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Solar Energy Basics II - Estimation of Solar Radiation to a Solar Panel

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Solar Energy Basics II - Estimation of Solar Radiation to a Collector

Harlan H. Bengtson, Ph.D., P.E.

COURSE CONTENT

1. Introduction

The type of solar radiation data typically needed for planning and design of solar installations is the rate striking a solar panel or solar collector at a specified location, often as monthly averages. Such data is available for a number of standard collector/panel configurations, from a variety of print and on-line sources. Three sources of solar radiation data from the Renewable Resource Data Center (RREDC), a unit of the National Renewable Energy Laboratory (NREL) are discussed in this course. The web address for the solar resource portion of the RREDC website is: http://www.nrel.gov/rredc/solar_resource.html . In the following sections, the types and formats of data available from this website will be described, details for obtaining the data from the website will be given, interpretation of the data will be discussed, and examples of retrieving data will be presented.

2. Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors

This 259 page publication of the NREL is out of print, but is available for free download from the RREDC website at: http://www.nrel.gov/docs/legosti/old/5607.pdf, by clicking on "Manual and Data Tables", under the "PDF" heading. It provides solar radiation values for common flat-plate and concentrating collector configurations for 239 stations in the United States and its territories.

The solar radiation values in this manual are expressed as monthly and yearly averages for the period 1961-1990. Minimum and maximum monthly and yearly averages are included to show the variability of the solar radiation at each station. In addition to the solar radiation data, this manual contains climatic information, such as average temperatures, average daily minimum and maximum temperatures, average heating and cooling degree days, average relative humidity, and average wind speed.

The data for each station is presented on a single page. The pages are arranged alphabetically by the state or territory two-letter abbreviation, and within each state or territory, the pages are arranged alphabetically by city or island. The map below, from page 1 of the manual, shows the locations of the 239 stations used for data in the manual. There are two types of stations in the 1961-1990 database used to prepare this manual. Primary stations are denoted by asterisks on the station map and secondary stations are denoted by dots on the map. There are 56 primary stations, at which solar radiation was measured for a part (from 1 to 27 years) of the 30-year period. The remaining 183 secondary stations made no solar radiation measurements and have modeled solar radiation data that was derived from meteorological data, such as cloud cover. Both primary and secondary stations are National Weather Service stations that collected meteorological data for the entire 1961-1990 period.

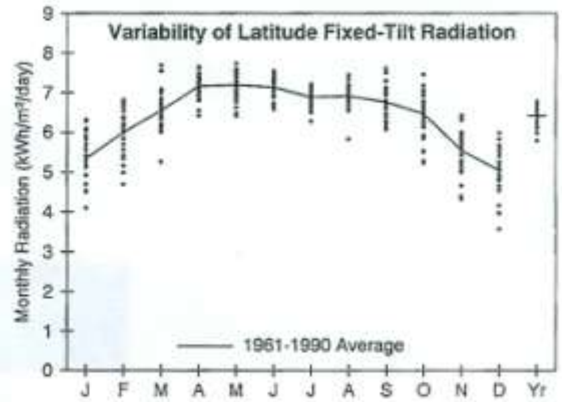
Figure 1. Map showing the location of the 239 stations used for data in this manual

Albuquerque, NM

WBAN NO. 23050

LATITUDE: 35.05° N
LONGITUDE: 106.62° W
ELEVATION: 1619 meters
MEAN PRESSURE: 838 millibars

STATION TYPE: Primary



Solar Radiation for Flat-Plate Collectors Facing South at a Fixed Tilt (kWh/m²/day), Uncertainty ±9%

Tilt (°)		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
0	Average	3.2	4.2	5.4	6.8	7.7	8.1	7.5	6.9	5.9	4.7	3.5	2.9	5.6
	Min/Max	2.6/3.7	3.4/4.7	4.4/6.2	6.2/7.3	6.9/8.3	7.4/8.7	6.8/7.9	5.9/7.4	5.4/6.6	4.0/5.3	2.8/3.9	2.2/3.3	5.1/5.9
Latitude -15	Average	4.6	5.4	6.3	7.3	7.7	7.8	7.4	7.2	6.6	5.9	4.8	4.3	6.3
	Min/Max	3.6/5.4	4.3/6.1	5.1/7.3	6.5/7.8	6.8/8.3	7.2/8.3	6.7/7.8	6.1/7.7	6.0/7.4	4.9/6.8	3.8/5.5	3.1/5.0	5.7/6.6
Latitude	Average	5.3	6.0	6.5	7.2	7.2	7.1	6.9	6.9	6.8	6.5	5.5	5.0	6.4
	Min/Max	4.1/6.3	4.7/6.8	5.3/7.7	6.4/7.7	6.4/7.7	6.6/7.5	6.3/7.2	5.8/7.4	6.1/7.6	5.2/7.4	4.3/6.4	3.6/6.0	5.8/6.8
Latitude +15	Average	5.8	6.2	6.5	6.6	6.3	6.1	6.0	6.3	6.5	6.6	5.9	5.5	6.2
	Min/Max	4.4/6.9	4.8/7.1	5.1/7.6	5.9/7.1	5.7/6.8	5.6/6.4	5.5/6.3	5.3/6.7	5.8/7.3	5.3/7.7	4.6/6.9	3.8/6.6	5.5/6.5
90	Average	5.2	5.1	4.5	3.7	2.8	2.4	2.5	3.2	4.2	5.1	5.2	5.1	4.1
	Min/Max	3.9/6.4	3.9/5.8	3.5/5.4	3.4/4.0	2.5/3.0	2.2/2.5	2.3/2.7	2.8/3.4	3.7/4.6	4.0/6.0	3.9/6.2	3.5/6.2	3.5/4.4

Solar Radiation for 1-Axis Tracking Flat-Plate Collectors with a North-South Axis (kWh/m²/day), Uncertainty ±9%

Axis Tilt (°)		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
0	Average	4.9	6.2	7.6	9.6	10.6	10.9	9.9	9.2	8.3	7.0	5.3	4.5	7.8
	Min/Max	3.7/5.9	4.7/7.1	5.7/9.3	8.4/10.6	9.0/11.8	9.5/12.1	8.5/10.8	7.4/10.3	7.0/9.6	5.5/8.4	4.1/6.3	3.2/5.4	6.9/8.3
Latitude -15	Average	5.9	7.1	8.3	10.0	10.6	10.8	9.9	9.5	8.8	7.9	6.3	5.5	8.4
	Min/Max	4.4/7.2	5.4/8.1	6.2/10.2	8.7/11.0	9.1/11.9	9.5/12.0	8.5/10.8	7.6/10.6	7.5/10.4	6.1/9.5	4.8/7.5	3.8/6.7	7.4/8.9
Latitude	Average	6.5	7.5	8.6	9.9	10.3	10.4	9.5	9.3	9.0	8.3	6.8	6.1	8.5
	Min/Max	4.8/7.9	5.7/8.7	6.4/10.5	8.7/10.9	8.8/11.6	9.1/11.5	8.1/10.4	7.5/10.4	7.6/10.5	6.3/10.0	5.2/8.1	4.2/7.4	7.5/9.1
Latitude +15	Average	6.9	7.7	8.5	9.5	9.7	9.7	8.9	8.9	8.8	8.4	7.1	6.5	8.4
	Min/Max	5.1/8.4	5.8/8.9	6.3/10.4	8.3/10.6	8.3/10.9	8.4/10.7	7.6/9.8	7.1/9.9	7.4/10.3	6.4/10.1	5.3/8.5	4.4/7.9	7.3/8.9

Solar Radiation for 2-Axis Tracking Flat-Plate Collectors (kWh/m²/day), Uncertainty ±9%

Tracker		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
2-Axis	Average	6.9	7.7	8.6	10.0	10.8	11.1	10.0	9.5	9.0	8.4	7.2	6.6	8.8
	Min/Max	5.1/8.5	5.8/8.9	6.4/10.5	8.8/11.1	9.2/12.1	9.7/12.3	8.6/11.0	7.7/10.6	7.6/10.5	6.4/10.1	5.3/8.6	4.4/8.1	7.7/9.4

Direct Beam Solar Radiation for Concentrating Collectors (kWh/m²/day), Uncertainty ±8%

Tracker		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
1-Axis, E-W Horiz Axis	Average	4.5	4.6	4.6	5.3	5.9	6.3	5.5	5.2	4.9	5.1	4.6	4.4	5.1
	Min/Max	3.1/5.8	3.0/5.7	3.0/6.2	4.3/6.1	4.7/7.1	5.3/7.4	4.3/6.4	3.7/6.0	3.9/6.2	3.3/6.5	2.8/5.9	2.6/5.7	4.3/5.5
1-Axis, N-S Horiz Axis	Average	3.7	4.6	5.6	7.2	8.0	8.4	7.2	6.7	6.2	5.4	4.0	3.4	5.9
	Min/Max	2.5/4.8	3.0/5.7	3.4/7.6	5.7/8.4	6.1/9.7	6.8/10.0	5.4/8.4	4.7/7.9	4.7/7.9	3.4/7.2	2.4/5.2	2.0/4.5	4.8/6.4
1-Axis, N-S Tilt=Latitude	Average	5.1	5.7	6.3	7.4	7.7	7.8	6.8	6.8	6.7	6.5	5.4	4.8	6.4
	Min/Max	3.4/6.6	3.7/7.2	3.9/8.6	5.8/8.6	5.9/9.3	6.4/9.4	5.1/7.9	4.7/8.0	5.1/8.6	4.1/8.6	3.2/6.9	2.8/6.3	5.3/7.0
2-Axis	Average	5.4	5.9	6.3	7.5	8.1	8.5	7.3	7.0	6.8	6.6	5.7	5.2	6.7
	Min/Max	3.7/7.1	3.8/7.3	3.9/8.6	5.9/8.8	6.2/9.9	6.9/10.2	5.5/8.5	4.9/8.2	5.2/8.7	4.2/8.6	3.4/7.3	3.1/6.8	5.6/7.3

Average Climatic Conditions

Element	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
Temperature (°C)	1.2	4.4	8.3	12.9	17.9	23.4	25.8	24.4	20.3	13.9	6.8	1.8	13.4
Daily Minimum Temp	-5.7	-3.1	0.1	4.2	9.2	14.6	18.0	17.0	12.9	6.1	-0.4	-4.9	5.7
Daily Maximum Temp	8.2	11.9	16.3	21.6	26.5	32.2	33.6	31.7	27.7	21.7	14.1	8.6	21.2
Record Minimum Temp	-27.2	-20.6	-13.3	-7.2	-2.2	4.4	11.1	11.1	2.8	-6.1	-21.7	-21.7	-27.2
Record Maximum Temp	20.6	24.4	29.4	31.7	36.7	40.6	40.6	38.3	37.8	32.8	25.0	22.2	40.6
HDD, Base 18.3°C	531	389	312	167	49	0	0	0	10	144	345	512	2458
CDD, Base 18.3°C	0	0	0	4	36	155	233	188	70	6	0	0	691
Relative Humidity (%)	56	50	40	33	31	30	42	47	48	45	50	57	44
Wind Speed (m/s)	3.7	3.9	4.5	4.9	4.8	4.5	4.0	3.8	3.8	3.6	3.6	3.5	4.1

A copy of the page for Albuquerque, New Mexico, from the manual, is given on the previous page, as an example, to show the information available for each of the stations. Following is information from pages 3, 4, & 5 of *Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors* on the subject of "Interpreting the Data Tables."

Interpreting the Data Tables

Station Description

Information at the top of each page describes the station with the following information:

- City and state in which the station is located
- Station Weather Bureau Army Navy WBAN ID number
- Latitude (degrees; north)
- Longitude (degrees; east or west)
- Elevation of station (meters)
- Mean atmospheric pressure of station (millibars)
- Type of station (primary or secondary)

Solar Radiation Data for Flat-Plate and Concentrating Collectors

For the period of 1961-1990, tables provide solar radiation data of the following types for flat-plate and concentrating collectors.

- Monthly and yearly averages of solar radiation (kWhr/m^2/day)
- Minimum and maximum monthly and yearly averages of solar radiation (kWhr/m^2/day)
- Uncertainty of solar radiation data (± %)

Minimum and maximum monthly and yearly averages are included to show the variability of a station's solar resource. The uncertainty of the data is presented in the table headings. The manual includes data for flat-plat and concentrating collectors as described in the next few paragraphs.

Flat-Plate Collectors Facing South at Fixed Tilt

Data are presented for five tilt angles from the horizontal: 0^o, latitude minus 15^o, latitude, latitude plus 15^o, and 90^o. Data for a tilt of 0^o, referred to as global horizontal solar radiation, show how much solar radiation is received by a horizontal surface such as a solar pond.

Maximum yearly solar radiation can be achieved using a tilt angle approximately equal to a site's latitude. To optimize performance in the winter, the collector should be tilted about 15^o greater than the latitude; to optimize performance in the summer, the collector should be tilted about 15^o less than the latitude. Data for a tilt of 90^o apply to collectors mounted vertically on south-facing walls and apply to south-facing windows for passive solar designs. See Figure 2 below.

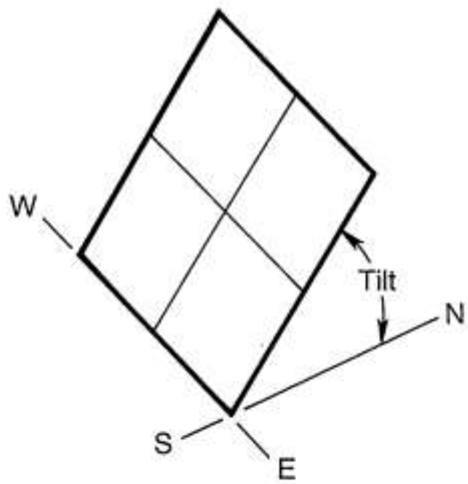


Figure 2. Flat-Plate Collector Facing South at Fixed Tilt

One-Axis Tracking Flat-Plate Collectors with Axis Oriented North-South

Data are presented for four different axis tilt angles from the horizontal: 0^o, latitude minus 15^o, latitude, latitude plus 15^o. These trackers pivot on their single axis to track the sun, facing east in the morning and west in the afternoon. Large collectors can use an axis tilt angle of 0^o to minimize collector height and wind force. Small collectors can have their axis tilted up to increase the solar radiation on the collector. Just as for the flat-plate, fixed tilt collector, the yearly and seasonal solar radiation can by optimized by the choice of tilt angle. The data presented assume continuous tracking of the sun throughout the day. See Figure 3, on the next page.

Two-Axis Tracking Flat-Plate Collectors

Data for two-axis trackers represent the maximum solar radiation at a site available to a collector. Tracking the sun in both azimuth and elevation, these collectors keep the sun's rays normal to the collector surface. See Figure 4 on the next page.

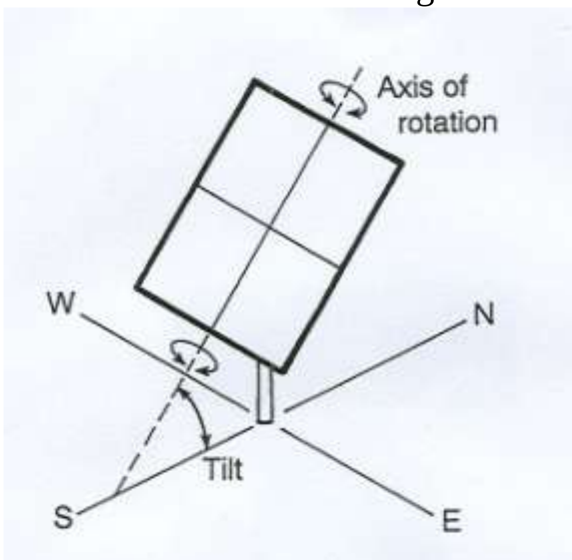


Figure 3. One-Axis Tracking Flat-Plate Collector with Axis Oriented North-South

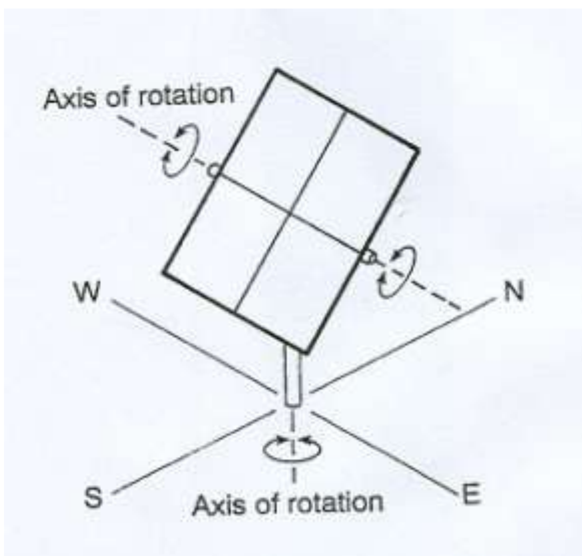


Figure 4. Two-Axis Tracking Flat-Plate Collector

Concentrating Collectors

Direct beam solar radiation data are presented for four concentrator types: one-axis tracking parabolic troughs with a horizontal east-west axis, one axis tracking parabolic troughs with a horizontal north-south axis, one-axis concentrators with the axis oriented north-south and tilted from the horizontal at an angle equal to the latitude, and two-axis tracking concentrator systems. Direct beam radiation comes in a direct line from the sun and is measured with instruments having a field-of-view of 5.7°. These instruments see only the sun's disk and a small portion of the sky surrounding the sun. See Figures 5 and 6 below.

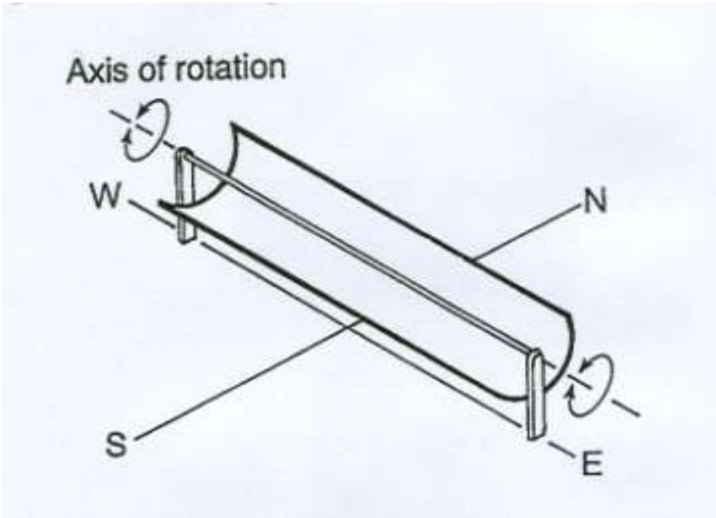


Figure 5. One-Axis Tracking Parabolic Trough with Axis Oriented East-West

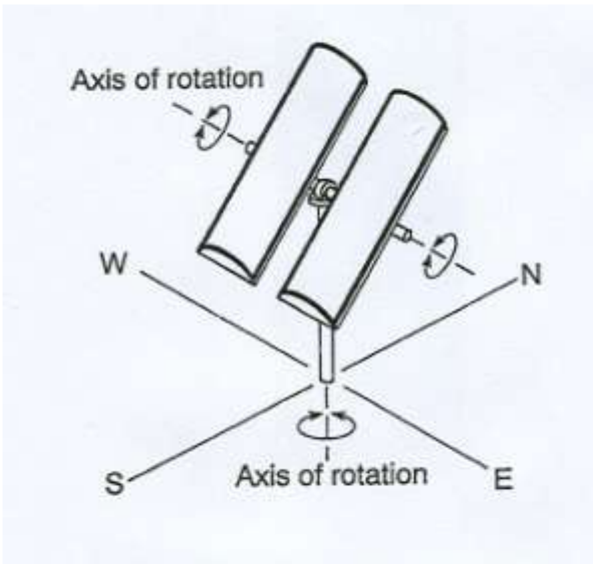


Figure 6. Two-Axis Tracking Concentrator

Solar Radiation Graph

The graph at the top of each data page shows the variability of monthly and yearly solar radiation for a flat-plate collector facing south with a tilt equal to the station's latitude. For each month and year, 30 data values representing each year of the National Solar Radiation Data Base (NSRDB) are plotted along with the 1961-1990 averages for the months and year. The graph shows how the minimum and maximum values compare with the 1961-1990 average. It also shows the distribution of data points with respect to the average, minimum and maximum values.

Climatic Conditions

The last table on each page shows average climatic conditions at the station, by listing monthly and yearly values for the following parameters.

- Monthly and yearly average temperature (^oC)
- Average daily minimum temperature (^oC)
- Average daily maximum temperature (^oC)
- Record minimum temperature (^oC)
- Record maximum temperature (^oC)
- Average heating degree days (HDD), base 18.3 ^oC
- Average cooling degree days(CDD), base 18.3 ^oC
- Average relative humidity (%)
- Average wind speed (m/s).

Degree days indicate heating and cooling requirements of buildings. They are defined as the difference between the average temperature for the day and a base temperature. If the average for the day (calculated by averaging the maximum and minimum temperature for the day) is less than the base value, then the difference is designated as heating degree days. If the average for the day is greater than the base value, the difference is designated as cooling degree days.

Example #1: Using the publication, *Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors*, find the average rate at which solar radiation would strike a horizontal flat-plate collector in Albuquerque, NM in March. What would the rate be for a horizontal, 1-axis, tracking flat-plate collector for the same location and month? What would it be for a 1-axis, tracking flat-plate collector with tilt equal to the latitude (about 35^o), for the same location and month?

Solution: The required data is available from page 3 of this course, which is the table for Albuquerque, NM, from *Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors.* The results are as follows:

Horiz. flat-plate collector: **5.4 kWh/m^2/day**

Horiz. 1-axis, tracking collector: **7.6 kWh/m^2/day**

latitude tilt, 1-axis, tracking collector: **8.6 kWh/m^2/day**

The table below, from the last page of *Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors*, gives conversion factors between metric and U.S. units.

To Convert	Into	Multiply By
kilowatt-hours per square meter	megajoules per square meter	3.60
kilowatt-hours per square meter	Btus per square foot	317.2
kilowatt-hours per square meter	Langleys	86.04
kilowatt-hours per square meter	calories per square centimeter	86.04
meters	feet	3.281
meters per second	miles per hour	2.237
millibars	pascals	100.0
millibars	atmospheres	0.0009869
millibars	kilograms per square meter	10.20
millibars	pounds per square inch	0.0145
degrees Centigrade	degrees Fahrenheit	°C x 1.8 + 32
degrees (angle)	radians	0.017453
degree days (base 18.3°C)	degree days (base 65°F)	1.8

Table 1. Conversion Factors

Example #2: Find the same information requested in **Example #1**, for St. Louis, MO.

Solution: This would be a good point for you to download *Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors,* from the RREDC website, http://www.nrel.gov/docs/legosti/old/5607.pdf, if you think you might have a use for it. You can also use the copy of page 119 from the manual, containing St. Louis data, which is on page 25 of this course. You should find the following results:

Horiz. flat-plate collector: **3.9 kWh/m^2/day**

Horiz. 1-axis, tracking collector: **5.1 kWh/m^2/day**

latitude tilt, 1-axis, tracking collector: **5.8 kWh/m^2/day**

3. Solar Radiation Data Manual for Buildings

This publication provides solar radiation and illuminance values for horizontal and four vertical windows (facing north, east, South, and west) for 239 stations in the United States. It also provides some climatic data for each of the stations. This publication was produced by the NREL and is available for free download from by clicking on "download a pdf" near the bottom of the page. This publication, *Solar Radiation Data Manual for Buildings*, was produced from the same 1961-1990 data set that was used for *Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors*, using the same 239 stations shown on the map given in Figure 1, on page 2 of this course.

The general information and climatic information about each station are the same in both publications. This booklet, however, provides illuminance data and the solar radiation data is set up to be useful for passive solar design. Following is information to assist in interpreting the illuminance and solar radiation data in *Solar Radiation Data Manual for Buildings*, from pages 3, 4, & 5 of that publication.

Interpreting the Data Tables

Solar Radiation

For the period 1961-1990, tables provide solar radiation data in units of Btu/ft^2/day for five surfaces: a horizontal window and vertical windows facing north, east, south, and west. An estimate of the uncertainty (± %) of the solar radiation data is given in the table headings. The manual includes the solar radiation incident on the outside of the window and the solar radiation transmitted through the window into the living space.

Incident solar radiation: For the five windows, monthly and yearly averages of incident solar radiation are given as global radiation, clear-day global radiation, and diffuse radiation.

Global radiation is the total radiation received by the window and is the sum of the direct beam radiation component, sky radiation, and radiation reflected from the ground in front of the surface. Clear-day global radiation represents the global radiation obtainable under clear skies.

The diffuse radiation data in the tables do not include the direct beam radiation component. Diffuse radiation is the sum of sky radiation and radiation reflected from the ground in front of the surface. The ground-reflected radiation was calculated using a ground reflectivity or albedo of 0.2, a nominal value for green vegetation and some soil types. Values in the table may be adjusted for other albedo values by adding an adjustment (I_{adj}) to the incident global and diffuse solar radiation values in the data tables. I_{adj} can be calculated using equation 1:

$$I_{adj} = 0.5(\rho_d - 0.2)I_h(1 - \cos\beta) \qquad (1)$$

where: ρ_d = desired albedo
I_h = monthly or yearly average from data tables for incident global horizontal radiation.
β = tilt angle of surface from horizontal

Standard deviations and minimum and maximum monthly and yearly values of global horizontal radiation are provided to show the variability of the solar radiation at each station. These quantities pertain to monthly and yearly values rather than to single days.

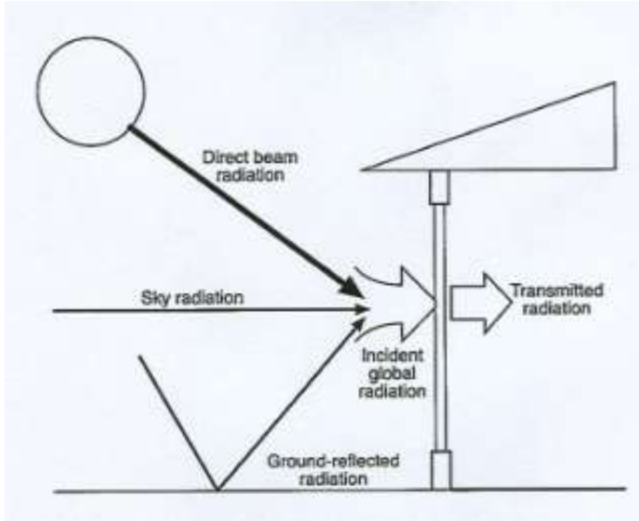


Figure 7. The components of incident global solar radiation

Transmitted solar radiation: The solar radiation transmitted into a living space is less than the radiation that strikes the outside of a window because of losses associated with radiation reflected off of and absorbed by the glass. The manual presents data for windows with conventional, single-strength clear double glazing and a glass thickness of 0,125 in. (3.18 mm).

The tables contain values for unshaded and shaded windows. Unshaded values are for windows with no external shading. Shaded values are for windows shaded by a roof overhang. The roof overhang and window geometry are shown at the top of each data page. The overhang width and the vertical distance from the window to the overhang are given in dimensionless units for a window height of 1.0.

For south-facing windows, the geometry balances the need for maximum heat gain during the heating season without creating unreasonable heat gain during the cooling season. The same shading geometry is used for all vertical windows for a station. The shading geometry is not applicable for the horizontal surface; consequently, shaded transmitted solar radiation values for a horizontal surface are not included.

The shading geometry is generally a function of the station latitude but consideration is also given to heating and cooling requirements. For example, Hawaii, Guam, and Puerto Rico have zero heating degree days; consequently, their shading geometry provides complete shading of south-facing windows at noon throughout the year. Alaskan stations, with no summer cooling loads, have shading geometries that do not shade south facing windows at noon throughout the year.

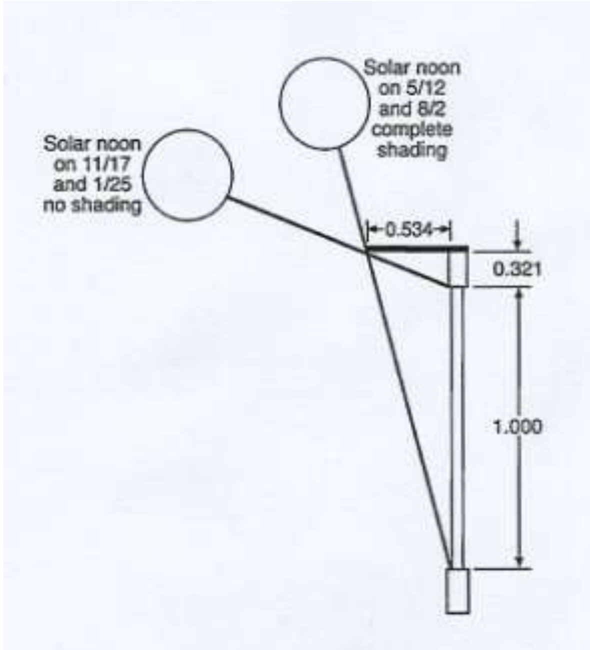


Figure 8. Shading Geometry and Sun Positions for 40° North Latitude

For south-facing windows, the shading geometries provide guidance for the appropriate dimensions of roof overhangs. However, situations may require a different geometry, depending on the balance between heating and cooling loads for the particular building and factors such as required window sizes and building practices. For east- and west-facing windows, overhangs are not particularly effective in preventing unwanted heat gain. Additional shading strategies such as vertical louvers may be needed.

Solar Radiation Graph

The graph at the top of each data page shows the variability, by month and window orientation, of the average amount of solar radiation transmitted through the windows into the living space. For the vertical windows, the graphs are based on the data values for transmitted solar radiation with external shading. The shading geometry is shown adjacent to the graph.

Climatic Conditions

The information given on climatic conditions for each station are the same as in *Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors*, except that temperatures are given in °F, the base for HDD and CDD is 65°F, the average humidity is given as lb water per lb dry air, the average wind speed is given in mph and values for Average clearness index, K_t, are included.

The clearness index (K_t) is the station's global horizontal solar radiation divided by its extraterrestrial horizontal radiation. Because clouds decrease the amount of solar radiation reaching the earth, stations in cloudy regions will have lower values for K_t than stations in regions with fewer clouds.

Illuninance

The illuninance tables contain diurnal profiles of the average illuninance incident on five surfaces: a horizontal window and vertical windows facing north, east, south, and west. The illuninance profiles are given for 4 months of the year (March, June, September, and December) and consist of two data values, separated by a slash, for each of the following hours: 9 a.m., 11 a.m., 1 p.m., 3 p.m., and 5 p.m. The value before the slash is the average illuninance for mostly clear conditions (total cloud cover less than 50%), and the value after the slash is the average illuminance for mostly cloudy conditions (total cloud cover equal to or greater than 50%).

The last line in the illuninance tables indicates the percentage of time during the hour that the station location was mostly clear (M.Clr.). These values, along with the illuminance values, can be used to determine the average hourly illuminance using the following equation:

$$\text{Ave. illuminance} = [(\text{M.Clr.})*(\text{illuminance for mostly clear}) + (100 - \text{M.Clr.})*(\text{illuminance for mostly cloudy})]/100 \qquad (2)$$

The illuminance data are given in units of kilolux-hours (klux-hr) and represent the illuminance received during the preceding hour. For example, data for 3 p.m. include the illuminance received from 2 p.m. to 3 p.m. The hours for March and December are local standard time. The hours for June and September are either local standard time or daylight savings time, depending on whether the station observes daylight savings time. Arizona, Hawaii, Indiana (except Evansville), Puerto Rico, and Guam do not observe daylight savings time; consequently, the hours for June and September for these stations are local standard time. For all other stations, the hours for June and September are daylight savings time. An estimate of the uncertainty (+ or - %) of the illuminance data is given in the table headings.

Example #3: Using the publication, *Solar Radiation Data Manual for Buildings,* find the average rate at which solar radiation would strike a horizontal flat-plate collector in Albuquerque, NM in March. Convert from Btu/ft^2/day to kWhr/m^2/day, and confirm that this is the same as the value found from *Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors.*

Solution: To do this example, you can download *Solar Radiation Data Manual for Buildings,* from the RREDC website, https://www.nrel.gov/docs/legosti/old/7904.pdf?gathStaticon=true , or else you can use the copy of page 148 from the manual, containing Albuquerque data, which is on page 26 of this course. You should find the following results:

Horiz. surface, Albuq., NM, March: **1700 Btu/ft^2/day**

From table 1, on page 9: divide by 317.2 to convert Btu/ft^2 to kWh/m^2

Thus: 1700 Btu/ft^2/day / 317.2 = **5.4 kWh/m^2/day**

This is indeed the same value as that obtained from *Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors*, for a horizontal flat-plate collector.

Example #4: Using the publication, *Solar Radiation Data Manual for Buildings,* find the average rate at which diffuse solar radiation would strike a south-facing, vertical window in Albuquerque, NM in March, assuming the default value of 0.2 for ground reflectivity (albedo). What would be the value for the same parameter if the albedo is 0.15 rather than 0.2?

Solution: From page 148 of *Solar Radiation Data Manual for Buildings*, (page 26 of this course) for Albuquerque, NM, the average rate of diffuse solar radiation striking a south-facing, vertical window in March is: **540 Btu/ft^2/day**.

Equation (1) from page 12, can be used to calculate a correction factor, I_{adj}, for an albedo of 0.15. Equation (1) [$I_{adj} = 0.5(\rho_d - 0.2)I_h(1 - \cos\beta)$] becomes:

$I_{adj} = 0.5(0.15 - 0.2)(1700)(1 - \cos 90^o) =$ **- 42.5**, where I_h (average incident horizontal global radiation) is 1700 Btu/ft^2/day, from the table on page 148. The corrected value for diffuse solar radiation striking a south-facing, vertical window, is thus: 540 – 42.5 = **498 Btu/ft^2/day**

Example #5: Using the publication, *Solar Radiation Data Manual for Buildings,* find the following dimensions for design of roof overhang shading of a south-facing window in Albuquerque, New Mexico: For a window of 24" vertical height, find the vertical distance for the top of the window below the roof overhang and the horizontal distance that the roof overhang should extend beyond the wall, so that the window will be completely shaded at solar noon on 5/12 and 8/2, and will have no shading at solar noon on 11/17 and 1/25.

Solution: As shown in figure 9 below, taken from page 148 in *Solar Radiation Data Manual for Buildings*, (page 26 of this course) the distance of the top of the window below the overhang should be 0.286 times the vertical height of the window, and the horizontal distance of the overhang beyond the wall should be 0.394 times the vertical window height. (more detail on the interpretation of Fig. 9, below, is given in Figure 8, on page 12 of this course.) Thus:

Dist. from top of window to overhang = 0.286*2 feet = **0.572 ft,** and

Horiz. dist. overhang extends beyond wall = 0.394*2 feet = **0.788 ft.**

This solution is also shown in Figure 10, below.

Fig. 9. Shading Geometry (not to scale)
For Albuquerque, NM

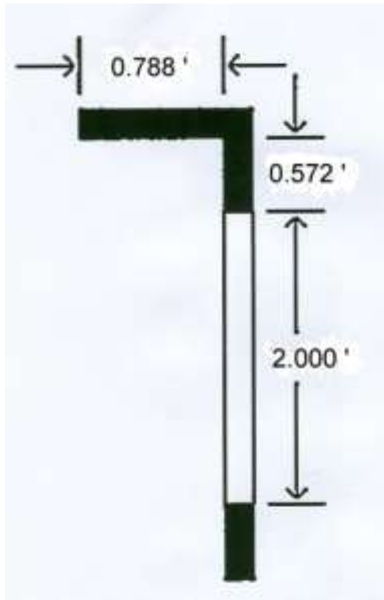


Fig. 10. Solution to Example #5

Example #6: Using the publication, *Solar Radiation Data Manual for Buildings*, find the average fraction of incident global solar radiation striking a south-facing surface which would be transmitted through a south-facing window, in Kansas City, MO in August, if overhang shading is provided per the manual recommendation.

Solution: From the tables on page 117 (for Kansas City, MO) of the manual (or on page 27 of this course), the average global radiation striking a south-facing surface in August is 980 Btu/ft^2/day. Assuming that the window is of the standard construction described in the manual, the average rate of solar radiation transmitted through the shaded window (from the tables on page 117) is 380 Btu/ft^2/day. The percentage transmitted is calculated as follows:

% transmitted = (380/980)*100% = **39 %**

4. NASA Prediction of Worldwide Energy Resources Website

Data from the NASA Prediction of Worldwide Energy Resources website is accessible from the website: **https://power.larc.nasa.gov/** . This site provides access to data for a wide range of meteorology and solar energy parameters for locations around the world. The monthly averages in the data come from 22 years of data. Data for a given site can be accessed either by entering the latitude and longitude of the site, or by clicking on the desired map location on a world map.

To get started in retrieving data from the website, click on "DATA ACCESS" in the menu along the top of the screen. This will take you down a bit on the page and you should next scroll down a bit on the page if necessary and click on the blue button with "POWER DATA ACCESS VIEWER" on it. This takes you to a screen with information about the four data access widgets. Click on the "Access Data" button at the lower right part of the screen. This should take you to a screen with a world map at the top and a place for user entry about the data you want to access on the bottom part of the screen.

The heading across the middle of the screen should say: "POWER Single Point Data Access". Your entries in the bottom part of the screen should be as follows:

1. Choose a User Community – Choose: SSE-Renewable Energy

2. Choose a Temporal Average – Choose: Climatology (You need to select "Climatology" here in order to access data for Tilted Solar Panels.)

3. Enter Lat/Lon or Add a Point to Map – Here you should either enter the latitude and longitude of the location for which you want data, or click on the symbol in a box at the left below the heading in order to select a point on the map with the resulting pointer. If you select a point on the map with the pointer, its latitude and longitude will show up in the latitude and longitude boxes.

Note that most places where you find latitude and or longitude information for a location will give the Latitude as XXX^o north or XXX^o south and the Longitude as XXX^o east or XXX^o west. For the NASA POWER website, the latitude and longitude must be entered simply as a positive or negative number. The sign convention is that north latitude is positive, south latitude is negative, east longitude is positive and west longitude is negative.

4. Select Time Extent – For "Climatology" selected in item 2, no entry is needed for the Time Extent.

5. Select Output File Formats – Selecting CSV will give you an output that can be opened as an Excel spreadsheet.

6. Select Parameters – There is a list of categories from which you should select the data that you want to obtain for the location that you specified in item 3 above. Double-clicking on a category title will generate a dropdown list of the items available in that category

The two categories that contain data most similar to that from the NREL *Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors*, are summarized below.

Parameters for Sizing and Pointing of Solar Panels and for Solar Thermal Applications

Items available in this category include:

- Direct normal radiation (Average, Min, Max)
- Normalized clear sky insolation clearness index
- Normalized insolation clearness index
- Max & Min monthly difference from Monthly Averaged All Sky Insolation

- Diffuse radiation on horizontal surface (Average, Min, Max)
- All Sky Insolation on a Horizontal Surface at 3-hourly intervals
- Insolation clearness index
- Downward Longwave Radiative Flux
- Clear sky insolation incident on a horizontal surface
- All sky insolation incident on a horizontal surface

Parameters for Tilted Solar Panels

Items available in this category include:

- Solar irradiance on equator facing tilted surfaces (this includes horizontal, vertical, latitude tilt, latitude – 15^{o} tilt, and latitude + 15^{o} tilt)
- Direct Normal Radiation (Max, Min, & Ave)
- Diffuse Radiation on a Horizontal Surface (Max, Min, & Ave)
- Insolation Clearness Index
- All Sky Insolation Incident on a Horizontal Surface

The parameters for which data is available in the other categories are summarized in the following outline

Diurnal Cloud Information

- Daylight cloud amount
- Cloud amount at 3-hourly intervals
- Frequency of clear skies at 3-hourly intervals

Meteorology (Moisture and Other)

- Relative Humidity at 2 meters
- Specific Humidity at 2 meters
- Surface Pressure
- Total Column Precipitable Water
- Precipitation

Meteorlogy (Temperature)

- Air Temperature at 2 m
- Daily Temperature Range at 2 m
- Cooling Degree Days above 0^oC, 10^oC & 18.3^oC
- Heating Degree Days below 0^oC, 10^oC & 18.3^oC
- Max and Min Earth Skin Temperature
- Daily Mean Earth Temperature (Min, Max, Amplitude)
- Frost Days
- Dew/Frost Point Temperature at 2 m

Meteorology (Wind)

- Wind Speed at 50 m (Average, Min, Max)
- Wind Direction at 50 m and at 10 m
- Wind speed at 10 m for terrain similar to airports

Parameters for Sizing Battery or other Energy-storage Systems

- Minimum available insolation as % of average values over consecutive 1, 3, 7, 14, or 21 day period
- Equivalent number of NO-SUN days over consecutive 1, 3, 7, 14, or 21 day period

Parameters for Solar Cooking

- Midday Insolation Incident on a Horizontal Surface
- Clear Sky Insolation Incident on a Horizontal Surface
- All Sky Insolation Incident on a Horizontal Surface

Solar Geometry

- Hourly solar angles relative to the horizon
- Hourly solar azimuth angles
- Solar Noon
- Sunset Hour Angle
- Cosine Solar Zenith Angle at Mid-Time Between Sunrise and Solar Noon
- Maximum solar angle relative to the horizon

- Declination
- Daylight Hours
- Daylight average of hourly cosine solar zenith angles

Solar Irradiance and Related Parameters

- Surface Albedo
- Top-of-Atmosphere insolation

As an example of the data available from this website, the values for solar irradiance on a horizontal surface and solar irradiance on a vertical surface for latitude 35.05 and longitude 106.62 (Albuquerque, NM) are shown below.

Monthly Averaged Insolation Incident on Horizontal and Vertical Surfaces in Albuquerque, NM (from NASA POWER website)

Monthly Averaged Insolation Incident on A Horizontal Surface (kWh/m²/day)

Lat 35.05 Lon -106.62	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
22-year Average	3.05	3.67	5.19	6.43	7.13	7.18	6.44	5.75	5.23	4.34	3.31	2.81	5.04

Monthly Averaged Insolation Incident on A Vertical Surface (kWh/m²/day)

Lat 35.05 Lon -106.62	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
22-year Average	4.73	4.13	4.09	3.19	2.48	2.3	2.29	2.64	3.52	4.48	4.68	4.73	3.61

The parameters shown in the table above are also available in either of the two publications described above from the RREDC website. The values may be slightly different, because these data come from 22 years of satellite measurements, and the values in the other two publications come from U. S. Weather Bureau measurements at 239 stations around the U.S. and its territories from 1961-1990.

The data from the NASA POWER website can be obtained for any location around the world by specifying latitude and longitude or by clicking on a map location.

Example #7: Using the NASA Langley website at **https://power.larc.nasa.gov/** , find the average rate at which solar radiation would strike a horizontal flat-plate collector in Albuquerque, NM in March. How does this compare with the value from the RREDC 1961-1990 database in *Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors*?

Solution: The required value can be obtained from the example table on page 22. It is **5.19 kWhr/m^2/day**, whereas the value from the RREDC 1961-1990 database, is **5.4 kWhr/m^2/day** (as found in example #1).

Values from the two databases are quite close. The difference between the two helps to emphasize the fact that the values in the tables are averages. The values will vary from year to year, and the averages will be somewhat different, depending upon the years used to collect the data.

Example #8: Still using the NASA Langley website at **https://power.larc.nasa.gov/**, find the same information requested in **Example #1**, for St. Louis, MO.

Solution: For practice you may want to access the NASA Langley website at **https://power.larc.nasa.gov/** . From *Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors*, St. Louis, MO, is at 38.75^o N latitude and 90.38^o W longitude. Using these latitude and longitude values, you should find the results summarized below. (NOTE: If you prefer not to access the website, the information from the website, for St. Louis, MO, for several of the available solar parameters, is printed out on page 29 of this course.)

Ave. rate of solar radiation on a horiz. surface in St. Louis, MO, in March
= **3.79 kWhr/m^2/day**.

This compares with a value of **3.9 kWhr/m^2/day** from the RREDC 1961-1990 database, as found earlier in example #2. The two values are quite close.

Example #9: Still using the NASA POWER website at **https://power.larc.nasa.gov/** , find the average rate at which solar radiation would strike a horizontal flat-plate collector in Dar es Salaam, Tanzania, in March.

Solution: First find the latitude and longitude for Dar es Salaam. This can be done by doing a Google or Yahoo search for "Dar es Salaam latitude and longitude". This should show that the latitude and longitude for Dar es Salaam are 6^o 48' south latitude and 39^o 17' east longitude. These need to be converted to decimal degrees: 6 + 48/60 degrees = 6.8^o and 39 + 17/60 degrees = 39.28^o. Next, go to the NASA POWER website and access the data for Dar es Salaam using –6.8 for latitude and 39.28 for longitude. Selecting "Solar Irradiance for Equator Facing Tilted Surfaces (Set of Surfaces)" and downloading the resulting CSV file, should lead to a value **5.27 kWhr/m^2/day** as the solar irradiance on a horizontal flat plate for that location in March.

(NOTE: If you prefer not to access the website, the information for Dar es Salaam, for "solar insolation on a horizontal surface" is printed out on page 30 of this course.)

5. Summary

Through the information in this course, one will be able to download publications and access websites to obtain a wide range of solar radiation data for solar collectors, panels, and buildings and meteorological data for locations in the United States and throughout the world.

6. Related Links

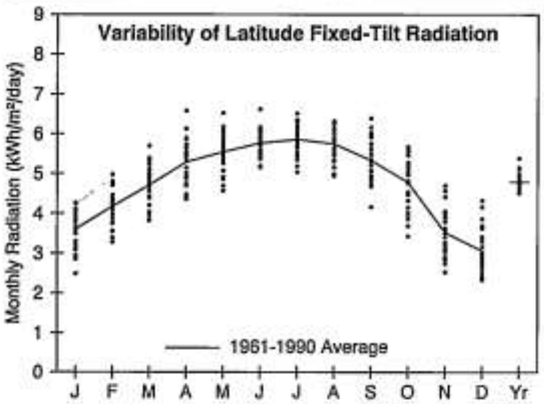
1. **Renewable Resource Data Center** homepage for solar resource information
http://www.nrel.gov/rredc/solar_resource.html

2. ***Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors***
(Provides solar radiation values for common flat-plate and concentrating collectors for 239 stations in the United States and its territories.)
http://www.nrel.gov/docs/legosti/old/5607.pdf

3. ***Solar Radiation Data Manual for Buildings*** (Provides solar radiation and illuminance values for a horizontal window and four vertical windows (facing north, east, south, and west) for 239 stations in the United States and its territories.)
https://www.nrel.gov/docs/legosti/old/7904.pdf?gathStaticon=true

4. NASA Prediction of Worldwide Energy Resources website, available at:

https://power.larc.nasa.gov/



St. Louis, MO

WBAN NO. 13994

LATITUDE: 38.75° N
LONGITUDE: 90.38° W
ELEVATION: 172 meters
MEAN PRESSURE: 997 millibars

STATION TYPE: Secondary

Solar Radiation for Flat-Plate Collectors Facing South at a Fixed Tilt (kWh/m²/day), Uncertainty ±9%

Tilt (°)		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
0	Average	2.2	2.9	3.9	5.0	5.9	6.4	6.4	5.7	4.6	3.5	2.3	1.8	4.2
	Min/Max	1.7/2.5	2.5/3.4	3.3/4.5	4.3/6.1	4.9/6.9	5.8/7.4	5.5/7.1	4.9/6.2	3.8/5.3	2.8/3.9	1.9/2.7	1.6/2.3	4.0/4.7
Latitude -15	Average	3.2	3.8	4.6	5.4	5.9	6.3	6.3	6.0	5.3	4.5	3.2	2.7	4.8
	Min/Max	2.3/3.7	3.1/4.5	3.8/5.5	4.5/6.7	4.9/6.9	5.6/7.2	5.4/7.0	5.1/6.6	4.2/6.3	3.3/5.2	2.4/4.1	2.1/3.7	4.5/5.3
Latitude	Average	3.6	4.2	4.7	5.3	5.6	5.8	5.9	5.7	5.3	4.8	3.5	3.1	4.8
	Min/Max	2.5/4.3	3.3/5.0	3.8/5.7	4.4/6.6	4.6/6.5	5.2/6.6	5.0/6.5	4.9/6.3	4.2/6.4	3.4/5.7	2.5/4.7	2.3/4.3	4.5/5.4
Latitude +15	Average	3.8	4.3	4.6	4.9	4.9	5.0	5.1	5.2	5.1	4.8	3.7	3.3	4.6
	Min/Max	2.6/4.6	3.3/5.2	3.7/5.6	4.0/6.1	4.1/5.8	4.5/5.7	4.4/5.7	4.5/5.8	4.0/6.2	3.4/5.8	2.6/5.0	2.4/4.7	4.3/5.1
90	Average	3.5	3.7	3.4	3.1	2.6	2.4	2.6	3.0	3.5	3.8	3.2	3.0	3.2
	Min/Max	2.3/4.3	2.7/4.6	2.7/4.1	2.5/3.7	2.3/2.9	2.3/2.6	2.3/2.7	2.6/3.3	2.7/4.2	2.6/4.7	2.2/4.5	2.2/4.5	2.8/3.5

Solar Radiation for 1-Axis Tracking Flat-Plate Collectors with a North-South Axis (kWh/m²/day), Uncertainty ±9%

Axis Tilt (°)		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
0	Average	3.1	4.0	5.1	6.6	7.6	8.3	8.3	7.6	6.2	4.9	3.1	2.5	5.6
	Min/Max	2.2/3.7	3.1/4.8	4.0/6.4	5.2/8.5	6.1/9.4	7.3/10.0	7.2/9.5	6.3/8.4	4.7/7.8	3.4/5.9	2.3/4.2	2.0/3.5	5.3/6.5
Latitude -15	Average	3.8	4.7	5.7	6.9	7.7	8.3	8.4	7.8	6.8	5.6	3.8	3.2	6.1
	Min/Max	2.6/4.6	3.6/5.6	4.3/7.2	5.4/9.0	6.1/9.6	7.2/10.0	7.2/9.5	6.4/8.8	5.0/8.6	3.9/6.8	2.7/5.2	2.4/4.6	5.7/7.0
Latitude	Average	4.2	5.0	5.8	6.8	7.5	7.9	8.1	7.7	6.8	5.9	4.1	3.5	6.1
	Min/Max	2.8/5.1	3.7/6.0	4.4/7.3	5.3/8.9	5.9/9.3	6.9/9.6	6.9/9.2	6.3/8.6	5.0/8.7	4.0/7.2	2.8/5.7	2.6/5.1	5.7/7.1
Latitude +15	Average	4.4	5.1	5.7	6.5	7.0	7.4	7.6	7.3	6.7	5.9	4.2	3.7	6.0
	Min/Max	2.8/5.3	3.8/6.2	4.3/7.3	5.1/8.6	5.5/8.8	6.5/8.9	6.5/8.6	6.0/8.2	4.8/8.5	4.0/7.2	2.8/5.9	2.7/5.4	5.5/6.9

Solar Radiation for 2-Axis Tracking Flat-Plate Collectors (kWh/m²/day), Uncertainty ±9%

Tracker		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
2-Axis	Average	4.4	5.1	5.8	6.9	7.8	8.5	8.5	7.9	6.9	5.9	4.3	3.7	6.3
	Min/Max	2.9/5.4	3.8/6.2	4.4/7.4	5.4/9.0	6.2/9.7	7.4/10.2	7.3/9.7	6.5/8.8	5.1/8.7	4.0/7.3	2.9/5.9	2.7/5.5	5.9/7.3

Direct Beam Solar Radiation for Concentrating Collectors (kWh/m²/day), Uncertainty ±8%

Tracker		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
1-Axis, E-W Horiz Axis	Average	2.5	2.6	2.7	3.1	3.5	3.9	4.0	3.7	3.3	3.2	2.4	2.1	3.1
	Min/Max	1.3/3.4	1.7/3.4	1.7/4.0	1.9/4.8	2.3/5.1	3.2/5.5	2.8/5.1	2.6/4.5	2.0/4.7	1.8/4.2	1.2/3.8	1.3/3.6	2.8/3.9
1-Axis, N-S Horiz Axis	Average	1.9	2.4	3.0	4.0	4.7	5.2	5.3	4.9	4.0	3.3	1.9	1.5	3.5
	Min/Max	0.9/2.6	1.5/3.2	1.9/4.6	2.4/6.2	3.1/6.8	4.3/7.2	3.9/6.7	3.5/6.0	2.3/5.9	1.8/4.3	1.0/3.1	0.9/2.5	3.1/4.5
1-Axis, N-S Tilt=Latitude	Average	2.7	3.1	3.6	4.3	4.6	4.9	5.1	4.9	4.5	4.1	2.7	2.2	3.9
	Min/Max	1.4/3.8	2.0/4.2	2.2/5.3	2.5/6.5	3.1/6.7	4.0/6.8	3.7/6.4	3.5/6.1	2.6/6.6	2.3/5.4	1.4/4.3	1.4/3.8	3.5/5.0
2-Axis	Average	2.9	3.2	3.6	4.3	4.8	5.3	5.5	5.1	4.5	4.1	2.9	2.4	4.1
	Min/Max	1.5/4.0	2.0/4.2	2.2/5.3	2.6/6.6	3.2/7.1	4.3/7.4	4.0/6.9	3.6/6.3	2.6/6.6	2.3/5.4	1.4/4.6	1.5/4.2	3.6/5.2

Average Climatic Conditions

Element	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
Temperature (°C)	-1.5	1.1	7.3	13.7	18.9	24.1	26.6	25.3	21.2	14.7	7.9	1.1	13.4
Daily Minimum Temp	-6.2	-3.8	1.9	8.0	13.3	18.7	21.3	19.9	15.8	9.1	3.2	-3.3	8.2
Daily Maximum Temp	3.2	5.9	12.6	19.4	24.5	29.6	31.8	30.7	26.6	20.3	12.6	5.4	18.6
Record Minimum Temp	-27.8	-23.3	-20.6	-5.6	-0.6	6.1	10.6	8.3	2.2	-5.0	-17.2	-26.7	-27.8
Record Maximum Temp	24.4	29.4	31.7	33.9	33.9	38.9	41.7	41.7	40.0	34.4	29.4	24.4	41.7
HDD, Base 18.3°C	615	484	343	148	62	0	0	0	12	132	313	536	2643
CDD, Base 18.3°C	0	0	0	9	81	173	255	217	98	18	0	0	852
Relative Humidity (%)	73	72	68	63	66	67	68	70	72	69	72	76	70
Wind Speed (m/s)	4.9	4.8	5.3	5.2	4.3	4.1	3.8	3.6	3.8	4.1	4.6	4.8	4.4

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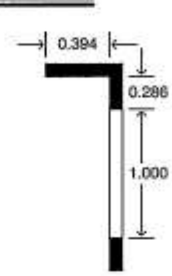
Albuquerque, NM

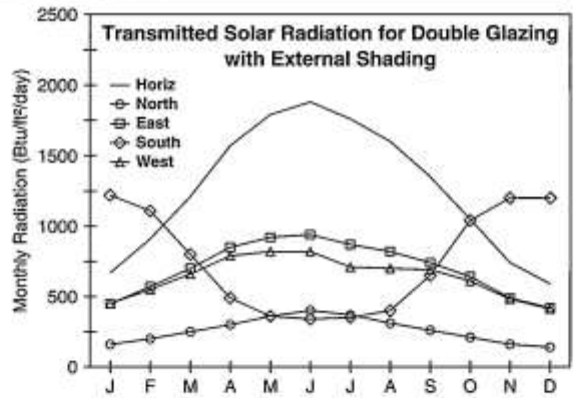
WBAN NO. 23050

LATITUDE: 35.05° N
LONGITUDE: 106.62° W
ELEVATION: 5312 feet
MEAN PRESSURE: 12.2 psia

STATION TYPE: Primary



Shading Geometry
(Not to Scale)



Average Incident Solar Radiation (Btu/ft²/day), Uncertainty ±9%

Orientation		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
Horizontal	Global	1010	1320	1700	2160	2430	2560	2380	2180	1860	1500	1100	910	1760
	Std.Dev.	79	96	121	91	119	105	81	93	95	101	79	74	56
	Minimum	830	1100	1410	1950	2170	2350	2160	1870	1700	1270	890	710	1630
	Maximum	1140	1470	1930	2310	2630	2720	2510	2350	2070	1680	1220	1030	1850
	Diffuse	310	400	540	600	650	640	700	640	520	390	310	280	500
	Clear-Day Global	1200	1550	2020	2490	2740	2830	2730	2490	2120	1660	1250	1080	2020
North	Global	240	300	390	480	620	700	630	500	400	320	250	220	420
	Diffuse	240	300	390	450	510	520	520	470	400	320	250	220	380
	Clear-Day Global	210	260	330	430	620	750	680	480	350	280	220	190	400
East	Global	700	870	1070	1310	1430	1460	1360	1270	1130	970	750	650	1080
	Diffuse	300	380	480	560	610	610	620	570	490	400	310	270	470
	Clear-Day Global	870	1070	1300	1490	1580	1580	1540	1470	1320	1110	900	810	1250
South	Global	1640	1620	1430	1170	900	760	810	1020	1320	1620	1640	1610	1290
	Diffuse	410	470	540	550	540	530	540	540	520	470	410	380	490
	Clear-Day Global	2190	2130	1830	1330	930	760	820	1110	1580	1990	2130	2160	1580
West	Global	690	850	1010	1220	1290	1290	1140	1120	1060	940	740	630	1000
	Diffuse	300	380	480	570	620	620	620	580	500	400	320	270	470
	Clear-Day Global	870	1070	1300	1490	1580	1580	1540	1470	1320	1110	900	810	1250

Average Transmitted Solar Radiation (Btu/ft²/day) for Double Glazing, Uncertainty ±9%

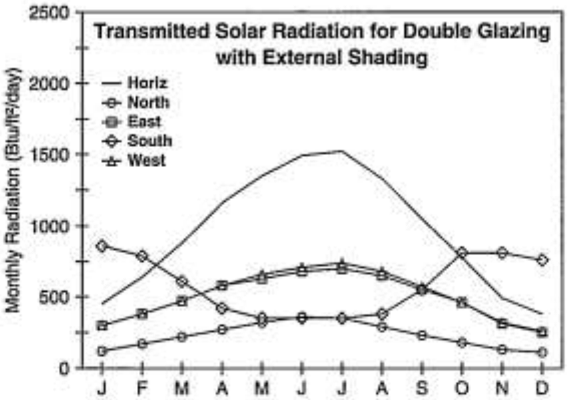
Orientation		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
Horizontal	Unshaded	670	910	1210	1570	1790	1880	1760	1600	1350	1050	740	590	1260
North	Unshaded	170	210	270	320	390	440	400	330	270	220	170	150	280
	Shaded	160	200	250	300	360	400	370	310	260	210	160	140	260
East	Unshaded	490	610	770	940	1020	1050	970	910	810	690	520	450	770
	Shaded	450	570	700	850	920	940	870	820	740	640	490	420	700
South	Unshaded	1230	1170	970	720	510	430	460	600	860	1140	1220	1210	880
	Shaded	1220	1110	800	490	360	340	350	400	650	1040	1200	1200	760
West	Unshaded	480	600	720	870	920	920	800	790	750	660	510	440	700
	Shaded	450	550	660	790	820	820	710	700	690	610	480	410	640

Average Climatic Conditions

Element	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
Temperature (°F)	34.2	40.0	46.9	55.2	64.2	74.2	78.5	75.9	68.6	57.0	44.3	35.3	56.2
Daily Minimum Temp	21.7	26.4	32.2	39.6	48.6	58.3	64.4	62.6	55.2	43.0	31.2	23.1	42.2
Daily Maximum Temp	46.8	53.5	61.4	70.8	79.7	90.0	92.5	89.0	81.9	71.0	57.3	47.5	70.1
Record Minimum Temp	-17.0	-5.0	8.0	19.0	28.0	40.0	52.0	52.0	37.0	21.0	-7.0	-7.0	-17.0
Record Maximum Temp	69.0	76.0	85.0	89.0	98.0	105.0	105.0	101.0	100.0	91.0	77.0	72.0	105.0
HDD, Base 65°F	955	700	561	301	89	0	0	0	18	259	621	921	4425
CDD, Base 65°F	0	0	0	7	64	279	419	338	126	11	0	0	1244
Humidity Ratio (#w/#da)	0.0025	0.0027	0.0028	0.0031	0.0042	0.0058	0.0092	0.0097	0.0077	0.0049	0.0033	0.0027	0.0049
Wind Speed (mph)	8.3	8.8	10.1	11.0	10.7	10.0	9.0	8.4	8.6	8.1	8.1	7.9	9.1
Clearness Index, Kt	0.62	0.63	0.64	0.68	0.69	0.70	0.66	0.66	0.65	0.65	0.62	0.61	0.66

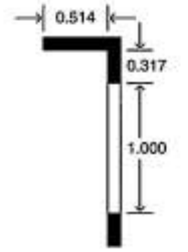
Average Incident Illuminance (klux-hr) for Mostly Clear/Mostly Cloudy Conditions, Uncertainty ±9%

Orientation	March					June					September					December				
	9am	11am	1pm	3pm	5pm	9am	11am	1pm	3pm	5pm	9am	11am	1pm	3pm	5pm	9am	11am	1pm	3pm	5pm
Horizontal	45/31	82/61	93/71	76/55	34/23	49/39	88/73	109/91	104/83	75/57	31/20	74/54	94/75	87/67	54/40	22/15	52/36	60/43	40/28	5/4
North	10/11	14/17	15/18	14/16	9/9	23/19	15/18	16/19	16/19	14/16	8/8	14/16	16/19	15/18	12/13	7/6	11/12	12/13	9/10	2/2
East	85/44	63/44	15/18	14/16	9/9	85/56	75/60	33/32	16/19	14/16	75/32	76/49	31/29	15/18	12/13	58/25	47/28	12/13	9/10	2/2
South	41/25	74/50	83/60	67/45	31/17	11/12	24/25	39/37	35/33	15/17	21/13	55/38	73/56	67/49	40/26	51/22	91/48	99/57	77/39	17/7
West	10/11	14/17	23/23	73/48	81/36	11/12	15/18	16/19	53/45	85/58	8/8	14/16	16/19	55/42	83/48	7/6	11/12	23/19	60/32	25/9
M. Clr (%hrs)	53	47	42	40	42	76	77	75	60	49	64	65	64	59	50	54	54	49	50	51



Kansas City, MO

WBAN NO. 03947



Shading Geometry
(Not to Scale)

LATITUDE: 39.30° N
LONGITUDE: 94.72° W
ELEVATION: 1034 feet
MEAN PRESSURE: 14.3 psia

STATION TYPE: Secondary

Average Incident Solar Radiation (Btu/ft²/day), Uncertainty ±9%

Orientation		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
Horizontal	Global	700	940	1240	1610	1870	2050	2080	1830	1460	1120	740	590	1360
	Std.Dev.	57	71	114	112	128	127	144	129	130	107	73	53	42
	Minimum	560	790	980	1330	1560	1750	1800	1550	1060	930	590	490	1280
	Maximum	820	1100	1410	1870	2130	2360	2350	2040	1760	1390	890	700	1490
	Diffuse	300	420	560	680	790	810	760	680	560	410	320	280	550
	Clear-Day Global	940	1280	1760	2230	2530	2640	2560	2290	1870	1390	990	820	1780
North	Global	200	270	350	440	550	630	600	480	380	290	210	180	380
	Diffuse	200	270	350	430	500	530	510	450	370	290	210	180	360
	Clear-Day Global	190	240	320	420	580	680	630	460	350	270	200	160	380
East	Global	480	610	760	940	1040	1110	1130	1040	880	730	500	400	800
	Diffuse	240	330	430	520	590	630	620	550	460	350	260	220	430
	Clear-Day Global	700	900	1140	1350	1450	1470	1440	1350	1180	950	740	630	1110
South	Global	1170	1170	1100	990	850	780	840	980	1130	1280	1120	1030	1040
	Diffuse	350	420	490	530	560	560	560	550	500	430	350	320	470
	Clear-Day Global	1940	1980	1800	1400	1060	910	960	1220	1610	1870	1900	1870	1540
West	Global	480	610	760	940	1070	1160	1190	1080	910	730	500	420	820
	Diffuse	250	330	430	530	600	640	630	570	470	360	260	220	440
	Clear-Day Global	700	900	1140	1350	1450	1470	1440	1350	1180	950	740	630	1110

Average Transmitted Solar Radiation (Btu/ft²/day) for Double Glazing, Uncertainty ±9%

Orientation		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
Horizontal	Unshaded	450	640	880	1160	1350	1490	1520	1330	1050	780	490	380	960
North	Unshaded	140	190	240	300	360	410	390	320	260	200	150	120	260
	Shaded	120	170	220	270	320	360	350	290	230	180	130	110	230
East	Unshaded	330	430	540	670	740	790	810	740	620	510	350	280	570
	Shaded	300	380	470	580	630	680	700	650	550	460	310	250	500
South	Unshaded	880	850	760	640	520	470	500	610	760	920	840	780	710
	Shaded	860	790	610	420	350	350	350	380	550	810	810	760	590
West	Unshaded	330	430	540	670	760	830	850	780	650	510	350	280	580
	Shaded	300	380	470	580	660	710	740	680	570	460	320	260	510

Average Climatic Conditions

Element	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
Temperature (°F)	25.7	31.2	42.7	54.5	64.1	73.2	78.5	76.1	67.5	56.6	43.1	30.4	53.6
Daily Minimum Temp	16.7	21.8	32.6	43.8	53.9	63.1	68.2	65.7	56.9	45.7	33.6	21.9	43.7
Daily Maximum Temp	34.7	40.6	52.8	65.1	74.3	83.3	88.7	86.4	78.1	67.5	52.6	38.8	63.6
Record Minimum Temp	-17.0	-19.0	-10.0	12.0	30.0	42.0	52.0	43.0	33.0	21.0	1.0	-23.0	-23.0
Record Maximum Temp	69.0	76.0	86.0	93.0	92.0	105.0	107.0	109.0	102.0	92.0	82.0	70.0	109.0
HDD, Base 65°F	1218	946	691	325	135	7	0	6	56	279	657	1073	5393
CDD, Base 65°F	0	0	0	10	107	253	419	350	131	18	0	0	1288
Humidity Ratio (#w/#da)	0.0023	0.0027	0.0040	0.0060	0.0090	0.0125	0.0143	0.0135	0.0107	0.0068	0.0045	0.0029	0.0074
Wind Speed (mph)	10.9	10.9	12.2	12.0	10.3	9.7	9.2	9.0	9.2	10.0	10.7	10.8	10.4
Clearness Index, Kt	0.50	0.50	0.50	0.52	0.53	0.55	0.58	0.56	0.54	0.54	0.48	0.46	0.53

Average Incident Illuminance (klux-hr) for Mostly Clear/Mostly Cloudy Conditions, Uncertainty ±9%

Orientation	March					June					September					December				
	9am	11am	1pm	3pm	5pm	9am	11am	1pm	3pm	5pm	9am	11am	1pm	3pm	5pm	9am	11am	1pm	3pm	5pm
Horizontal	34/20	69/42	82/51	68/42	32/20	42/27	81/55	101/70	98/72	73/53	23/13	63/37	85/53	81/53	53/34	11/7	39/23	48/29	33/20	4/3
North	9/8	13/15	15/17	13/15	9/8	20/14	16/17	17/19	17/19	16/16	7/6	13/14	16/17	15/17	12/13	4/3	9/9	10/11	8/8	2/2
East	73/24	62/31	15/17	13/15	9/8	75/35	76/46	38/30	17/19	16/16	61/18	73/34	35/25	15/17	12/13	36/9	43/18	10/11	8/8	2/2
South	35/15	70/34	83/43	69/34	33/15	11/10	28/23	45/35	43/35	24/21	17/8	53/27	75/41	71/41	43/25	30/8	79/27	92/34	70/24	13/4
West	9/8	13/15	16/17	63/32	71/26	11/10	16/17	17/19	46/37	78/50	7/6	13/14	16/17	48/31	75/37	4/3	9/9	16/13	49/18	18/5
M. Clr (%hrs)	34	32	31	30	32	39	40	39	38	41	46	47	47	46	47	35	36	35	36	37

Data for St. Louis, MO

NASA Prediction Of Worldwide Energy Resources

Latitude 38.75 / Longitude -90.38 was chosen.

Elevation: **167.69** meters
average for ½ x ½
degree lat/long region

Surface (kWh/m²/day)

Lat **38.75** Lon **-90.38**	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
Tilt **0**	2.07	2.62	3.79	4.85	5.44	5.95	6.07	5.44	4.66	3.45	2.25	1.83	4.04
Tilt **23**	2.93	3.3	4.35	5.08	5.37	5.73	5.92	5.57	5.24	4.33	3.06	2.66	4.46
Tilt **38**	3.29	3.52	4.44	4.91	4.99	5.23	5.43	5.28	5.27	4.61	3.39	3.03	4.45
Tilt **53**	3.47	3.55	4.29	4.51	4.41	4.53	4.73	4.76	5.01	4.63	3.52	3.22	4.22
Tilt 90	3.09	2.84	3.03	2.68	2.3	2.19	2.31	2.61	3.31	3.6	3.01	2.91	2.82

Data for Dar es Salaam, Tanzania

NASA Prediction Of Worldwide Energy Resources

Latitude - 6.8 / Longitude 39.28 was chosen.

Elevation: 40.85 meters
average for ½ x ½
degree lat/long region

Surface (kWh/m²/day)

Lat -6.8 Lon 39.28	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
Tilt 0	5.67	5.66	5.27	4.51	4.38	4.51	4.5	4.79	5.5	5.57	5.61	5.62	5.13
Tilt -9	3.04	2.49	2.09	2.56	3.11	3.65	3.41	2.98	2.47	2.27	2.88	3.2	2.85
Tilt 6	5.75	5.69	5.27	4.58	4.52	4.72	4.68	4.9	5.54	5.58	5.68	5.73	5.22
Tilt 21	5.76	5.56	5.08	4.6	4.71	5.05	4.95	5.02	5.43	5.4	5.65	5.77	5.25
Tilt 90	2.52	1.96	1.55	2.11	2.68	3.2	2.95	2.49	1.89	1.72	2.38	2.69	2.35