161	419	649	826	939	977	939	826	649	419	161	6965
4. $(t_{f,i} - t_a)/I_t$, (°C·m²)/W	0.0870	0.0334	0.0200	0.0145	0.0128	0.0072	0.0053	0.0048	0.0046	0.0048	0.0124	—
5. Collector thermal efficiency at normal incidence, fraction	0.0	0.0	0.48	0.58	0.60	0.68	0.70	0.71	0.71	0.71	0.61	—
6. Incident angle between the direct solar beam and outward drawn normal to the collector plane, °	75.2	60.5	45.9	31.5	18.0	10.0	18.0	31.5	45.9	60.5	75.2	—
7. Incident angle modifier, $K_{\alpha\tau}$	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	—
8. Energy output from the collector, W/m², line 3 [line 5 + $F_R (\tau\alpha)_{e,n} (K_{\alpha\tau} -$)]	0	0	312	479	563	644	657	586	461	297	98	4117
9. Collector thermal efficiency, fraction, line 8/line 3	0.0	0.0	0.48	0.58	0.60	0.68	0.70	0.71	0.71	0.71	0.61	0.59

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