SunCam

A SunCam online continuing education course

Solar Basics – Radiation Data Online

by

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1. Introduction

Whether you are planning, designing or surveying for a photovoltaic solar power system, a passive solar heating system or solar collectors for a solar thermal system to provide space heat or hot water, you could use data on the average rate of solar radiation to be expected at your project location each month. In fact, such information is readily available from online sources for locations in the United States and around the world. This course will provide information about three sources of such data. Two of the sources are from the Renewable Resource Data Center (RREDC), which is a unit of the National Renewable Energy Laboratory (NREL). The other source is a NASA Langley Distributed Active Archive (DAAC) Surface Meteorology and Solar Energy Data Set. Discussion of each of these sources will include how to access them, what type of data is available at each, and how to interpret that data.

Image Credit: Flicker.com/Wayne National Forest

2. Learning Objectives

At the conclusion of this course, the student will

- Be able to access the publication, *Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors*, and download it from the RREDC website.
- Be able to obtain yearly average and monthly average solar radiation data for fixed flat-plate collectors at the tilt angles provided at any of the 239 locations in the publication, *Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors.*
- Be able to obtain yearly average and monthly average solar radiation data for 1-axis & 2-axis, tracking flat-plate collectors and for concentrating collectors for the different orientations provided at any of the 239 locations in the publication *Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors.*
- Be able to access the publication *Solar Radiation Data Manual for Buildings* and download it from the RREDC website
- Be able to obtain solar radiation data for horizontal and vertical windows for the directions provided, at any of the 239 locations in the publication *Solar Radiation Data Manual for Buildings.*
- Be able to calculate corrected values for total global solar radiation and diffuse solar radiation to vertical windows for an albedo different than the default value of 0.2.
- Be able to calculate the required overhang dimensions to provide shading in summer and no shading in winter for windows at any of the 239 location in the publication *Solar Radiation Data Manual for Buildings.*
- Be able to access the NASA Langley Distributed Active Archive (DAAC) Surface Meteorology and Solar Energy Data Set website and login to that site.

- Be able to obtain solar radiation and meteorological data for any location in the world based on its latitude and longitude of the type available from the NASA Langley Distributed Active Archive (DAAC) Surface Meteorology and Solar Energy Data Set website.

3. Detailed Course Outline with Timeline

I. Introduction (2 min)

II. Learning Objectives (5 min)

III. Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors (30 mn)

A. Flat-Plate Collectors Facing South at Fixed Tilt (7 min)
B. One-Axis Tracking Flat-Plate Collectors with Axis Oriented North-South (7 min)
C. Two-Axis Tracking Flat-Plate Collectors (7 min)
D. Concentrating Collectors (7 min)
E. Solar Radiation Graph (1 min)
F. Climatic Conditions (5 min)
G. Examples #1 & #2 (10 min)
H. Unit Conversions (5 min)

IV. Solar Radiation Data Manual for Buildings (3 min)

A. Solar Radiation (2 min)
B. Incident Solar Radiation (8 min)
C. Transmitted Solar Radiation (8 min)
D. Solar Radiation Graph (2 min)
E. Climatic Conditions (4 min)

4. Solar Radiation Data for Flat-Plate and Concentrating Collectors

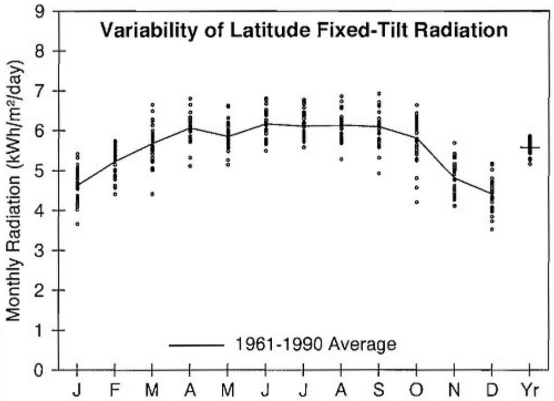
A publication with a wealth of data on solar radiation rates in the United States is the *Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors.* This publication is available to be downloaded from the first reference at the end of this course, the NREL website at www.nrel.gov/docs/legosti/old/5607.pdf. The rest of this section will provide information about this data manual and the solar radiation data it contains for 239 stations spread throughout the United States and its territories.

The solar radiation data in this manual are presented in the form of yearly and monthly averages, maximums and minimums for each of the 239 stations, based on data collected from 1961-1990. These data are available for several different types of collectors at different tilt angles as detailed below. The data for each of the locations are given on a separate page for that location. The pages are presented alphabetically by the two-letter postal abbreviation for the state or territory. There are several cities for most of the states and territories and they are arranged alphabetically within their state or territory section of the manual.

The data page for Colorado Springs, CO is shown on the next page as an example, and to show the type of data that is available in the manual for each station. The four major categories of data for each station are as follows:

- Solar Radiation for Flat-plate Collectors Facing South at a Fixed Tilt
- Solar Radiation for 1-Axis Tracking Flat-Plate Collectors
- Solar Radiation for 2-Axis Tracking Flat-Plate Collectors
- Direct Beam Radiation for Concentrating Collectors
- Average Climatic Conditions

The solar radiation data are all in units of kWhr/m^2/day.



Colorado Springs, CO

WBAN NO. 93037

From NREL Data Manual

LATITUDE: 38.82° N
LONGITUDE: 104.72° W
ELEVATION: 1881 meters
MEAN PRESSURE: 811 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	2.5	3.4	4.5	5.7	6.2	6.9	6.7	6.0	5.1	4.0	2.8	2.3	4.7
	Min/Max	2.2/2.8	3.0/3.7	3.7/5.1	4.8/6.3	5.5/7.0	6.2/7.7	6.1/7.4	5.2/6.7	4.3/5.8	3.2/4.5	2.5/3.1	2.0/2.5	4.5/4.9
Latitude -15	Average	4.0	4.7	5.5	6.2	6.2	6.7	6.6	6.4	6.0	5.4	4.2	3.7	5.5
	Min/Max	3.2/4.6	4.0/5.2	4.3/6.3	5.2/6.9	5.5/7.1	6.0/7.4	6.0/7.3	5.5/7.1	4.9/6.8	4.0/6.1	3.7/4.9	3.0/4.3	5.1/5.7
Latitude	Average	4.6	5.2	5.7	6.1	5.9	6.2	6.1	6.1	6.1	5.8	4.8	4.4	5.6
	Min/Max	3.7/5.4	4.4/5.7	4.4/6.7	5.1/6.8	5.2/6.6	5.5/6.8	5.6/6.8	5.3/6.9	4.9/6.9	4.2/6.6	4.1/5.7	3.5/5.2	5.2/5.9
Latitude +15	Average	5.0	5.4	5.6	5.6	5.2	5.3	5.3	5.6	5.9	5.9	5.1	4.8	5.4
	Min/Max	3.9/5.9	4.5/6.0	4.3/6.6	4.8/6.3	4.6/5.8	4.7/5.8	4.9/5.8	4.8/6.2	4.7/6.7	4.2/6.8	4.3/6.1	3.8/5.7	4.9/5.7
90	Average	4.7	4.6	4.2	3.5	2.7	2.5	2.6	3.2	4.0	4.8	4.6	4.6	3.8
	Min/Max	3.5/5.5	3.8/5.1	3.4/4.9	3.0/4.0	2.5/3.0	2.3/2.6	2.4/2.8	2.8/3.5	3.2/4.5	3.3/5.5	3.8/5.6	3.7/5.4	3.4/4.0

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	4.0	5.1	6.4	7.9	8.3	9.4	9.0	8.3	7.4	6.1	4.3	3.7	6.7
	Min/Max	3.1/4.7	4.4/5.7	4.7/7.7	6.3/9.1	7.0/9.8	8.0/10.8	8.0/10.3	6.7/9.5	5.7/8.7	4.3/7.1	3.5/5.2	2.9/4.3	6.1/7.1
Latitude -15	Average	5.1	6.1	7.2	8.3	8.5	9.3	9.0	8.6	8.1	7.1	5.4	4.7	7.3
	Min/Max	3.8/6.0	5.1/6.8	5.2/8.6	6.6/9.7	7.1/10.0	7.9/10.7	8.0/10.3	7.0/9.9	6.2/9.5	4.9/8.3	4.4/6.4	3.7/5.6	6.6/7.7
Latitude	Average	5.6	6.5	7.4	8.3	8.2	9.0	8.7	8.5	8.1	7.4	5.8	5.3	7.4
	Min/Max	4.2/6.6	5.4/7.3	5.3/8.9	6.6/9.6	6.8/9.7	7.6/10.3	7.7/10.0	6.9/9.7	6.2/9.6	5.1/8.7	4.8/7.1	4.1/6.2	6.7/7.8
Latitude +15	Average	5.9	6.6	7.3	7.9	7.7	8.4	8.1	8.1	8.0	7.5	6.1	5.6	7.3
	Min/Max	4.4/7.0	5.5/7.5	5.2/8.8	6.3/9.3	6.4/9.1	7.1/9.6	7.2/9.4	6.5/9.3	6.1/9.4	5.1/8.8	5.0/7.4	4.3/6.6	6.5/7.7

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	5.9	6.7	7.4	8.4	8.6	9.6	9.2	8.6	8.2	7.5	6.1	5.7	7.7
	Min/Max	4.4/7.1	5.5/7.5	5.3/8.9	6.7/9.7	7.2/10.1	8.1/11.0	8.2/10.5	7.0/9.9	6.3/9.6	5.1/8.8	5.0/7.4	4.3/6.8	6.9/8.1

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	Average	3.9	4.0	3.9	4.2	4.2	5.1	4.8	4.5	4.4	4.5	3.9	3.8	4.3
Horiz Axis	Min/Max	2.5/5.0	3.1/4.7	2.2/5.2	2.8/5.3	3.1/5.4	3.8/6.4	4.0/6.1	3.4/5.5	3.0/5.6	2.6/5.7	2.9/5.1	2.4/4.8	3.6/4.7
1-Axis, N-S	Average	2.9	3.7	4.5	5.6	5.7	6.8	6.4	6.0	5.5	4.7	3.2	2.7	4.8
Horiz Axis	Min/Max	1.8/3.8	2.8/4.5	2.4/6.0	3.7/7.1	4.2/7.4	5.1/8.5	5.2/8.1	4.4/7.4	3.6/7.1	2.6/5.9	2.3/4.2	1.6/3.5	4.1/5.3
1-Axis, N-S	Average	4.3	4.9	5.3	5.8	5.6	6.4	6.1	6.1	6.2	5.8	4.5	4.1	5.4
Tilt=Latitude	Min/Max	2.7/5.5	3.8/5.8	2.8/7.0	3.9/7.4	4.1/7.2	4.8/8.1	4.9/7.8	4.5/7.5	4.0/7.9	3.3/7.3	3.3/5.9	2.5/5.2	4.5/5.9
2-Axis	Average	4.6	5.0	5.3	5.9	5.9	7.0	6.6	6.2	6.2	5.9	4.8	4.4	5.6
	Min/Max	2.9/5.9	3.8/6.0	2.8/7.0	3.9/7.5	4.3/7.6	5.2/8.7	5.3/8.3	4.6/7.7	4.0/7.9	3.3/7.4	3.5/6.2	2.8/5.7	4.7/6.2

Average Climatic Conditions

Element	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
Temperature (°C)	-1.8	0.0	2.9	8.0	13.0	18.3	21.6	20.2	15.8	9.9	3.2	-1.2	9.2
Daily Minimum Temp	-8.8	-7.1	-4.1	0.6	5.6	10.6	13.9	12.9	8.4	2.4	-3.9	-8.1	1.9
Daily Maximum Temp	5.2	7.0	10.0	15.4	20.4	26.1	29.1	27.4	23.1	17.5	10.4	5.7	16.4
Record Minimum Temp	-32.2	-32.8	-23.9	-19.4	-6.1	0.0	5.6	6.1	-5.6	-15.0	-22.2	-31.1	-32.8
Record Maximum Temp	22.2	24.4	27.2	28.3	33.9	37.8	37.8	37.2	34.4	30.0	25.6	25.0	37.8
HDD, Base 18.3°C	623	513	477	310	168	48	3	10	91	260	453	606	3564
CDD, Base 18.3°C	0	0	0	0	0	48	103	67	14	0	0	0	233
Relative Humidity (%)	51	50	50	46	49	48	50	54	51	46	50	51	50
Wind Speed (m/s)	4.1	4.3	4.7	5.1	4.8	4.3	4.0	3.8	4.1	4.2	4.2	4.0	4.3

The image on the previous page came from the NREL website identified on page 5. This figure was prepared by the National Renewable Energy Laboratory for the U.S. Department of Energy. The aforementioned selected image from NREL's website was authored by an employee of the Alliance for Sustainable Energy, LLC (Alliance) under Contract No.: DE-AC36-08GO28308 with the U.S. Department of Energy.

As shown in the table, the first two categories have solar radiation data for a collector that is tilted at each of the following angles from the horizontal:

i) 0^o (horizontal),

ii) the latitude – 15^o,

iii) equal to the latitude, and

iv) the latitude + 15^o.

The first category (fixed flat-plate facing south) also has data for a 90^o tilt angle, that is, a vertical configuration. Data is given for three different configurations for the concentrating collector category.

In the Average Climatic Conditions category, monthly and average values are given for several climate parameters that are detailed a few pages down in this course. At the top of the page the latitude, longitude, elevation, and mean pressure are given for the station.

Also at the top of each page the station type is shown to be either primary or secondary. Of the 239 stations in the data manual, 56 are primary stations, for which solar radiation was measured for some portion of the 30 year period of data collection. The other 136 secondary stations had no actual solar radiation measurement, and instead have modeled solar radiation data derived from meteorological data, as for example, cloud cover. All 239 stations are National Weather Service stations, for which meteorological data was collected for all of the 1961-1990 period. The map on the next page shows the 239 locations for which solar radiation is available in the NREL data manual. The primary stations are indicated with an asterisk and the secondary stations are shown with a dot on the map. The map image came from the NREL website identified on page

5. This figure was prepared by the National Renewable Energy Laboratory for the U.S. Department of Energy. The aforementioned selected image from NREL's website was authored by an employee of the Alliance for Sustainable Energy, LLC (Alliance) under Contract No.: DE-AC36-08GO28308 with the U.S. Department of Energy.

The next several sections after the map give information on "Interpreting the Data Tables," from pages 3, 4, and 5 of *Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors*.

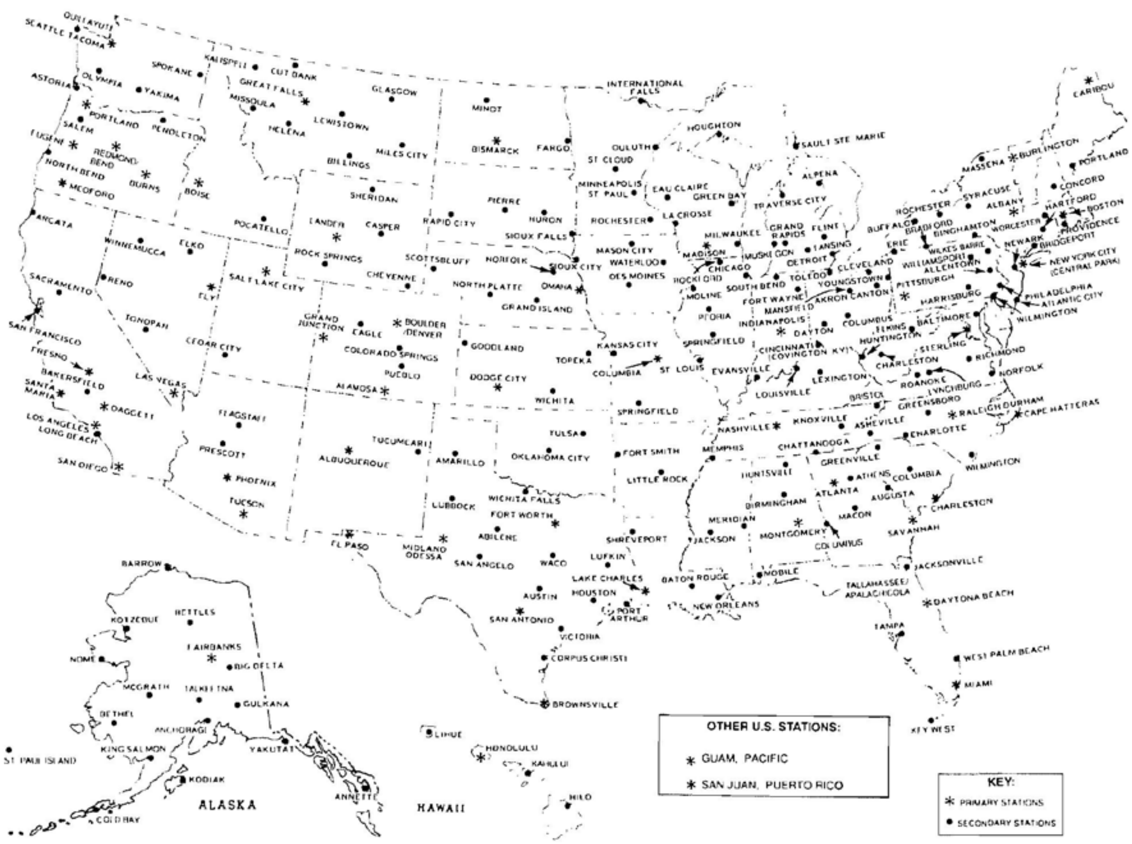


Figure 1. Map Showing the 239 NREL Data Stations

A. <u>Flat-Plate Collectors Facing South at Fixed Tilt:</u> There is a rationale for the five tilt angles mentioned above, for which solar radiation data are provided in this category. The data for a tilt angle of 0º is sometimes referred to as global horizontal solar radiation, show how much solar radiation will be incident upon a horizontal surface like a flat roof or a solar pond. A tilt angle that is approximately equal to the latitude of a site will receive the maximum yearly solar radiation. Maximum solar radiation during the winter months will be achieved by a collector that is tilted about 15º more than the latitude of the site. For optimum summer performance the collector tilt should be about 15º less than the site latitude. Data for a tilt of 90º give information about the solar radiation to a collector mounted vertically on a south-facing wall or to south-facing windows for passive solar heating. Figure 2 shows the orientation of a flat-plate collector facing south at a fixed tilt.

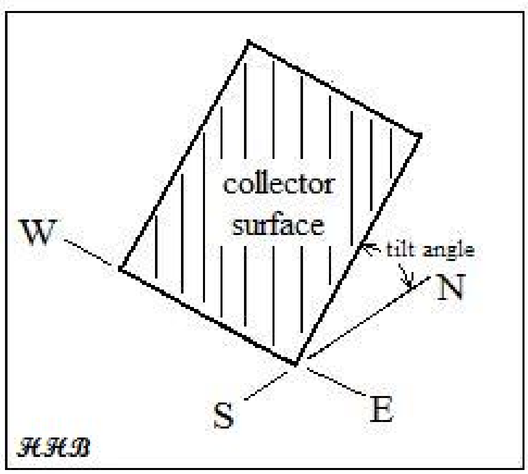


Figure 2. Fixed Tilt Flat-Plate Collector Facing South

B. <u>One-Axis Tracking Flat-Plate Collector with Axis Oriented North-South:</u> This type of tracking collector pivots on its single axis to track the sun. It will face east in the morning and move around to face west in the afternoon. A large collector may use an axis tilt angle of 0^o to minimize collector height and wind force. As another alternative the axis can be tilted up to increase the solar radiation on the collector. The same guidelines given above for a flat-plate, fixed tilt collector apply here. The annual, winter, or summer solar radiation can be maximized by the choice of tilt angle. The data presented in the manual are based on continuous tracking of the sun throughout the day. Figure 3 shows the general configuration of a one-axis tracking flat-plate collector with axis oriented north-south.

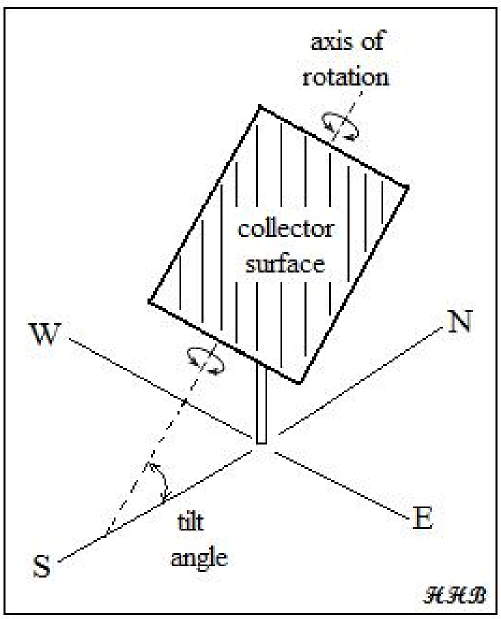


Figure 3. Single axis Tracking Flat-Plate Collector with North-South Axis

C. <u>Two-Axis Tracking Flat-Plate Collectors</u>: Two-axis tracking flat-plate collectors track the sun in both azimuth and elevation, thus keeping the sun's rays normal to the collector surface. Data for this type of collector give the maximum solar radiation rate available to a collector at a given site. Figure 4 shows the general configuration and orientation of a two-axis tracking flat-plate collector.

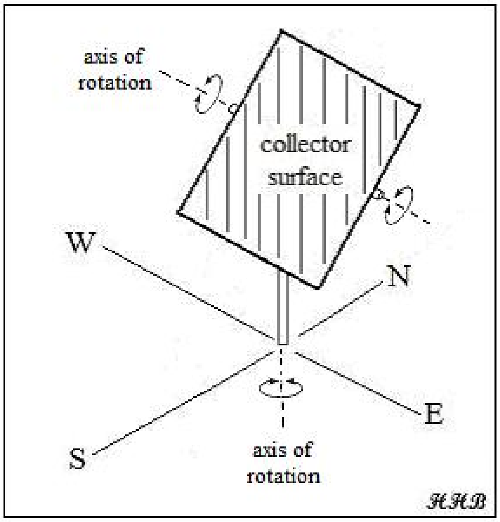


Figure 4. Two-Axis Tracking Flat-Plate Collector

D. <u>Concentrating Collectors:</u> The data for concentrating collectors consists of only the direct beam radiation (which comes in a direct line from the sun without being reflected, scattered or absorbed), because that is the only component of solar radiation that can be used by the parabolic trough concentrating collectors in this category. There are data for four types of concentrating collectors:

i) one-axis tracking parabolic troughs with a horizontal east-west axis,

ii) one-axis tracking parabolic trough with a horizontal north-south axis,

iii) one-axis concentrators with the axis oriented north-south and tilted from the horizontal at an angle equal to the latitude, and

iv) two-axis tracking concentrator systems.

Figure 5 shows a one-axis tracking parabolic trough with axis oriented east-west and Figure 6 shows a two axis tracking concentrator.

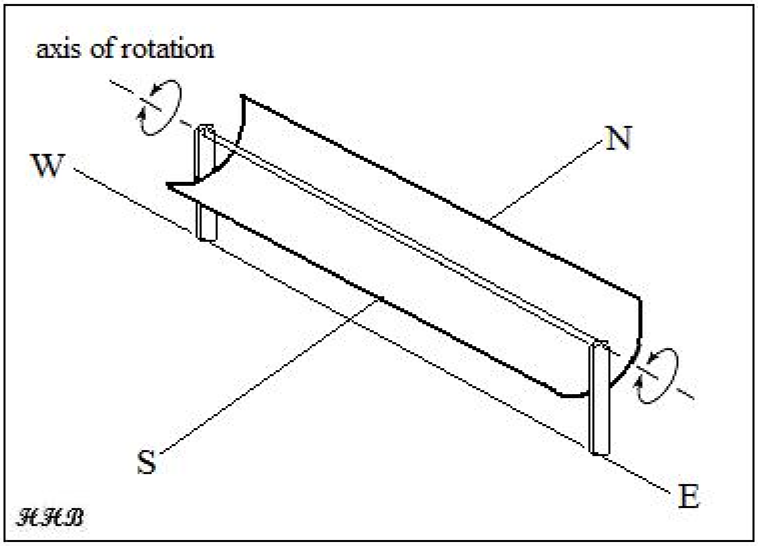


Figure 5. One-Axis Tracking Parabolic Trough with East-West Axis

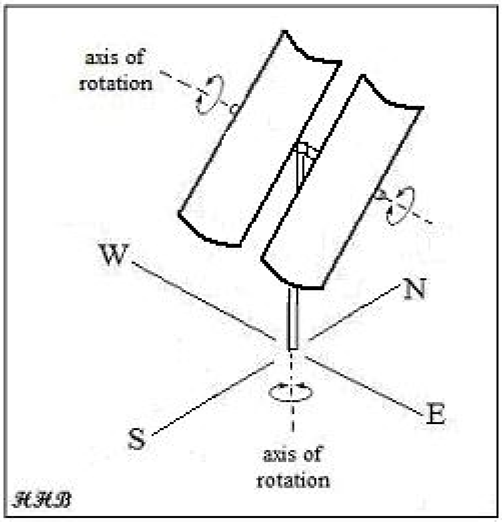


Figure 6. Two-Axis Tracking Concentrator

E. Solar Radiation Graph: There is a graph at the top of the data page for each station that is labeled, "Variability of Latitude Fixed-Tilt Radiation." This graph shows the variation in the solar radiation to a flat-plate collector with fixed tilt at the latitude of the site, by showing the data points for each of the 30 years (1961-1990) plotted for each month and for the yearly average for that type of collector. There is also a line showing the overall 1961-1990 average for each month and for the year.

F. Climatic Conditions: The last category on the page for each station lists monthly and annual values for each of the following parameters:

- Average temperature at the station in ^oC
- Average daily minimum temperature at the station in ^oC
- Average daily maximum temperature at the station in ^oC
- Record minimum temperature at the station in ^oC
- Record maximum temperature at the station in ^oC
- Average heating degree days (HDD) at the station below the base 18.3 ^oC
- Average cooling degree days (CDD) at the station above the base 18.3 ^oC
- Average relative humidity at the station in %
- Average wind speed at the station in m/s

Degree days give information about heating or cooling requirements for buildings. A degree day is defined as the difference between the average temperature for the day and a base temperature. As indicated in the list above, the difference is designated heating degree days if the average is less than the base temperature and it is designated as cooling degree days if the average for the day is greater than the base value.

G. <u>Unit Conversions:</u> The table below is based on information from the last page of *Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors.* It gives a variety of useful conversion factors for the type of data given for each of the stations.

Table 1. Unit Conversion Factors

Original Units	**Multiply By**	**Final Units**
kWhr/m^2	3.60	Mjoules/m^2
kWhr/m^2	317.2	Btu/ft^2
kWhr/m^2	86.04	Langleys
meters	3.281	feet
m/s	2.237	miles/hr
millibars	100.0	pascals
millibars	0.0009869	atmospheres
millibars	10.20	kg/m^2
millibars	0.0145	lb/in^2
degrees Centigrade	$^oC \times 1.8 + 32$	degrees Fahrenheit
degrees (angle)	0.017453	radians
degree days (base 18.3^{o}C)	1.8	degree days (base 65^{o}F)

Example #1: Using data from *Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors*, find:

a) the average rate of solar radiation to a fixed flat-plate collector tilted at 54^o from the horizontal in Colorado Springs, Colorado in January.

b) The average rate of solar radiation to a horizontal, 1-axis, tracking flat-plate collector for the same location and month.

Solution: The requested data is available on the page for Colorado Springs, CO, that is reproduced on page 7 of this course document. Note that the latitude of Colorado Springs is given as 38.82°N, so the specified 54° tilt angle is approximately the latitude + 15°. The results from the table on page 7 are:

a) Flat-Plate Collector with 54° Tilt Angle: **5.0 kWh/m²/day**

b) Horizontal, 1-Axis, Tracking Flat-Plate Collector: **4.0 kWh/m²/day**

Example #2: For the same Colorado Springs location and the month of January, find the following:

a) The average rate of solar radiation to a 1-axis, tracking flat-plate collector tilted at 54° from horizontal.

b) The average rate of solar radiation to a 2-axis, tracking flat-plate collector

Solution: From the same table on page 7, the results are as follows:

a) 1-Axis, Tracking Flat-Plate Collector with 54° Tilt Angle: **5.9 kWh/m²/day**

b) 2-Axis, Tracking Flat-Plate Collector: **5.9 kWh/m²/day**

Note that these two types of collectors receive the same rate of incident solar radiation in January.

5. Solar Radiation Data for Buildings

Another NREL publication is the *Solar Radiation Data Manual for Buildings,* available for downloading from http://rredc.nrel.gov/solar/pubs/bluebook/ . This manual is based on the same 239 stations and 1961-1990 data set that was described in the previous section for the NREL data manual for collectors. This manual provides data in a form that is useful in connection with passive solar heating of buildings. Data is provided for incident solar radiation and transmitted solar radiation for a horizontal window, and for vertical windows facing north, east, south or west. Climate data and illuninance data for a horizontal window and the same four vertical windows are also provided. Following is some information from pages 3, 4, and 5, of *Solar Radiation Data Manual for Buildings*, to assist in interpreting the data in that publication.

A. <u>Solar Radiation:</u> The tables in this publication provide solar radiation data in $Btu/ft^2/day$ for five surfaces, a horizontal window and vertical windows facing north, east, south or west. In the table headings, an estimate is given of the uncertainty (as $\pm$ %) of the solar radiation. The data for each station includes solar radiation incident on the outside of the windows and the solar radiation transmitted through the windows into the living space. More details follow.

B. <u>Incident Solar Radiation:</u> The incident solar radiation data for the five window configurations are given as i) global radiation, ii) clear-day global radiation, and iii) diffuse radiation.

Global radiation is all of the radiation that strikes the window. It is the sum of the direct beam radiation, sky radiation, and radiation reflected from the ground in front of the surface. Clear-day global radiation, as the name implies, is the global radiation that strikes the window surface when skies are clear.

The diffuse radiation data in the table are the sum of sky radiation and radiation reflected from the ground in front of the surface. It doesn't include direct beam radiation. The ground-reflected radiation in these tables was calculated using a ground reflectivity (also called albedo) of 0.2, which is a nominal value for green vegetation and some soil types. The diffuse and global radiation 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 from the data tables. I_{adj} can be calulcated from the following equation:

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

Where:

- ρ_d = desired albedo value

- I_h = monthly or yearly average for incident global horizontal radiation from data table

- 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 degree of variation in the solar radiation at each station. These variability quantities are for monthly and yearly values, not for single days.

Figure 6 shows the components included in the global solar radiation.

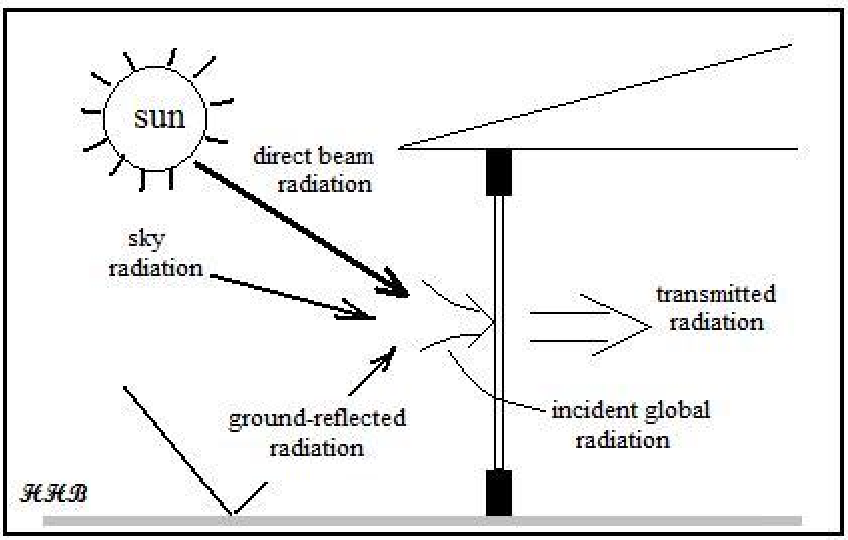


Figure 7. The Components of Global Solar Radiation

C. <u>Transmitted Solar Radiation:</u> Some of the solar radiation incident on a window is reflected off the glass and some of it is absorbed by the glass. Thus the solar radiation transmitted into the living space is less than the radiation striking the outside of the window. The data for transmitted solar radiation in the data manual are for windows with conventional, single-strength, clear, double glazing with a glass thickness of 0.125 inches (3.18 mm).

The tables in the data manual contain data for unshaded and for shaded windows. Unshaded values are for windows with no external shading to interfere with the incident solar radiation. Shaded values are for windows shaded by a roof overhang with the overhang/window geometry shown in a diagram at the top of each data page. Each shading diagram is specifically for the location of the station on that 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, as shown in Figure 8.

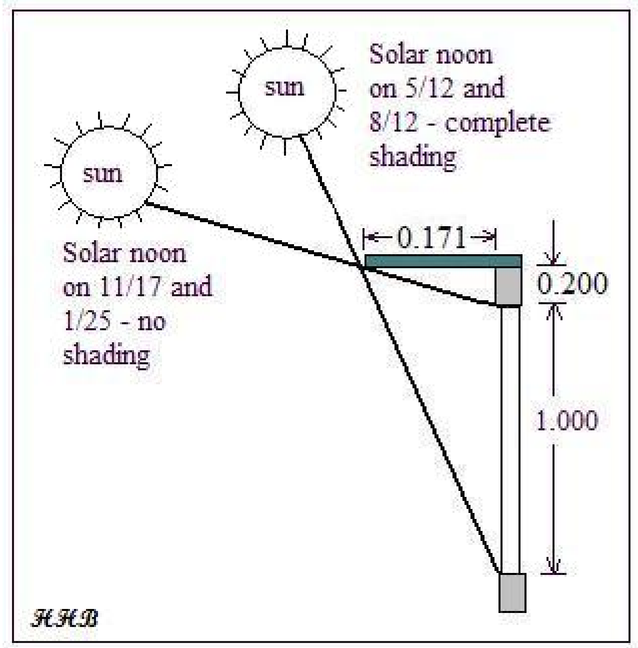


Figure 8. Shading Geometry and Sun Positions for 64º North Latitude

For south-facing windows, the geometry shown in Figure 8 balances the need for maximum heat gain during the heating season with the need to prevent unreasonable heat gain during the cooling season. The same shading geometry is used for all vertical windows for a station. The shading geometry isn't applicable for a horizontal surface, so the table doesn't include shaded transmitted solar radiation data for the horizontal surface.

The shading geometry is primarily a function of the station latitude, but consideration is also given to heating and cooling requirements. For example, Puerto Rico, Hawaii, and

Guam have no heating degee days. Thus their shady geometry provides complete shading at noon throughout the year for south-facing windows. Stations in Alaska, on the other hand, have no summer cooling load, so they have shading geometries that provide no shading at noon throughout the year for south-facing windows.

The shading geometries in the tables work well for south-facing windows. Roof overhangs aren't particularly effective in preventing unwanted heat gain for east- and west-facing windows. Some other strategy such as vertical louvers may be used.

D. Solar Radiation Graph: The graph at the top of each data page entitled, "Transmitted Solar Radiation for Double Glazing with External Shading," shows the variation monthly average transmitted solar radiation over the year, for each of the five window orientations.

E. Climatic Conditions: The monthly and annual climate data is very similar to that given in *Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors,* except for the units, as shown below:

- Average temperature at the station in °F
- Average daily minimum temperature at the station in °F
- Average daily maximum temperature at the station in °F
- Record minimum temperature at the station in °F
- Record maximum temperature at the station in °F
- Average heating degree days (HDD) at the station below the base 65 °F
- Average cooling degree days (CDD) at the station above the base 65 °F
- Average humidity ratio in lb water per lb dry air at the station
- Average wind speed in mph at the station
- Clearness Index, K_t at the station

The clearness index (K_t) is calculated as the global horizontal solar radiation at the station divided by its extraterrestrial horizontal radiation. Clouds decrease the amount of solar radiation reaching the earth, so stations in cloudy regions will have lower values of K_t than stations in regions with less clouds.

F. <u>Illuminance:</u> The illuminance tables show the average illuminance incident on five surfaces: a horizontal window and vertical windows facing north, east, south or west, in the form of diurnal profiles. The illuminance profiles are given only for, March, June, September, and December. At each of the following hours: 9 a.m., 11 a.m., 1 p.m., 3 p.m., and 5 p.m., there are two data values, separated by a slash. The value before the slash represents mostly clear conditions, which means total cloud cover of less than 50%). The value after the slash represents mostly cloudy conditions, which means total cloud cover equal to or greater than 50%.

The last line in the illuminance tables shows the percentage of time during the hour that the station location was mostly clear (M.Clr.). The average hourly illuminance can be calculated using the following equation:

Ave. illuminance = [(M.Clr.)*(illuminance for mostly clear conditions)

+ (100 – M.Clr.)*(illuminance for mostly cloudy conditons)]/100

The units for the illuminance data are kilolux-hours (klux-hr). The values given are the illuminance received during the preceding hour. The data for 11 a.m., for example is the incident illuminance from 10 a.m. to 11 a.m. The hours for March and December are local standard time. The hours represent local time for the months of March, June, September and December. For all stations this is local standard time for March and December. For most locations the hours are daylight savings time for June and September. For the few locations where daylight savings time is not observed, the times are local standard time for all four months. The table headings give an estimate of the uncertainty (+ or - %) of the illuminance data.

Example #3: a) Find the average rate at which solar radiation will strike a horizontal surface in Colorado Springs, CO, in January, from *Solar Radiation Data Manual for Buildings.*

b) Compare with the value of the solar radiation to a horizontal surface in Colorado Springs, CO, in January as obtained from *Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors.*

Solution: The Colorado Springs data page from the *Solar Radiation Data Manual for Buildings* is given on the next page. This figure was prepared by the National Renewable Energy Laboratory for the U.S. Department of Energy. The aforementioned selected image from NREL's website was authored by an employee of the Alliance for Sustainable Energy, LLC (Alliance) under Contract No.: DE-AC36-08GO28308 with the U.S. Department of Energy.

a) From that data page, the average global rate of solar radiation to a horizontal surface in January is: **800 Btu/ft^2/day**

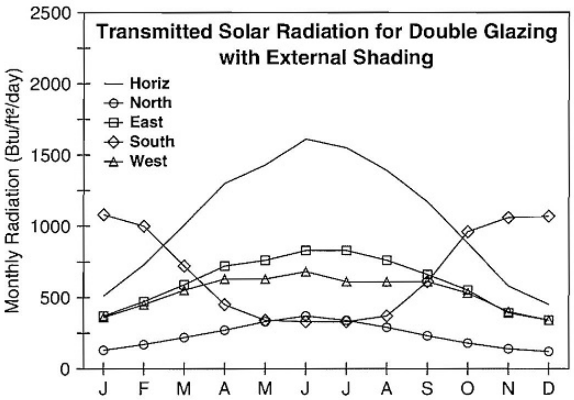
b) From the Colorado Springs data sheet on page 7 of this document (from *Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors*), the average solar radiation rate to a horizontal surface in January is 2.5 kWhr/m^2/day. From the unit conversion table on page 13, kWhr/m^2 x 317.2 = Btu/ft^2. Making the conversion:

$$(2.5 \text{ kWhr/m}^2\text{/day})(317.2) = 793 \text{ Btu/ft}^2\text{/day}$$

Thus the two data sources give essentially the same value for the total solar radiation to a horizontal surface in Colorado Springs, CO in January.

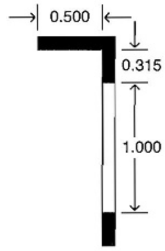
Example #4: a) From the *Solar Radiation Data Manual for Buildings*, find the average rate of diffuse solar radiation striking a vertical, south-facing window in Colorado Springs, CO in January, using the default value of 0.2 for ground reflectivity (albedo).

b) If the albedo is 0.30 instead of 0.2, what would be the value for the diffuse radiation striking that same window in January?



Colorado Springs, CO

WBAN NO. 93037



Shading Geometry (Not to Scale)

LATITUDE: 38.82° N
LONGITUDE: 104.72° W
ELEVATION: 6172 feet
MEAN PRESSURE: 11.8 psia

STATION TYPE: Secondary

From NREL Buildings Manual

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	800	1070	1420	1790	1960	2200	2110	1910	1630	1270	880	720	1480
	Std.Dev.	49	54	97	97	113	136	117	107	104	97	49	42	41
	Minimum	690	950	1170	1530	1740	1950	1930	1650	1360	1010	800	640	1410
	Maximum	890	1150	1610	2000	2210	2440	2350	2120	1820	1420	990	800	1550
	Diffuse	260	350	500	610	710	670	660	600	470	350	280	240	480
	Clear-Day Global	1010	1370	1870	2380	2680	2790	2710	2430	2000	1500	1080	900	1900
North	Global	200	260	350	440	560	640	590	470	360	280	220	180	380
	Diffuse	200	260	350	420	480	500	480	430	360	280	220	180	350
	Clear-Day Global	180	230	310	420	600	730	660	470	330	260	190	160	380
East	Global	580	740	940	1140	1220	1340	1340	1220	1050	860	620	530	970
	Diffuse	250	320	430	520	570	580	570	530	440	350	270	230	420
	Clear-Day Global	780	990	1250	1470	1580	1600	1560	1470	1290	1050	810	710	1210
South	Global	1450	1450	1300	1090	860	790	820	1000	1270	1510	1450	1430	1200
	Diffuse	360	420	490	530	540	520	520	520	480	420	370	330	460
	Clear-Day Global	2110	2120	1900	1440	1050	880	940	1230	1670	2010	2080	2060	1620
West	Global	580	710	870	1010	1030	1110	1000	990	960	840	630	530	860
	Diffuse	250	330	440	530	580	590	580	530	450	350	270	230	430
	Clear-Day Global	780	990	1250	1470	1580	1600	1560	1470	1290	1050	810	710	1210

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	510	730	1010	1300	1430	1610	1550	1390	1170	880	580	450	1050
North	Unshaded	140	180	240	300	360	410	380	310	250	200	150	130	250
	Shaded	130	170	220	270	330	370	340	290	230	180	140	120	230
East	Unshaded	400	520	670	820	870	960	970	880	750	610	430	360	690
	Shaded	370	470	590	720	760	830	830	760	660	550	390	340	610
South	Unshaded	1100	1070	900	700	520	460	480	620	850	1080	1090	1080	830
	Shaded	1080	1000	720	450	340	330	330	370	610	960	1060	1070	690
West	Unshaded	400	500	610	720	730	790	710	700	680	590	430	370	600
	Shaded	360	450	550	630	630	680	610	610	610	530	400	340	530

Average Climatic Conditions

Element	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
Temperature (°F)	28.8	32.0	37.3	46.4	55.4	65.0	70.8	68.3	60.4	49.9	37.8	29.8	48.5
Daily Minimum Temp	16.1	19.3	24.6	33.0	42.1	51.1	57.1	55.2	47.1	36.3	24.9	17.4	35.4
Daily Maximum Temp	41.4	44.6	50.0	59.8	68.7	79.0	84.4	81.3	73.6	63.5	50.7	42.2	61.6
Record Minimum Temp	-26.0	-27.0	-11.0	-3.0	21.0	32.0	42.0	43.0	22.0	5.0	-8.0	-24.0	-27.0
Record Maximum Temp	72.0	76.0	81.0	83.0	93.0	100.0	100.0	99.0	94.0	86.0	78.0	77.0	100.0
HDD, Base 65°F	1122	924	859	558	302	87	6	18	164	468	816	1091	6415
CDD, Base 65°F	0	0	0	0	0	87	186	120	26	0	0	0	419
Humidity Ratio (#w/#da)	0.0018	0.0020	0.0024	0.0033	0.0051	0.0070	0.0089	0.0089	0.0064	0.0038	0.0025	0.0019	0.0045
Wind Speed (mph)	9.2	9.6	10.6	11.3	10.8	9.7	8.9	8.5	9.2	9.5	9.4	8.9	9.6
Clearness Index, Kt	0.56	0.57	0.57	0.58	0.56	0.60	0.59	0.58	0.59	0.60	0.56	0.55	0.58

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	44/29	76/51	84/59	66/45	28/18	52/35	87/65	102/78	97/66	69/46	33/19	71/47	87/60	80/54	48/32	18/12	45/31	50/35	31/21	2/2
North	10/10	13/15	14/17	12/14	8/7	18/15	15/17	16/17	16/17	13/14	8/8	13/15	15/17	14/16	11/11	6/5	10/10	10/11	8/8	1/1
East	83/39	57/36	14/17	12/14	8/7	87/45	72/52	28/26	16/17	13/14	79/29	72/42	26/23	14/16	11/11	52/20	41/24	10/11	8/8	1/1
South	45/24	76/45	84/53	66/39	28/14	11/11	30/27	44/37	39/30	17/16	25/12	59/36	75/48	68/43	39/22	49/19	90/45	95/52	69/33	8/3
West	10/10	13/15	25/22	70/41	74/28	11/11	15/17	16/17	53/38	82/48	8/8	13/15	15/17	56/37	81/39	6/5	10/10	24/18	55/27	11/4
M. Clr (%hrs)	42	42	34	31	31	60	59	52	36	31	58	59	56	49	45	47	47	44	45	50

Solution: a) From the data sheet for Colorado Springs on the previous page, the average rate of diffuse solar radiation striking a vertical south-facing window in January is **360 Btu/ft^2/day**. Note that this value from the table is for the albedo = 0.2.

b) The calculation of diffuse radiation rate for a different value of albedo can be done as described on page 17 of this course document. Equation (1) is :

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

Substituting values into the equation: $I_{adj} = 0.5(0.3 - 0.2)800(1 - \cos 90^o) = 40$ Btu/ft^2/day

Note that I_h in the equation above is the average incident horizontal global radiation, which is 800 Btu/ft^2/day, from Example #3. Thus the corrected value for diffuse solar radiation striking a south-facing, vertical window is 360 + 40 = **400 Btu/ft^2/day**.

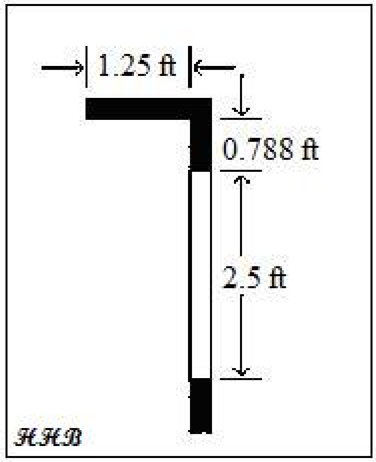
Example #5: Find the roof overhang dimensions (vertical distance of the top of the window below the overhang and the horizontal distance that the roof overhang extends beyond the wall) required so that a south-facing window, 30 inches tall, in Colorado Springs, CO, will have no shading at solar noon on 11/17 and 1/25 but will be completely shaded at solar noon on 5/12 and 8/2.

Solution: As shown in the shading geometry figure at the top of the Colorado Springs data sheet of the previous page, the distance of top of the window below the overhang should be 0.315 times the height of the window. Also, the horizontal distance of the overhang from the wall should be 0.500 times the window height. Thus, the required dimensions are:

Distance from top of window to overhang = 0.315*2.5 ft = **0.788 ft**

Horizontal distance that overhang extends beyond wall = 0.500*2.5 ft = **1.25 ft**

The solution is illustrated in the diagram below:



Example #6: Find the average percentage of incident global solar radiation that will be transmitted through a south-facing window in Colorado Springs, CO, in April, if overhang shading is provided as described on the Colorado Springs data page. Assume that the window has the standard window construction described on page 19 of this course document.

Solution: From the data tables for Colorado Springs on page 23 of this course document, the average global radiation incident on a south-facing window in Colorado Springs in April is 1090 $Btu/ft^2/day$. For the standard window construction, the average rate of solar radiation transmitted through the shaded window is 450 $Btu/ft^2/day$. The % transmitted is thus:

% transmitted = (450/1090)(100%) = **<u>42.3 %</u>**

Example #7: What will be the average daily amount of solar radiation (in Btu/day) transmitted through a shaded 24" by 24" south-facing window in Colorado Springs, CO, in January, assuming the standard window construction specified in the NREL *Solar Radiation Data Manual for Buildings.*

Solution: From the data sheet for Colorado Springs on page 23, the average rate of solar radiation transmitted through the south-facing window in January is 1080 Btu/sq ft/day. Since the area of the window is (2')(2') = 4 sq ft, the average daily amount transmitted through the window will be (1080 Btu/sq ft/day)(4 sq ft) = **<u>4320 Btu/day.</u>**

6. NASA Prediction of Worldwide Energy Resources Website

The NREL data manuals that have been discussed provide solar radiation data for the United States and its territories. The NASA Prediction of Worldwide Energy Resources Website gives access to a wide range of meteorology and solar energy parameters for locations all over the world. .Data for a site of interest can be accessed in two ways, either by clicking on the map location of interest on a world map, or by entering the latitude and longitude of the site.

This worldwide data set can be accessed from the website: https://power.larc.nasa.gov/ Alternative methods of accessing and viewing data from the website are available. A method will now be described here for obtaining solar radiation data similar to that available from the NREL data manuals.

A. Procedure for Data Retrieval

You can get started by clicking on “DATA ACCESS” in the menu along the top of the screen. This will take you down the page a bit and you should next scroll down a bit if necessary and click on the blue button with “POWER DATA ACCESS VIEWER” on it. If 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.

NOTE: For latitude entries, 0 to 90 degrees south latitude should be entered as a negative number and 0 to 90 degrees north latitude should be entered as a positive number. For longitude entries, 0 to 180 degrees east is positive and 0 to 180 degrees west is negative. Note that most places where you see latitude and/or longitude information, the latitude values are simply given as xx degrees N or xx degrees S and longitude values are simply given as xx degrees E or xx degrees W. For the NASA Langley website, however the indicated sign convention for latitude and longitude must be used in order to get the correct location, because there is no provision for entering N or S with the latitude value or E or W with the longitude value.

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 the output in an Excel spreadsheet.

6. Select Parameters - Double-clicking on "Tilted Solar Panels" at the bottom of the list will generate a drop-down list of options. In order to obtain solar irradiance values similar to those obtainable from the NREL manuals, select the first item, "Solar Irradiance for Equator Facing Tilted Surfaces (Set of Surfaces)"

7. Submit and Process - After appropriate selections have been made for the first six items as described above, you should click on the "Submit" button. This will result in a downloaded file, that you should open with Excel, in whatever manner you open downloaded files with your computer.

Note that the "RESOURCES" and "FAQ" tabs on the initial page of the NASA Power website provide additional information about the use of the site.

B. Examples of Data Retrieval

Example #8: a) Find the average rate of incident solar radiation on a horizontal flat-plate collector in Colorado Springs, Co, in November, based on the data from the NASA Power website.

b) Find the average rate of incident solar radiation on a flat-plate collector with a latitude tilt from the horizontal in Colorado Springs, CO, in November, from the same source.

c) Find values for the same two parameters from the NREL, *Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors.*

Solution: The table below shows some of the values from a CSV (Excel) file obtained as described above for Colorado Springs, CO (Latitude: 38.8, Longitude: -104.72) for "Solar Irradiance for Equator Facing Tilted Surfaces (Set of Surfaces)".

Data for Colorado Springs, CO

Elevation: 2070 meters (Ave. for ½ x ½ degree latitude/longitude region)

Solar Irradiance for Equator Facing Tilted Surfaces (Set of Surfaces):

Monthly Averaged Insolation Incident On a Horizontal Surface (kWh/m^2/day)

Lat 38.82 Long -104.72	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann Ave
30-year Ave	2.6	3.26	4.59	5.58	6.38	6.96	6.47	5.75	5.16	4.06	2.85	2.35	4.67

Monthly Averaged Insolation Incident On a Latitude Tilt Surface (kWh/m^2/day)

Lat 38.82 Long -104.72	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann Ave
30-year Ave	4.55	4.73	5.62	5.73	5.84	6.09	5.78	5.61	5.95	5.73	4.74	4.37	5.4

a) From the top part of the table above for Colorado Springs, CO, the average rate of solar radiation on a flat-plate collector in November is: **2.85 kWhr/m^2/day**.

b) From the bottom part of the table, the average rate of solar radiation on a flat plate collector with latitude tilt from the horizontal in November is: **4.74 kWhr/m²/day**

c) From the NREL data manual (on page 8 of this course material):

average radiation rate on a horizonal flat plate collector in Nov = **2.8 kWhr/m²/day**

average radiation rate on a latitude tilt flat plate collector in Nov = **4.8 kWhr/m²/day**

Note that the values from these two sources agree quite well, although the time periods for the two databases are different.

Example #9: Find the average rate at which solar radiation would strike a horizontal flat-plate collector and the average rate at which solar radiation would strike a latitude tilt flat plate collector in Melbourne, Australia, in November, using the NASA Power website.

Solution: The latitude and longitude of Melbourne, Australia were found by a Google search to be: latitude = 37° , 50' South and longitude = 145° , 0' East. Converting to decimal format, they are: latitude = 37.833° South and longitude = 145.0° East. Using the sign convention used on the NASA Langley website, the entries for Melbourne, AU are: Latitude = - 37.833 and Longitude = 145.0. Entering these values leads to tables with the data shown below for Melbourne, Australia. From that data table:

Ave. radiation rate on a horiz, flat plate collector in Nov. = **5.74 kWhr/m²/day**

Ave. radiation rate on a latitude tilt flat plate collector in Nov. = **5.27 kWhr/m²/day**

Data for Melbourne, Australia

Elevation: 675 meters (Ave. for ½ x ½ degree latitude/longitude region)

Solar Irradiance for Equator Facing Tilted Surfaces (Set of Surfaces):

Monthly Averaged Insolation Incident On a Horizontal Surface (kWh/m²/day)

Lat -37.83 Long 145.0	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann Ave
30-year Ave	6.35	5.58	4.51	3.24	2.22	1.78	1.93	2.59	3.58	4.75	5.74	6.23	4.04

Monthly Averaged Insolation Incident On a Latitude Tilt Surface (kWh/m²/day)

Lat -37.83 Long 145.0	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann Ave
30-year Ave	5.71	5.45	5.01	4.21	3.32	2.87	2.98	3.48	4.12	4.81	5.27	5.5	4.39

C. Other Parameters to Choose from for Output

Following are the other parameters available in the Climatology category.

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 0ºC, 10ºC & 18.3ºC
- Heating Degree Days below 0ºC, 10ºC & 18.3ºC
- 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 Sizing and Pointing of Solar Panels and for Solar Thermal Applications

- Direct Normal Radiation
- Normalized clear sky insolation clearness index
- Normalized insolation clearness index
- Max. & Min monthly difference from Monthly Averaged All Sky Insolation
- Max. & Min difference from Monthly Averaged Direct Normal Radiation
- Diffuse radiation on horizontal surface (Average, Min, Max)

- All Sky Insolation Incident 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 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

Parameters for Tilted Solar Panels

- Solar Irradiance for Equator Facing Tilted Surfaces (Set of Surfaces)
- 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

You may have noticed that there are many parameters for you to choose from. You can click on the parameter or parameters for which you want values and then click “Submit” at the bottom of the list.

This will take you to tables with the data that you requested. The table below shows data for a couple of parameters for Colorado Springs, CO. This table was obtained by entering the latitude of 38.82 and the longitude of –104.72 (values obtained from the NREL *Solar Radiation Data Manual for Buildings.*)

7. 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.

8. References

1**.** *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

2. *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.)
http://www.nrel.gov/docs/legosti/old/7904.pdf

3. *Shining On* (Provides a primer on solar radiation and solar radiation data.)
http://rredc.nrel.gov/solar/pubs/shining/

4. NASA Prediction of Worldwide Energy Resources (Provides solar and meteorological data sets from NASA research for support of renewable energy, building energy efficiency, and agricultural needs.) https://power.larc.nasa.gov/

5. Bengtson, H.H., Estimating Solar Radiation Rate to the Tilted Surface of a Solar Panel in the U.S., an online article at www.brighthub.com.

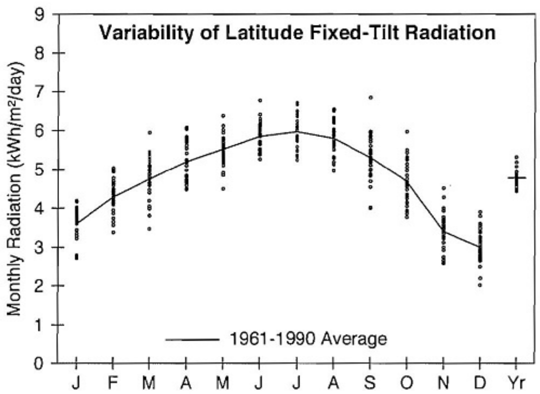
6. Bengtson, H.H., Solar Insolation Data for Passive Solar Heating at Your Location in the U.S., an online article at www.brighthub.com.

9. Appendix

The data sheet for Des Moines, IA on page 35 is from the *Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors.* This figure was prepared by the National Renewable Energy Laboratory for the U.S. Department of Energy. The aforementioned selected image from NREL's website was authored by an employee of the Alliance for Sustainable Energy, LLC (Alliance) under Contract No.: DE-AC36-08GO28308 with the U.S. Department of Energy.

The data sheet for Des Moines, IA on page 36 is from the *Solar Radiation Data Manual for Buildings*. This figure was prepared by the National Renewable Energy Laboratory for the U.S. Department of Energy. The aforementioned selected image from NREL's website was authored by an employee of the Alliance for Sustainable Energy, LLC (Alliance) under Contract No.: DE-AC36-08GO28308 with the U.S. Department of Energy.

Page 37 contains data for Des Moines, Iowa from the NASA Power website. Data from pages 35-37 will be needed for quiz questions.



Des Moines, IA

WBAN NO. 14933

From NREL Data Manual

LATITUDE: 41.53° N
LONGITUDE: 93.65° W
ELEVATION: 294 meters
MEAN PRESSURE: 982 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	2.0	2.8	3.8	4.9	5.8	6.5	6.5	5.7	4.4	3.2	2.1	1.7	4.1
	Min/Max	1.7/2.2	2.5/3.2	3.0/4.4	4.3/5.6	4.8/6.7	5.8/7.5	5.8/7.3	4.9/6.3	3.6/5.5	2.8/3.9	1.7/2.4	1.4/2.0	3.9/4.5
Latitude -15	Average	3.2	3.9	4.6	5.3	5.9	6.4	6.5	6.0	5.2	4.4	3.1	2.6	4.8
	Min/Max	2.4/3.6	3.2/4.6	3.4/5.7	4.6/6.2	4.8/6.8	5.7/7.4	5.7/7.3	5.2/6.8	4.0/6.7	3.6/5.5	2.4/4.0	1.9/3.3	4.4/5.3
Latitude	Average	3.6	4.3	4.7	5.2	5.5	5.8	6.0	5.8	5.3	4.7	3.4	3.0	4.8
	Min/Max	2.7/4.2	3.4/5.0	3.5/5.9	4.5/6.1	4.5/6.4	5.3/6.8	5.2/6.7	5.0/6.5	4.0/6.8	3.8/6.0	2.6/4.5	2.0/3.9	4.4/5.3
Latitude +15	Average	3.9	4.4	4.7	4.8	4.9	5.1	5.2	5.3	5.1	4.7	3.6	3.2	4.6
	Min/Max	2.8/4.6	3.5/5.2	3.3/5.9	4.1/5.6	4.0/5.6	4.6/5.8	4.6/5.8	4.5/5.9	3.8/6.6	3.8/6.1	2.6/4.8	2.1/4.3	4.2/5.1
90	Average	3.7	4.0	3.6	3.2	2.8	2.7	2.8	3.2	3.6	3.9	3.2	3.1	3.3
	Min/Max	2.6/4.4	3.0/4.8	2.5/4.5	2.7/3.6	2.4/3.1	2.5/2.9	2.5/3.0	2.8/3.6	2.7/4.7	3.0/5.1	2.4/4.4	1.9/4.2	3.0/3.6

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	3.0	4.0	5.1	6.5	7.6	8.6	8.6	7.7	6.2	4.7	2.9	2.4	5.6
	Min/Max	2.2/3.4	3.1/4.8	3.7/6.5	5.4/7.8	6.0/9.1	7.2/10.3	7.3/10.1	6.4/8.8	4.5/8.3	3.7/6.1	2.3/3.9	1.7/3.1	5.2/6.4
Latitude -15	Average	3.8	4.9	5.8	6.9	7.7	8.6	8.7	8.0	6.8	5.5	3.7	3.1	6.1
	Min/Max	2.8/4.5	3.7/5.9	4.1/7.4	5.7/8.3	6.0/9.4	7.2/10.3	7.4/10.2	6.7/9.2	4.9/9.2	4.3/7.2	2.7/5.0	2.0/4.1	5.6/7.0
Latitude	Average	4.2	5.2	5.9	6.8	7.5	8.2	8.4	7.9	6.8	5.8	4.0	3.4	6.2
	Min/Max	3.0/5.0	3.9/6.3	4.1/7.7	5.6/8.3	5.8/9.1	6.9/9.9	7.1/9.9	6.5/9.1	4.8/9.3	4.4/7.6	2.9/5.4	2.2/4.6	5.7/7.1
Latitude +15	Average	4.4	5.3	5.8	6.5	7.1	7.7	7.9	7.5	6.7	5.8	4.1	3.6	6.0
	Min/Max	3.1/5.3	3.9/6.4	4.0/7.6	5.3/7.9	5.5/8.6	6.4/9.3	6.7/9.3	6.2/8.6	4.7/9.1	4.4/7.7	2.9/5.6	2.3/4.9	5.5/6.9

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

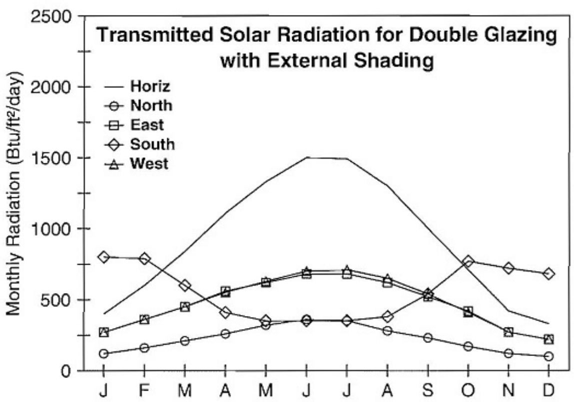
Tracker		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
2-Axis	Average	4.5	5.3	5.9	6.9	7.8	8.8	8.9	8.1	6.9	5.8	4.1	3.7	6.4
	Min/Max	3.1/5.3	3.9/6.4	4.1/7.7	5.7/8.4	6.1/9.5	7.3/10.6	7.5/10.4	6.7/9.3	4.9/9.3	4.5/7.7	3.0/5.7	2.3/4.9	5.9/7.3

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	Average	2.6	2.8	2.8	3.1	3.6	4.2	4.3	3.9	3.4	3.2	2.4	2.1	3.2
Horiz Axis	Min/Max	1.4/3.3	1.7/3.8	1.6/4.4	2.2/4.4	2.2/5.0	3.0/5.9	3.2/5.5	2.8/4.8	1.9/5.4	2.3/4.7	1.2/3.6	1.0/3.0	2.7/4.0
1-Axis, N-S	Average	1.8	2.4	3.1	4.0	4.7	5.6	5.7	5.1	4.1	3.2	1.8	1.4	3.6
Horiz Axis	Min/Max	1.0/2.3	1.5/3.4	1.7/4.8	2.9/5.7	3.0/6.6	3.8/7.7	4.2/7.4	3.7/6.4	2.3/6.5	2.2/4.7	0.9/2.8	0.6/2.0	3.1/4.5
1-Axis, N-S	Average	2.8	3.3	3.7	4.3	4.7	5.3	5.5	5.3	4.7	4.1	2.7	2.2	4.0
Tilt=Latitude	Min/Max	1.5/3.5	2.0/4.6	2.1/5.8	3.1/6.0	3.0/6.5	3.6/7.3	4.1/7.1	3.8/6.6	2.6/7.4	2.8/6.0	1.3/4.1	1.0/3.2	3.5/5.1
2-Axis	Average	3.0	3.4	3.7	4.4	4.9	5.7	5.9	5.4	4.7	4.1	2.8	2.4	4.2
	Min/Max	1.6/3.8	2.1/4.7	2.1/5.8	3.2/6.1	3.2/6.8	3.9/7.9	4.3/7.6	3.9/6.8	2.6/7.4	2.9/6.0	1.4/4.3	1.1/3.5	3.6/5.3

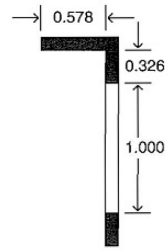
Average Climatic Conditions

Element	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
Temperature (°C)	-7.0	-4.1	2.9	10.5	16.8	22.1	24.8	23.3	18.4	11.9	3.9	-4.2	9.9
Daily Minimum Temp	-11.8	-9.1	-2.4	4.4	10.8	16.2	19.2	17.6	12.5	5.9	-1.2	-8.8	4.4
Daily Maximum Temp	-2.2	0.9	8.3	16.6	22.8	27.9	30.4	29.0	24.2	17.9	8.9	0.3	15.4
Record Minimum Temp	-31.1	-28.9	-30.0	-12.8	-1.1	3.3	8.3	4.4	-3.3	-10.0	-20.0	-30.0	-31.1
Record Maximum Temp	18.3	22.8	32.8	33.9	36.7	39.4	40.6	42.2	38.3	35.0	24.4	20.6	42.2
HDD, Base 18.3°C	786	627	477	238	92	6	0	6	39	207	433	699	3609
CDD, Base 18.3°C	0	0	0	3	45	119	200	159	41	8	0	0	576
Relative Humidity (%)	71	71	68	63	63	65	68	70	71	67	71	75	68
Wind Speed (m/s)	5.1	5.0	5.5	5.5	4.8	4.4	3.9	3.8	4.1	4.4	4.8	4.9	4.7



Des Moines, IA

WBAN NO. 14933



Shading Geometry
(Not to Scale)

LATITUDE: 41.53° N
LONGITUDE: 93.65° W
ELEVATION: 965 feet
MEAN PRESSURE: 14.2 psia

STATION TYPE: Secondary

From NREL Buildings Manual

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	630	890	1200	1550	1840	2060	2050	1790	1410	1030	650	520	1300
	Std.Dev.	45	60	97	121	122	122	132	112	122	90	55	43	40
	Minimum	530	770	950	1350	1510	1850	1820	1550	1140	880	550	430	1230
	Maximum	700	1010	1410	1770	2110	2390	2300	2000	1730	1230	780	620	1430
	Diffuse	300	420	560	680	790	800	770	670	550	400	310	270	550
	Clear-Day Global	850	1200	1690	2190	2520	2640	2550	2260	1810	1300	900	740	1720
North	Global	190	260	350	440	550	630	600	480	370	270	200	170	380
	Diffuse	190	260	350	420	500	530	510	450	360	270	200	170	350
	Clear-Day Global	170	230	320	420	580	690	630	470	340	250	180	150	370
East	Global	440	590	740	920	1050	1140	1150	1040	860	680	440	370	790
	Diffuse	240	330	420	510	590	630	620	550	450	340	240	210	430
	Clear-Day Global	660	870	1130	1350	1470	1500	1460	1360	1170	910	690	590	1100
South	Global	1090	1160	1100	990	880	840	890	1020	1150	1230	1010	930	1020
	Diffuse	350	430	490	530	570	580	570	550	500	420	340	310	470
	Clear-Day Global	1910	1990	1840	1470	1140	990	1040	1300	1660	1870	1870	1820	1570
West	Global	450	580	740	920	1060	1170	1180	1070	890	670	450	370	800
	Diffuse	240	330	420	520	600	640	630	560	460	340	250	210	430
	Clear-Day Global	660	870	1130	1350	1470	1500	1460	1360	1170	910	690	590	1100

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	400	600	840	1110	1330	1500	1490	1300	1000	710	420	330	920
North	Unshaded	130	180	240	300	360	410	390	320	250	190	140	120	250
	Shaded	120	160	210	260	320	360	350	280	230	170	120	100	220
East	Unshaded	300	420	530	650	740	810	820	740	610	480	310	250	560
	Shaded	270	360	450	560	620	680	680	620	520	420	270	220	470
South	Unshaded	820	860	770	650	550	510	540	650	780	890	750	700	710
	Shaded	800	790	600	410	350	350	350	380	540	770	720	680	560
West	Unshaded	310	410	520	650	750	840	850	770	630	470	310	250	560
	Shaded	270	360	450	550	630	700	710	650	540	410	270	220	480

Average Climatic Conditions

Element	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
Temperature (°F)	19.4	24.7	37.3	50.9	62.3	71.8	76.6	73.9	65.1	53.5	39.0	24.4	49.9
Daily Minimum Temp	10.7	15.6	27.6	40.0	51.5	61.2	66.5	63.6	54.5	42.7	29.9	16.1	40.0
Daily Maximum Temp	28.1	33.7	46.9	61.8	73.0	82.2	86.7	84.2	75.6	64.3	48.0	32.6	59.8
Record Minimum Temp	-24.0	-20.0	-22.0	9.0	30.0	38.0	47.0	40.0	26.0	14.0	-4.0	-22.0	-24.0
Record Maximum Temp	65.0	73.0	91.0	93.0	98.0	103.0	105.0	108.0	101.0	95.0	76.0	69.0	108.0
HDD, Base 65°F	1414	1128	859	428	165	10	0	11	71	372	780	1259	6497
CDD, Base 65°F	0	0	0	5	81	214	360	287	74	15	0	0	1036
Humidity Ratio (#w/#da)	0.0018	0.0022	0.0033	0.0052	0.0078	0.0111	0.0134	0.0126	0.0096	0.0060	0.0038	0.0023	0.0066
Wind Speed (mph)	11.5	11.1	12.4	12.4	10.8	9.9	8.8	8.5	9.2	9.9	10.8	10.9	10.5
Clearness Index, Kt	0.49	0.51	0.50	0.51	0.53	0.56	0.57	0.56	0.53	0.52	0.46	0.45	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	67/43	79/50	65/40	29/18	44/30	81/55	100/71	96/72	72/52	24/13	62/38	83/51	78/51	50/32	10/6	36/22	44/27	29/18	3/2
North	9/8	13/15	14/17	13/14	8/8	19/14	16/17	17/19	17/19	15/16	7/6	13/14	15/17	15/16	12/12	4/3	9/9	10/11	8/8	2/1
East	72/24	60/32	14/17	13/14	8/8	77/38	75/46	36/30	17/19	15/16	61/18	72/34	33/24	15/16	12/12	33/8	40/17	10/11	8/8	2/1
South	36/15	73/36	86/44	71/33	32/14	11/11	32/25	49/37	46/37	25/21	18/8	56/28	77/41	72/41	43/23	28/7	77/26	89/32	66/22	8/3
West	9/8	13/15	17/18	63/31	68/25	11/11	16/17	17/19	47/38	78/50	7/6	13/14	15/17	49/31	75/35	4/3	9/9	17/12	47/17	11/3
M. Clr (%hrs)	32	30	28	28	30	40	40	35	35	39	46	44	44	45	46	33	31	30	30	31

(From NASA Power Website)

Data for Des Moines, Iowa

Elevation: 301.5 meters (Ave. for ½ x ½ degree latitude/longitude region)

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

Monthly Averaged Insolation Incident On a Horizontal Surface (kWh/m^2/day)

Lat 41.53 Long -93.85	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann Ave
22-year Ave	1.91	2.45	3.62	4.55	5.39	6.11	6.05	5.33	4.41	3.15	2.02	1.64	3.89

Monthly Averaged Diffuse Radiation Incident On a Horizontal surface (kWh/m^2/day)

Lat 41.53 Long -93.85	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann Ave
22-year Ave	0.74	1.05	1.49	1.96	2.30	2.40	2.28	1.99	1.54	1.14	0.82	0.66	1.53
Minimum	0.68	0.94	1.29	1.80	2.09	2.08	2.09	1.85	1.30	0.94	0.66	0.60	1.36
Maximum	0.76	1.07	1.51	1.99	2.29	2.51	2.43	2.12	1.68	1.22	0.80	0.68	1.59

Monthly Averaged Cooling Degree Days Above 18.3 °C

Lat 41.53 Long -93.85	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann Ave
22-year Ave	0	0	0.27	3.66	24.9	102.5	178	149	55.6	5.64	0.01	0	519.2