

Our Solar Resource



THIS CHAPTER INTRODUCES SOLAR radiation. Solar radiation is a universal energy source supplied by sunshine to all life on Earth. This chapter describes the concepts of irradiance, irradiation, direct versus diffuse radiation, peak sun hours, and insolation. You will also learn about the nature of light.

This chapter also investigates the relationship between the sun and the Earth. This relationship is something that everyone experiences daily, without fully understanding it. Major topics discussed in this chapter include the angle of the sun, day length measurements, the scattering of radiation, and absorption. Lastly, you will learn how these factors affect PV design and installation.

Topics & Concepts

This chapter covers the following topics and concepts:

- What is solar radiation
- The nature of light
- The relationship between the sun and the Earth

Goals

When you complete this chapter, you will be able to:

- Define solar radiation
- Differentiate between irradiance and irradiation
- Explain how the relationship between the sun and Earth affects PV systems

What Is Solar Radiation?

Solar radiation is a universal energy source supplied by sunshine to all life on Earth. **Radiation** is the process of radiating or reflecting energy particles or waves. The absence of sunlight would mean death to all living things. Energy from the sun is generated at its core through fusion of hydrogen atoms into helium. You can look at the sun as a nuclear fusion reactor. The intense pressure and heat of the sun cause hydrogen atoms to fuse. This creates larger helium atoms and releases energy. Energy migrates to the sun's surface. This energy radiates from the sun in waves as heat and light.



Only about two-millionths of the sun's radiation reaches Earth. This is due to the enormous distance between the sun and the Earth. The sun and the Earth are approximately 93 million miles apart at their closest point. The amount of energy that Earth receives is around 10,000 times the energy requirements of the world. You would need to capture only 0.01 percent of the radiation to meet the energy needs of humankind.

On a clear day, the sun's radiation has the least impediment in its travel to hit a surface on the Earth and provides the maximum amount of radiation. This intensity is variable on days when the Earth's atmosphere is denser and absorbs, reflects, and scatters radiation. The distance the energy travels through the atmosphere is called the air mass (AM). Radiation must travel through the air mass before hitting the Earth's surface.

Irradiance

You can think of **irradiance** as a measure of the amount of solar radiation that hits a square meter of the Earth's surface or atmosphere. You can measure irradiance in watts per square meter (W/m^2). Almost 30 percent of the sun's radiation is absorbed or reflected by water vapor and dust in the atmosphere.

Low-angled sunlight provides considerably less energy per square meter. This results in low energy density. As the sun reaches its apparent high point in the sky—its altitude—energy density increases. At solar noon, irradiance can reach about $1,000 W/m^2$. This measure is the irradiance measurement used in standard test conditions (STC) for PV panel certification. Energy density is affected by the amount of filtering in the atmosphere. The amount of atmosphere that the sun's rays have to penetrate determines the amount of energy reaching PV arrays.

NOTE

About three-quarters of daily output from solar modules occurs between 9:00 a.m. and 3:00 p.m.

Irradiation

The amount of irradiance over time is referred to as **irradiation** (described as watts per square meter), which strikes a solar module over a given time. You can measure time over an hour or within a day. An example is 1,000 watts of energy hitting a square meter for an hour. You can describe this as 1,000 watt-hours per square meter per hour (1 kWh).

Irradiance sensors are frequently used with larger PV arrays for monitoring the system's operation. The use of a sensor with the same cell technology increases the effectiveness of its evaluation.

As a solar installer, you need to know the amount of energy over time that you can capture. This helps determine the PV system size.

Direct vs. Diffuse Radiation

Sunlight reaches the Earth's surface in the form of direct radiation and diffuse radiation. **Direct radiation** is the portion of sunlight received directly from the sun without scattering and reflection by the atmosphere and ground.

Diffuse radiation is the sunlight that ultimately reaches the Earth's surface after having been scattered by molecules or particles in the atmosphere, which can also cause sky color changes. You can also use the pyranometer to monitor the effectiveness of solar arrays.

Many factors affect the proportion and radiant power of direct and diffuse sunlight that hits the Earth. This includes cloud conditions and the angle of the sun.

The atmosphere reduces radiation by about 30 percent by the time it hits a surface on the Earth. The interference is caused by such effects as short wavelength molecules, dust particles and aerosols (causing scattering), and absorption by gases, including ozone, water vapor, carbon dioxide, and oxygen.

Atmospheric scattering causes diffuse sunlight. Diffuse light scatters the energy in the blue frequency range. This amazing process is what causes the sky to appear blue and change color. This is what causes colorful sunsets.

About half the direct radiation blocked by cumulus clouds returns as diffuse radiation. Wispy, high-altitude cirrus clouds do not block as much sunlight. About two-thirds of the direct radiation blocked from cirrus clouds returns as diffuse radiation.

NOTE

Scientists use a measurement device called a pyranometer to determine the density of solar irradiance. You can measure both direct and diffuse radiation using pyranometers.



Peak Sun, Peak Sun Hours, and Insolation

PV installers must consider the measurement of peak sun when designing PV systems. **Peak sun hours** are the equivalent number of hours per day when the irradiance averages 1 kW/m^2 . This measurement is based upon a fixed maximum solar irradiance existing on a clear day of $1,000 \text{ W/m}^2$. One hour of peak sun is a peak sun hour. This is also called a sun hour. There are maps of the Earth that indicate the average daily insolation in sun hours. You can measure these hours using $\text{kWh/m}^2/\text{day}$.

Let us use Phoenix, Ariz., as an example. On an annual basis in Phoenix, the daily average of sun hours is about 6.85. This means the energy received during total daylight hours is about the same as would have been received if the irradiance had been constant for 6.85 hours at a constant 1 kW/m^2 .

You can use peak sun hours as a tool for calculating solar irradiation at a site. This is also called solar insolation, or **insolation**. Solar insolation is the solar radiation incident on an area over time, normally expressed as sun hours in kilowatt-hours per square meter per day. You can use insolation to compare solar resources in various locations in the world. You can also use insolation information to determine the amount of energy available in a location to size a PV system.

You can determine the size of an array for a particular customer by multiplying the average peak sun hours in a location by the capacity of the system. This

will give you an estimate of the average daily creation of energy in kilowatt-hours. You should adjust the result of this figure using factors such as system losses, temperature, and the local environmental to determine the size of a solar array.

The Nature of Light

Light is a wonder. Today, physicists claim that light has a dualistic nature. Decades earlier, scientists believed that radiation transmitted and emitted as waves. Albert Einstein proposed in 1905 that light is composed of discrete particles of energy. When investigating PV, you should discuss light as waves and particles or photons.

Light reacts differently depending on the receiver of the radiation. For example, when light displays wave behavior, different waves interacting can cancel one another out. You can refer to this occurrence as **destructive interference**, which happens when one light wavelength cancels another. When light interacts with matter, it bends and changes speed. This is known as refraction. When light interacts with matter, it can also display particle behavior and transfer to these materials small amounts of energy. This energy generates electricity for PV cells.

Light that hits PV cells travels through space in packets of energy called photons. Photons are basic particles. A photon carries all forms of **electromagnetic radiation**, which is radiation, or energy in the case of PV, from the sun, composed of electromagnetic waves, including radio waves, infrared, visible light, ultraviolet, x-rays, and gamma rays.

Photons can travel through a vacuum at the speed of light because they have a zero rest mass.

The Relationship Between the Sun and the Earth

Earth orbits around the sun and completes an elliptical orbit every 365 days. The elliptical path causes variations in the distance between Earth and the sun. Distance does not determine the amount of sunlight that hits Earth. The amount of sunlight that hits Earth is impacted by **Earth's tilt**. The tilt of Earth is a major factor affecting sunlight and used to design and install PV systems. The tilt causes the various seasons: When either the Northern or the Southern Hemisphere tilts toward the sun, summer occurs there, and when the hemisphere tilts away from the sun, winter occurs.



Continuous concentrator cell current versus voltage measurement test bed. The light is directed from a 1,000W xenon lamp on to a sample.

Courtesy of DOE/NREL, Credit: Jim Yost

The Southern Hemisphere is tilted farthest from the sun during June, July, and August and closest during December, January, and February.

Motion of the Sun

When you calculate radiation intensity for PV systems, you should determine the path and angle of the sun. The greatest radiation will fall on a location on the Earth when the sun is directly overhead. One example would be midday during the summer. At this time, Earth's tilt is toward the sun and the sun is at its highest point in the sky. This results in less distance that radiation must travel to reach the Earth's surface.

Radiation is reduced when sunlight has longer to travel through the atmosphere. One example would be at 5:00 p.m. At this time, you can see the sun closer to the sky's horizon. The result is greater travel distance. When light has a further distance to travel, radiation encounters more materials in the atmosphere. These materials scatter and absorb the radiation. This means lower radiation intensity.

The air mass (AM) factor determines the relative thickness the sunlight has to travel through the atmosphere at a perpendicular angle. Irradiance is reduced as light travels through the Earth's atmosphere because of the following:

- **Mie scattering**
- **Rayleigh scattering**
- Reflection of the atmosphere
- Absorption by molecules

Rayleigh scattering and absorption increase as the sun's angle to a given point deviates from its highest point in the sky. Pollution scattering in the atmosphere occurs more in industrialized areas. Weather also reduces irradiance.

- At the northern summer solstice, around June 21, and northern winter solstice, around December 22, the sun's altitude at solar noon changes by the Earth's axis. At this time, Earth is tilted at about 23 degrees, 27 minutes.
- At the sun's equinoxes, around March 21 and September 23, its altitude equals 90 degrees minus the latitude.

The Oregon Solar Radiation Monitoring Laboratory website provides software that allows users to determine the sun's path by entering information. Information includes latitude, longitude, time zone, and date. The program also requires you to set parameters to assist in determining the sun's path.

NOTE

Mie scattering is the scattering of sunlight off molecules in the atmosphere, which is not wavelength dependent. Cloud droplets of a relatively large size scatter all visible wavelengths equally, so clouds appear to be white. Rayleigh scattering refers to the scattering of sunlight off molecules in the atmosphere, which causes the blue color of the sky.



Day Length

Earth completes its path around the sun every 365 days. Earth is tilted on its axis of rotation at 23.5 degrees, the same value as 23 degrees, 27 minutes, which has significant implications on solar energy use and day-length calculations. The angle of the tilt remains relatively constant, as if Earth were attached to a pole anchored somewhere in outer space.

The angle of Earth in relation to the sun determines day length. Calculating day length is a critical task when designing and installing site-specific PV systems. Of course, in one sense every day is 24 hours long, but in this context “day” refers to the daily period of sunlight, and days are longer during the summer.

Earth maintains its tilt of about 23.5 degrees for the entire year as it orbits around the sun **TABLE 2-1**. Due to the relatively constant tilt, the Northern Hemisphere tilts toward the sun during its summer months. The sunlight moves through Earth’s atmosphere at a more direct angle. The result is that the solar rays travel through less water vapor and dust. This increases irradiance and the output of a solar array. The apparent angle from the sun to the irradiated surface also results in a higher energy density.

TABLE 2-1 ANGLE OF THE SUN ON A SURFACE AT DIFFERENT TIMES OF THE YEAR

Season	Angle from Northern Side of Horizon	Angle from True South
Equinox	140°	40°
June Solstice	116.5°	63.5°
December Solstice	163.5°	16.5°

This diagram illustrates how sunlight spreads over a greater area in the polar regions. In addition to the density of incident light, the dissipation of light in the atmosphere is greater when it falls at a shallow angle.

The amount of heat energy received at any location on the globe is a direct effect of sun angle. Solar gain decreases during the winter for the following reasons:

- The days are shorter.
- Most of the sunshine strikes the other hemisphere.
- The angle of Earth in relation to the sun influences day length.

Altitude Angle

Altitude angle is the angle between the horizon and the sun at any point in time. The altitude angle gradually decreases between the summer solstice and the winter solstice. After the winter solstice, the altitude angle grows gradually until the summer solstice occurs. Thus, day length varies with changes in the altitude angle. It gets shorter from the summer solstice until the winter solstice. It increases until the summer solstice occurs again.

Angle Definition

When calculating the output of solar energy systems and irradiance values, it is critical to determine the sun's path. When discussing solar energy systems, due south, or true south, is normally indicated as south: $a = 0$ degrees. Angles to the west are denoted with a positive number: $a = 90$ degrees. Angles to the east are denoted with a negative number: $a = -90$ degrees.

Ground Reflection

You can use the amount of reflected solar radiation in calculations to determine irradiance on an inclined plane. **Ground reflection** occurs where light waves are reflected off the Earth's surface, whether on water or land.

You can use the reflective properties of the surface the sunlight hits to determine the **albedo value** applied. Albedo value is a value assigned to indicate the fraction of solar energy reflected from the Earth's surface back into space.

The albedo value increases as reflection properties increase. The higher the albedo value, the greater the diffuse radiation. You can also take waves in bodies of water into consideration. Waves reflect sunlight in a different way than still water.

When sunlight strikes ice or snow, a portion of it reflects back into space. A portion is also absorbed and transmitted through the snow. When sunlight strikes deep water, the majority of the sunlight is absorbed.

Implications for Solar Installation

There are many factors involved when making decisions about solar installation including mounting hardware and racks, and aligning solar arrays for optimum results.

You can choose among four types of mounting hardware and racks:

- **Single-axis trackers**—These follow the sun by adjusting for azimuth angle changes. These trackers can increase an array's output by 20 to 30 percent.
- **Dual-axis trackers**—These automatically adjust both the azimuth and tilt angles and can increase an array's output by 30 to 40 percent.



This 2007 Solar Decathlon competition home includes residential photovoltaic modules from SunPower Corporation of San Jose, Calif., and a solar collector from OkoTech of Budapest, Hungary. The PV modules also provide shade for the patio in the back of the home.

Courtesy of DOE/NREL, Credit: Jim Tetro

- **Fixed racks**—These are set at a fixed angle, preferably equal to the latitude of the site and oriented to true south. You can install these racks on the ground, using poles, or on rooftops.
- **Seasonally adjustable fixed racks**—These are similar to fixed racks, but the angle can be increased or decreased, adjusting for each season.

For optimum results, you'll need to point solar arrays toward true south, not magnetic south. (For the Northern Hemisphere, refer to a map for magnetic declination, which varies depending upon the location.) **Magnetic declination** is the angle between true north and magnetic north, which varies from location to location.

You can determine the magnetic north and south using the Earth's magnetic field. This field can differ considerably from true north and south. This deviation is the magnetic declination. Magnetic north and south also shift slightly from year to year. Geo professionals track this annual variation.

It is also vital that you align the array with the sun at all times. You can reduce the **angle of incidence** by using trackers. The angle of incidence is the angle that sunlight hitting a surface creates in variation with a line perpendicular to the surface. You can design these trackers as actively or passively controlled.

NOTE

If you want to do things the old way: You can locate true north by locating the North Star, also called Polaris. It is the third star off the handle of the Little Dipper. Polaris is just a few tenths of a degree from true north.

As a solar installer, you must consider many things when locating true south. You must first find magnetic south (with a compass) and adjust for magnetic declination. It is important to know that nearby iron ore deposits, or even keys in pockets, steel posts, cell phones, metal tools, or audio speakers can affect magnetic fields. Iron, other magnets, and steel all affect compass readings.

Orienting a solar array with a tilt angle matching the site latitude usually generates the most effective year-round output for a fixed array.

You can improve an array's output during the summer by reducing the tilt angle by 15 degrees and during the winter by increasing the tilt angle by about 15 degrees.

You should also adjust the tilt angle based on the specific local site to capture the most sunlight possible. This can improve the annual output of a PV system.

You can reap the greatest benefits from a solar system by adjusting to factor in the sun's seasonally and daily changing position. If used properly, solar energy can power household devices, heat and cool our homes, and power electric cars.

PHOTOVOLTAIC'S MODERN BEGINNINGS

Sputnik 3 was launched on May 15, 1958. Sputnik was a major step forward for PV. It was the first satellite to use solar arrays. In 1958, a photovoltaic (PV) system was used in space to backup Vanguard's transmitter. Since then, the United States shuttle fleet has generated much of its electrical power using PV. PV also powers most satellites. PV has proven reliable after several decades of use.

PV is flexible and one of the most attractive alternative energy forms. The US government began encouraging use of PV-powered systems in the 1980s. Through projects like the Coast Guard's aids to navigation, telecommunications, and remote meteorological monitoring, PV proved its competitiveness and reliability.

The 21st century has seen an explosion of PV uses and milestones, including:

- The world's first totally PV-powered neighborhood in Gardner, Mass.
- Skyrocketing usage of solar energy in remote areas not served by a utility grid

There are still several challenges associated with PV. The PV industry will eventually overcome them. PV has increasingly become the power source of choice and more people are viewing it as limitless in scope. It is also clean and abundant. PV is the power of the future.

CHAPTER 2 SUMMARY

This chapter introduced solar radiation. The chapter covered topics including the concepts of irradiance, irradiation, direct versus diffuse radiation, peak sun, peak sun hours, and insolation. You also read about the nature of light.

This chapter also covered interesting facts about the relationship between the sun and the Earth. This included factors you should consider when designing and installing a PV system, such as the motion of the sun, altitude angle of the sun, Earth's tilt, and its orbit around the sun. Other factors discussed include day length measurements, ground reflection, and the scattering of radiation and absorption.

KEY CONCEPTS AND TERMS

Albedo value	Insolation
Altitude angle	Irradiance
Angle of incidence	Irradiation
Destructive interference	Magnetic declination
Diffuse radiation	Mie scattering
Direct radiation	Peak sun hours
Earth's tilt	Radiation
Electromagnetic radiation	Rayleigh scattering
Ground reflection	

CHAPTER 2 ASSESSMENT

Our Solar Resource

- The distance between the sun and the Earth is approximately 93 million miles.
 - A. True
 - B. False
- What is solar radiation?
 - A. The fusion of hydrogen atoms
 - B. The heating of helium
 - C. Fission
 - D. The energy supplied by sunshine to all life on Earth.
- Only about two-millionths of the sun's radiation reaches Earth.
 - A. True
 - B. False
- Scientists believe that radiation has properties of:
 - A. particles.
 - B. waves.
 - C. Both A and B
 - D. None of the above

5. Physicists claim that light has a one-dimensional nature.
- A. True
 - B. False
6. _____ occurs when waves of light interact and cancel each other out.
- A. Destructive interference
 - B. Refraction
 - C. Both A and B
 - D. None of the above
7. Because photons have zero rest mass, they can travel at the speed of light through a vacuum.
- A. True
 - B. False
8. Physicists claim that light has a dualistic nature, which means that radiation:
- A. is emitted and transmitted as waves.
 - B. has properties of particles.
 - C. occurs both during the day and at night.
 - D. Both A and B
 - E. None of the above
9. Irradiance is reduced as light travels through Earth's atmosphere as a result of:
- A. Mie scattering.
 - B. Rayleigh scattering.
 - C. reflection by the atmosphere.
 - D. absorption of light by gas molecules.
 - E. All the above
10. Solar gain is decreased during the winter in the Northern Hemisphere because:
- A. the days are shorter.
 - B. most of the sun's radiation strikes the Southern Hemisphere.
 - C. day length is affected by the angle of the Earth in relation to the sun.
 - D. The Northern Hemisphere blocks the sun's rays.
 - E. A, B, and C
11. The reflective properties of the surface the sunlight hits determines the albedo value applied.
- A. True
 - B. False
12. Waves reflect sunlight in the same way as still water.
- A. True
 - B. False