Chapter 2

Solar Radiation


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Overview

- Defining basic terminology associated with solar radiation, including solar irradiance (power), solar irradiation (energy) and peak sun hours.

- Identifying the instruments used for measuring solar radiation.

- Understanding the effects of the earth’s movements and atmospheric conditions on the solar energy received on the earth’s surface.

- Locating the sun’s position using sun path diagrams and defining the solar window.

- Accessing solar radiation data resources and quantifying the effects of collector orientation on the amount of solar energy received.
Sun - Earth Relationships

Sun:
- Diameter: 865,000 miles (1,392,000 km, 109 times earth)
- Mass: $2 \times 10^{30}$ kg (330,000 times earth)
- Density: 1.41 g/cm$^3$
- Gravity: 274 m/s$^2$ (28 g)
- Surface Temperature: 10,000 F (5800 K)

Earth:
- Diameter: 7,930 miles (12,756 km)
- Mass: $5.97 \times 10^{24}$ kg
- Density: 5.52 kg/cm$^3$
- Gravity: 9.81 m/s$^2$ (1 g)
- Typical Surface Temperature: 68 F (300K)
- Earth’s Orbit Around Sun: 1 year
- Earth’s Rotation about its Polar Axis: 1 day

93 million miles, average ($1.5 \times 10^8$ km)
1 Astronomical Unit
(Distance traveled in 8.31 minutes at the Speed of Light)
Solar radiation is electromagnetic radiation ranging from about 0.25 to 4.5 μm in wavelength, including the near ultraviolet (UV), visible light, and near infrared (IR) radiation.

Common units of measure for electromagnetic radiation wavelengths:

1 Angstrom (Å) = 10^{-10} meter (m)
1 nanometer (nm) = 10^{-9} meter
1 micrometer (μm) = 10^{-6} meter
1 millimeter (mm) = 10^{-3} meter
1 kilometer (km) = 1000 meters

NASA
Electromagnetic Spectrum

- Gamma rays
- X-rays
- Ultraviolet Radiation
- Visible Light
- Infrared Radiation
- Microwaves
- Short Radio Waves (FM/TV)
- AM Radio
- Long Radio Waves

Wavelength (µm):
- 0.25 µm
- 4.5 µm
- 0.3
- 0.5
- 0.7

Solar spectrum:
- Visible light
- Near ultra-violet
- Near infra-red
- **Solar irradiance** is the sun's radiant power, represented in units of W/m² or kW/m².

- The Solar Constant is the average value of solar irradiance outside the earth’s atmosphere, about 1366 W/m².

- Typical peak value is 1000 W/m² on a terrestrial surface facing the sun on a clear day around solar noon at sea level, and used as a rating condition for PV modules and arrays.

    ![Diagram](Diagram.png)

    One Square Meter

    Typical peak value per m²

    1000 watts = 1 kilowatt
For south-facing fixed surfaces, solar power varies over the day, peaking at solar noon.
Solar irradiation is the sun’s radiant energy incident on a surface of unit area, expressed in units of kWh/m².

- Typically expressed on an average daily basis for a given month.
- Also referred to as solar insolation or peak sun hours.

Solar irradiation (energy) is equal to the average solar irradiance (power) multiplied by time.

Peak sun hours (PSH) is the average daily amount of solar energy received on a surface. PSH are equivalent to:

- The number of hours that the solar irradiance would be at a peak level of 1 kW/m².
- Also the equivalent number of hours per day that a PV array will operate at peak rated output levels at rated temperature.
Solar Power and Solar Energy

Solar irradiation (energy) is the area under the solar irradiance (power) curve.
Peak Sun Hours

Time of Day (hrs)

Solar Irradiance (W/m²)

1000 W/m²

Area of box equals area under curve

Peak Sun Hours

Solar Insolation

Solar Irradiance

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Solar Radiation: 2 - 10
The solar power incident on a surface averages 400 W/m² for 12 hours. How much solar energy is received?
- 400 W/m² x 12 hours = 4800 Wh/m² = 4.8 kWh/m² = 4.8 PSH

The amount of solar energy collected on a surface over 8 hours is 4 kWh/m². What is the average solar power received over this period?
- 4 kWh/m² / 8 hours = 0.5 kW/m² = 500 W/m²

A PV system produces 6 kW AC output at peak sun and average operating temperatures. How much energy is produced from this system per day if the solar energy received on the array averages 4.5 peak sun hours?
- 6 kW x 4.5 hours/day = 27 kWh/day
Atmospheric Effects

- Approximately 30% of extraterrestrial solar power is absorbed or reflected by the atmosphere before reaching the earth’s surface.
  - Effects vary significantly with altitude, latitude, time of day and year, air pollutants, weather patterns and wavelength of solar radiation.

- Direct beam (normal) radiation is the component of total global solar radiation incident on a surface normal to the sun’s rays, that travels in parallel lines directly from the sun.

- Diffuse radiation is the component of the total global solar radiation incident on a surface that is scattered or reflected.
  - May also include ground reflected radiation (albedo).

- Total global solar radiation is comprised of the direct, diffuse and reflected components (albedo).
Atmospheric Effects

Parallel rays from sun

Solar Constant = 1366 W/m²

Reflection

Outer Limits of Atmosphere

Atmospheric Absorption, Scattering and Reflections

Diffuse Radiation

Direct Radiation

Reflected (Albedo) Radiation

Cloud Reflections

Diffuse Radiation

Earth’s Surface

TOTAL GLOBAL SOLAR RADIATION - DIRECT + DIFFUSE
Air mass is calculated by the following:

\[ AM = \frac{1}{\cos \theta_z} \left[ \frac{P}{P_o} \right] \]

where
- \( AM \) = air mass
- \( \theta_z \) = zenith angle (deg)
- \( P \) = local pressure (Pa)
- \( P_o \) = sea level pressure (Pa)
Measuring Zenith and Altitude Angles

Zenith Angle:

\[ \tan \theta_z = \frac{\text{Length of shadow (l)}}{\text{Height of ruler (h)}} \]

\[ \theta_z = \arctan \left( \frac{l}{h} \right) \]

Altitude Angle:

\[ \tan \alpha = \frac{\text{Height of ruler (h)}}{\text{Length of shadow (l)}} \]

\[ \alpha = \arctan \left( \frac{h}{l} \right) \]
U.S. Solar Radiation Data

**Average Daily Solar Radiation Per Month**

**JUNE**

**Collector Orientation**

Flat plate collector facing south at an angle equal to the latitude of the site. Capturing the maximum amount of solar radiation throughout the year can be achieved using a tilt angle approximately equal to the site’s latitude.

**kWh/m²/day**

- 10 to 14
- 8 to 10
- 7 to 8
- 6 to 7
- 5 to 6
- 4 to 5
- 3 to 4
- 2 to 3
- 0 to 2
- none

*Flat Plate Tilted South at Latitude*

Maps of average values are produced by averaging all 30 years of data for each site. Maps of maximum and minimum values are composite of specific months and years for which each site achieved its maximum or minimum amounts of solar radiation.

Though useful for identifying general trends, this map should be used with caution for site-specific resource evaluations because variations in solar radiation not reflected in the maps can exist, introducing uncertainty into resource estimates.

Maps are not drawn to scale.

NREL

National Renewable Energy Laboratory Resource Assessment Program

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U.S. Solar Radiation Data

Average Daily Solar Radiation Per Month

DECEMBER

Collector Orientation

Flat plate collector facing south at an angle equal to the latitude of the site. Capturing the maximum amount of solar radiation throughout the year can be achieved using a tilt angle approximately equal to the site's latitude.

Maps of average values are produced by averaging all 30 years of data for each site. Maps of minimum and maximum values are comprised of specific months and years for which each site achieved its minimum or maximum amount of solar radiation.

Though useful for identifying general trends, this map should be used with caution for site-specific resource evaluations because variations in solar radiation not reflected in the maps can exist, introducing uncertainty into resource estimates.

Maps are not drawn to scale.

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U.S. Solar Radiation Data

Collector Orientation

Flat plate collector facing south at fixed tilt equal to the latitude of the site. Capturing the maximum amount of solar radiation throughout the year can be achieved using a tilt angle approximately equal to the site's latitude.

Maps of average values are produced by averaging all 30 years of data for each site. Maps of maximum and minimum values are composed of specific months and years for which each site achieved its maximum or minimum amount of solar radiation.

Though useful for identifying general trends, this map should be used with caution for site-specific resource evaluations because variations in solar radiation not reflected in the maps can exist, introducing uncertainty into resource estimates.

Maps are not drawn to scale.

NREL
National Renewable Energy Laboratory
Resource Assessment Program

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Solar Radiation: 2 - 18
Solar Spectral Irradiance

Spectral Solar Irradiance

- Extraterrestrial (AM0)
- Terrestrial Total Global (AM1.5)
- Terrestrial Direct Normal (AM1.5)

Absorbed by water vapor

Absorbed by CO₂ and water vapor
Solar Radiation Measurements

- **A pyranometer** measures total global solar irradiance (solar power).
  - Measurements over time are integrated to calculate the total solar irradiation (solar energy) received.

- Irradiance measurements are used in the field to translate the actual output of PV array and systems to a reference condition and verify performance with expectations.

- Small inexpensive meters using calibrated PV cells as sensors are available from $150 and up.
  - A small PV module with calibrated short-circuit current can also be used to approximate solar radiation levels.
A pyranometer measures broadband global solar radiation (direct and diffuse) with a thermopile.

Used for precision laboratory measurements and weather stations.

Dual glass domes improve low incidence angle and thermal accuracy.

$$$$
A pyrheliometer measures the direct normal component of total global solar radiation.

Instrument must always track the sun.

Sensor is located at the back of a long tube with a field of view of 5.7° - the width of the solar disk.
Photovoltaic Reference Cell

- **A *reference cell* is a small PV device used to measure solar irradiance.**

- **Calibrated current output is proportional to solar irradiance.**

- **Used for measuring solar radiation for PV cell or module performance in indoor simulators.**

*PV Measurements, Inc.*
LI-COR LI200 Pyranometer

- Silicon pyranometers use a calibrated PV device to measure solar radiation.
- Meter sets instrument calibration, averages and integrates solar irradiance.
- Ideal for field use and long-term system performance monitoring.
- $$$
Daystar Solar Meter

- Handheld solar meters use a small PV cell to measure solar irradiance.

- Careful alignment with plane of array required for accurate measurements.

- Low cost, good for basic field measurements.

- $$

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Measures and records solar irradiance, ambient and PV module temperatures, array orientation and tilt angles.

200R features wireless connectivity with the PV150 Solar Installation tester, built-in data logger and USB interface.

See: www.seawardsolar.com
Two major motions of the earth affect the solar radiation received on a surface at any location:
- The rotation of the earth about its polar axis defines a day.
- The orbit of the earth around the sun defines a year.

The amount of solar radiation received at any location on earth depends on the time of day and year, the local latitude, and the orientation of the surface.
- Also significantly affected by weather conditions.
Earth’s Orbit

- The *ecliptic plane* is the earth’s orbital plane around the sun.

- The *equatorial plane* is the plane containing the earth’s equator and extending outward into space.

- The earth’s annual orbit around the sun is slightly elliptical.
  - Perihelion is the earth’s closest approach to the sun in its orbit, which is about 90 million miles and occurs around January 3.
  - Aphelion is the earth’s furthest distance to the sun in its orbit, which is about 96 million miles and occurs around July 4.

- One *Astronomical Unit (AU)* is the average sun-earth distance, which is approximately 93 million miles.
Earth’s Orbit Around the Sun

- **Autumnal Equinox:** September 22 / 23
  - Declination = 0°

- **Vernal Equinox:** March 20 / 21
  - Declination = 0°

- **Perihelion:** January 2-5
  - 96 million miles (1.017 AU)

- **Aphelion:** July 3-7
  - 90 million miles (0.983 AU)

- **Summer Solstice:** June 20 / 21
  - Declination = +23.5°

- **Winter Solstice:** December 21 / 22
  - Declination = -23.5°

Earth’s Polar Axis Tilt

- The earth’s polar rotational axis is tilted at a constant 23.5° angle with respect to the ecliptic plane.

- During its annual orbit around the sun, the earth's polar axis is never perpendicular to the ecliptic plane, but it is always inclined to it at the same angle, 23.5°.

- This results in a constantly varying angle between the earth’s equatorial plane and the ecliptic plane as the earth orbits the sun over a year.

- Except at the equinoxes, the earth’s axis is tilted either toward or away from the sun, causing the change in seasons.
Solar declination ($\delta$) is the angle between the earth’s equatorial plane and the sun’s rays.

Solar declination varies continuously in a sinusoidal fashion over the year due to the earth’s nearly circular orbit around the sun.

Solar declination varies from –23.5° to +23.5°, and defines the limits of sun position in the sky relative to any point on earth.
Solar Declination

Equator

Tropic of Cancer (23.5° N)

Ecliptic Plane

Tropic of Capricorn (23.5° S)

Arctic Circle (66.5° N)

Antarctic Circle (66.5° S)

North Pole

Sun’s Rays

Solar Declination

23.5°
Solar Declination

- **Autumnal Equinox**: September 22
- **Vernal Equinox**: March 21
- **Summer Solstice**: June 21
- **Winter Solstice**: December 21

![Solar Declination Graph](image)
The solstices define the points in earth’s orbit around the sun having maximum and minimum solar declination.

The solstices occur when the earth’s axis is inclined at the greatest angle either toward or away from the sun, and defines the annual range of sun position relative to any point on earth.

The winter solstice occurs on December 21 or 22 when solar declination is at its minimum (-23.5°) and the Northern Hemisphere is tilted away from sun.

The summer solstice occurs on June 21 or 22 when solar declination is at its maximum (23.5°), and the Northern Hemisphere is tilted towards the sun.
The equinoxes define the two points in Earth’s orbit around the sun having zero solar declination.

On the equinoxes, the earth’s axis is neither tilted toward or away from the sun's rays, but is perpendicular.

- The sun rises and sets due east and west, respectively, and days and nights equal length (12 hours) everywhere on Earth.
- The sun is directly overhead at solar noon on the equator (at zenith).

The vernal equinox occurs on March 20 / 21.

- Days become longer than nights in the Northern Hemisphere for the next six months.

The autumnal equinox occurs on September 22 / 23.

- Days become shorter than nights in the Northern Hemisphere for the next six months.
Winter Solstice

- Arctic Circle (66.5° N)
- Tropic of Cancer (23.5° N)
- Ecliptic Plane
- Equator
- Tropic of Capricorn (23.5° S)
- Antarctic Circle (66.5° S)

Sun's Rays

North Pole

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Vernal Equinox

- Equator
- Tropic of Cancer (23.5° N)
- Tropic of Capricorn (23.5° S)
- Antarctic Circle (66.5° S)
- Sun’s Rays
- Ecliptic Plane
- North Pole Titled Backward

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Summer Solstice

- Equator
- Tropic of Cancer (23.5° N)
- Tropic of Capricorn (23.5° S)
- Arctic Circle (66.5° N)
- Antarctic Circle (66.5° S)
- Sun's Rays
- Ecliptic Plane
- North Pole

23.5°
Autumnal Equinox

- Equator
- Tropic of Cancer (23.5° N)
- Tropic of Capricorn (23.5° S)
- Arctic Circle (66.5° N)

North Pole Tilted Forward

Ecliptic Plane

23.5°

Sun’s Rays
**Solar Time**

- **Apparent solar time** is based on the interval between daily sun crossings above a local meridian. Apparent solar time can be measured by a sundial.

- **Mean solar time** is based on the average position of the sun assuming the earth rotates and orbits at constant rates.

- The **equation of time (EOT)** is the difference between mean and apparent solar time.
  - EOT varies annually with apparent time ahead of mean solar time by about 16.5 min on November 3, or behind by about 14 min on February 12.
  - Due to changing speed of earth at points in elliptical orbit around sun.
Equation of Time

Equation of Time

Autumnal Equinox
September 22

Vernal Equinox
March 21

Summer Solstice
June 21

Winter Solstice
December 21

Julian Day (1-365)
**Coordinated Universal Time (UTC)** is based on an atomic clock and mean solar time at the Royal Observatory in Greenwich, London, UK.

- The prime meridian passes through Greenwich and is arbitrarily taken as 0° longitude.

**Standard time** is based on sun crossing reference meridians or geographical boundaries, generally separated by 15° of longitude.

- Local standard time is referenced to UTC
- Eastern Standard Time is UTC-5 hours (UTC-4 during Daylight Savings Time)

UTC varies from local solar time by as much as +/- 45 min depending on the day of year, whether Daylight Savings Time is in effect, and longitude of the specific location with respect to the reference time zone meridian.
U.S. Time Zones

- Eastern (UTC-5)
- Atlantic (UTC-4)
- Central (UTC-6)
- Mountain (UTC-7)
- Pacific (UTC-8)
- Alaska (UTC-9)
- Hawaii (UTC-10)
- Guam (UTC+10)

UTC with no Daylight Savings Time

NIST/USNO
Example: Determine the local standard time that solar noon occurs on November 3 in Atlanta, GA (33.65° N, 84.43° W).

The adjustment for longitude is determined by:

\[ t_L = (L_{\text{local}} - L_S) \times 4 \]

where

- \( t_L \) = longitude time correction (min)
- \( L_{\text{local}} \) = local longitude (deg)
- \( L_S \) = longitude at standard meridian (deg)

\[ t_L = (84.43 - 75) \times 4 = 37.7 \text{ min} = 37:43 \text{ mm:ss} \]

Local standard time of solar noon is determined by:

\[ t_S = t_0 - t_E + t_L \]

where

- \( t_S \) = local standard time (hh:mm:ss)
- \( t_0 \) = solar time (hh:mm:ss)
- \( t_E \) = Equation of Time (mm:ss)

\[ t_S = 12:00:00 - (00:16:30) + (00:37:43) = 12:21:13 \text{ EST} \]
This Analemma was created by superimposing photographs of the sun taken in the morning at the same clock time, each week of the year, and represents the variation in solar declination and the equation of time over the year.
The sun’s position in the sky at any moment relative to an observer on earth is defined by two angles.

1. **Solar altitude angle** ($\alpha$) is the angle between the sun’s rays and the horizon.

2. **Solar azimuth angle** ($\theta_z$) is the angle between the horizontal projection of the sun’s rays and geographic due south.

3. The zenith angle is the angle between the line to the sun and directly overhead.
   - The zenith and altitude angles are complementary: $\alpha + \theta_z = 90^\circ$
Sun Position

- Zenith Angle
- Altitude Angle
- Azimuth Angle

Zenith
- North
- West
- Horizontal Plane
- East
- South
Sun Path Diagrams at the Equinoxes

0° Latitude (Equator):
Altitude at Solar Noon = 90°

23.5° N Latitude (Tropic of Cancer):
Altitude at Solar Noon = 66.5°

47° N Latitude (Seattle, WA):
Altitude at Solar Noon = 43°
Sun Path Diagrams at the Summer Solstice

0° Latitude (Equator):
Altitude at Solar Noon = 66.5°
(Sun in Northern Sky)

23.5° N Latitude (Tropic of Cancer):
Altitude at Solar Noon = 90°
(Directly Overhead)

47° Latitude (Seattle, WA):
Altitude at Solar Noon = 66.5°
(Sun in Southern Sky)
Sun Path Diagrams at the Winter Solstice

0° Latitude (Equator):
Altitude at Solar Noon = 66.5°

23.5° N Latitude (Tropic of Cancer):
Altitude at Solar Noon = 43°

47° Latitude (Seattle, WA):
Altitude at Solar Noon = 19.5°
Sun Position on the Equator

Sun Position for 0° Latitude

Winter Solstice | Summer Solstice | Vernal and Autumnal Equinox

Altitude Angle (positive above horizon)

Azimuth Angle

<< East (positive) << | Noon | >> West (negative) >>

0 | 15 | 30 | 45 | 60 | 75 | 90

(180)(150)(120)(90)(60)(30)0306090120150180

Altitude Angle (positive above horizon)

Azimuth Angle

<< East (positive) << | Noon | >> West (negative) >>

0 | 15 | 30 | 45 | 60 | 75 | 90

(180)(150)(120)(90)(60)(30)0306090120150180

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Solar Radiation: 2 - 52
Sun Position for 15°N

Altitude Angle (positive above horizon)

Azimuth Angle

Winter Solstice
Summer Solstice
Vernal and Autumnal Equinox

Altitude Angle (positive above horizon)

180 150 120 90 60 30 0 (30) (60) (90) (120) (150) (180)

<< East (positive) <<

> West (negative) >>

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Sun Position for 30°N

Sun Position for 30° N Latitude

- Winter Solstice
- Summer Solstice
- Vernal and Autumnal Equinox

Altitude Angle (positive above horizon)

Azimuth Angle

0 15 30 45 60 75 90 (180) (150) (120) (90) (60) (30) 0

<< East (positive) <<

Noon

10 AM

11 AM

1 PM

2 PM

4 PM

8 AM

10 AM

Winter Solstice

Summer Solstice

Vernal and Autumnal Equinox

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Sun Position for 45°N

Sun Position for 45° N Latitude

- Winter Solstice
- Summer Solstice
- Vernal and Autumnal Equinox

Altitude Angle (positive above horizon)

Azimuth Angle

East (positive)  West (negative)

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Sun Position for 75°N

Sun Position for 75°N Latitude

- Winter Solstice
- Summer Solstice
- Vernal and Autumnal Equinox

Altitude Angle (positive above horizon)

Azimuth Angle

- << East (positive) <<
- >> West (negative) >>

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The solar window represents the range of sun paths for a given latitude between the winter and summer solstices.

As latitudes increase from equator:
- The solar window is inclined at a closer angle with the southern horizon.
- Sun path and days are longer during summer; shorter during winter.

For any location, the maximum altitude of the sun at solar noon varies 47° between the winter and summer solstice.

PV arrays should be oriented toward the unobstructed solar window for maximum solar energy collection.
Solar Window on the Equator

Winter Solstice
Equinoxes
Summer Solstice

Zenith

47°
Solar Window on the Tropic of Cancer (23.5°N)

Zenith

Winter Solstice
Equinoxes
Summer Solstice

47°
Solar Window in Seattle, WA (47°N)
The orientation of PV arrays and other solar collectors is defined by two angles with respect to the earth’s surface.

- The *collector azimuth angle* represents the angle between due geographic south and direction the collector faces.

- The *collector tilt angle* represents the angle the array surface makes with the horizontal plane.

- The *solar incidence angle* represents the angle between the sun’s rays and the normal (perpendicular) to a collector surface.
Array Orientation

- **Zenith**
- **North - 0°**
- **East - 90°**
- **South - 180°**
- **West - 270°**

- **Collector Tilt Angle**
- **Horizontal Plane**
- **Solar Incidence Angle**
- **Collector Azimuth Angle**
- **Surface Normal**
- **Surface Direction**
Optimal Collector Orientation

- Maximum annual solar energy is received on a fixed surface that faces due south, and is tilted from the horizontal at an angle slightly less than local latitude.

  - Fall and winter performance is enhanced by tilting collectors at angles greater than latitude.
  - Spring and summertime performance is enhanced by tilting collectors at angles lower than latitude.

- For the central and southern U.S., latitude-tilt surfaces with azimuth orientations of ± 45 degrees from due south and with tilt angles ± 15 of local latitude will generally receive 95 % or more of the annual solar energy received on optimally-tilted south-facing surfaces.
Effect of Collector Tilt Angle on Solar Energy Received

Orlando, FL

Predicted Insolation on South-Facing Tilted Surfaces

- H (0 deg)
- H (15 deg)
- H (30 deg)
- H (45 deg)

Insolation (kWh/m²·day)

Month

Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

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Effects of Collector Tilt and Azimuth on Annual Solar Energy Received

Miami, FL

Boston, MA

Available Irradiation (% of maximum)

Azimuth (deg)

Tilt (deg)

Available Irradiation (% of maximum)

Azimuth (deg)

Tilt (deg)
Available from National Renewable Energy Laboratory (NREL) - Renewable Resource Data Center (RReDC):


Includes extensive collection of renewable energy data, maps, and tools for using biomass, geothermal, solar, and wind resources.

Solar resource data is used for sizing and estimating the performance of solar energy utilization systems.
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National Solar Radiation Database

- **NSRDB 1961-1990**
  - 30 years of solar radiation and meteorological data from 239 NWS sites in the U.S.
  - TMY2 hourly data files

- **NSRDB 1991-2005 Update**
  - Contains solar and meteorological data for 1,454 sites.
  - TMY3 hourly data files

NREL
Standard format spreadsheets provide minimum and maximum data for each month and annual averages for:

- Total global solar radiation for fixed south-facing flat-plate collectors tilted at angles of 0°, Lat-15°, Lat, Lat+15° and 90°.
- Total global solar radiation for single-axis, north-south tracking flat-plate collectors at tilt angles of 0°, Lat-15°, Lat and Lat+15°.
- Total global solar radiation for dual-axis tracking flat-plate collectors.
- Direct beam radiation for concentrating collectors.
- Meteorological data.
Solar Radiation Data Tables

City: DAYTONA BEACH
State: FL
WBAN No: 12834
Lat(N): 29.18
Long(W): 81.05
Elev(m): 12
Pres(mb): 1017
Stn Type: Primary

SOLAR RADIATION FOR FLAT-PLATE COLLECTORS FACING SOUTH AT A FIXED-TILT (kWh/m2/day), Percentage Uncertainty = 9

<table>
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<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
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Sun-Tracking Arrays

- **Two-Axis Tracking**
- **Vertical-Axis Tracking**
- **East-West Tracking**

Optional seasonal adjustment
### Solar Radiation Data Tables

**City:** DAYTONA BEACH  
**State:** FL  
**WBAN No:** 12834  
**Lat(N):** 29.18  
**Long(W):** 81.05  
**Elev(m):** 12  
**Pres(mb):** 1017  
**Stn Type:** Primary

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© 2012 Jim Dunlop Solar  
NREL
### Solar Radiation Data Tables

**City:** DAYTONA BEACH  
**State:** FL  
**WBAN No.:** 12834  
**Lat(N):** 29.18  
**Long(W):** 81.05  
**Elev(m):** 12  
**Pres(mb):** 1017  
**Stn Type:** Primary

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<td>5.3</td>
<td>5.0</td>
<td>4.9</td>
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</tbody>
</table>

**Element**  
**Jan** | **Feb** | **Mar** | **Apr** | **May** | **Jun** | **Jul** | **Aug** | **Sep** | **Oct** | **Nov** | **Dec** | **Year**  
--- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | ---
Temp. (deg C) | 14.2 | 15.0 | 17.9 | 20.7 | 23.7 | 26.3 | 27.3 | 27.2 | 26.3 | 23.0 | 18.8 | 15.6 | 21.3  
Daily Min (deg C) | 8.3 | 9.1 | 12.2 | 14.8 | 18.3 | 21.6 | 22.5 | 22.7 | 22.2 | 18.4 | 13.5 | 9.8 | 16.1  
Daily Max (deg C) | 20.0 | 20.8 | 23.8 | 26.7 | 29.2 | 31.1 | 32.1 | 31.7 | 30.4 | 27.5 | 24.2 | 21.3 | 26.6  
Record Lo (deg C) | -9.4 | -4.4 | -3.3 | 1.7 | 6.7 | 11.1 | 15.6 | 18.3 | 11.1 | 5.0 | -2.8 | -7.2 | -9.4  
Record Hi (deg C) | 30.6 | 31.7 | 32.8 | 35.6 | 37.8 | 38.9 | 38.9 | 37.8 | 37.2 | 35.0 | 31.7 | 31.1 | 38.9  
HDD/Base, 18.3C | 157 | 114 | 62 | 12 | 0 | 0 | 0 | 0 | 0 | 46 | 115 | 505 |
CDD/Base, 18.3C | 28 | 21 | 50 | 83 | 167 | 240 | 279 | 276 | 240 | 147 | 61 | 31 | 1622 |
Rel Hum percent | 75 | 72 | 71 | 69 | 72 | 77 | 78 | 80 | 79 | 75 | 76 | 75 |
Wind Spd. (m/s) | 3.8 | 4.1 | 4.2 | 4.1 | 3.8 | 3.4 | 3.2 | 3.0 | 3.5 | 4.0 | 3.7 | 3.6 | 3.7 |
PVWATTS Performance Calculator

- Used to evaluate solar energy collected and the performance of grid-tied PV systems for any array azimuth and tilt angles.

- User selects state and city from map, and enters size of PV system, array orientation and derating factors.

- Results give monthly and annual solar energy received and PV system AC energy production.
## Station Identification

<table>
<thead>
<tr>
<th>City</th>
<th>Daytona Beach</th>
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<tbody>
<tr>
<td>State</td>
<td>FL</td>
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<tr>
<td>Latitude</td>
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</tr>
<tr>
<td>Longitude</td>
<td>81.05° W</td>
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<tr>
<td>Elevation</td>
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## PV System Specifications

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<thead>
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<th>DC Rating</th>
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<td>Array Azimuth</td>
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<td>Energy Specifications</td>
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<td>Cost of Electricity</td>
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## Results

<table>
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<tr>
<th>Month</th>
<th>Solar Radiation (kWh/m²/day)</th>
<th>AC Energy (kWh)</th>
<th>Energy Value ($)</th>
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</tbody>
</table>

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NREL
The solar radiation received on earth is affected by the earth’s movements and atmospheric conditions.

Solar irradiance (power) is expressed in units of W/m² or kW/m², and measured with a pyranometer.
- Typical peak values are around 1000 W/m² on a surface at sea level facing the sun around solar noon; used as the rating condition for PV modules and arrays.

Solar irradiation (energy) is solar power integrated over time, expressed in units of kWh/m²/day.
- Solar energy resource data are used in sizing and estimating the performance of PV systems, and varies location and with collector orientation.

The solar window defines the range of sun paths between the winter and summer solstices for a specific latitude.
- PV arrays are oriented toward the solar window for maximum energy gain.
Questions and Discussion