

CAI335 SOLAR AND WIND ENERGY SYSTEM
UNIT I NOTES



SOLAR RADIATION MEASUREMENT

In PV system design it is essential to know the amount of sunlight available at a particular location at a given time. The solar radiation may be characterized by the measured solar irradiance (power per area at a given moment) (or radiation) and by the solar insolation (the energy per area delivered over a specified time period). The solar radiance is an instantaneous power density in units of kW/m^2 . The solar radiance varies throughout the day from 0 kW/m^2 at night to a maximum of about 1 kW/m^2 . The solar irradiance is strongly dependent on location and local weather and varies throughout each day.

Solar irradiance measurements consist of global and/or direct radiation measurements taken periodically throughout the day. The measurements are taken using either a pyranometer (measuring global radiation) and/or a pyrheliometer (measuring direct radiation). In well established locations, these data have been collected for more than forty years.

The two most common sensors used as pyranometers are thermopiles (which measure the heat reaching the surface directly) and reference cells (which measure the number of photons reaching a surface that are successful in delivering an electron to an outside circuit). A thermopile is an array of thermocouples that collectively measure the temperature difference between the irradiated side and the side that is in the dark. Thermopiles are preferred for characterizing the solar resource for solar thermal collectors or for comparing the performance of solar thermal and solar photovoltaic systems. Reference cells are typically silicon solar cells packaged in such a way as to measure the photocurrent. A reference cell may be most useful when constructed to mimic the response of the solar panels being measured and may be fabricated of any semiconductor material with a package (i.e. textured glass) that matches that of the solar panels.

Sensors may vary in their response to different wavelengths of light (especially if a solar cell with a different band gap is used) and to their angular response (the dome on the thermopile shown to the right is designed to accept light equally well from all angles, while a reference cell typically has a higher reflection for light striking at a glancing angle.) Some silicon-based pyranometers use a diffusing dome on the top to change the angular acceptance to be more isotropic, which may be useful for some applications, but using a reference cell that mimics the angular response of the solar panels being studied gives a more precise measurement of the solar resource available to those solar panels.

An alternative method of measuring solar radiation, which is less accurate but also less expensive, is using a sunshine recorder. These sunshine recorders (also known as Campbell-Stokes recorders), measure the number of hours in the day during which the sunshine is above a certain level (typically 200 mW/cm^2). Data collected in this way can be used to determine the solar insolation by comparing the measured number of sunshine hours to those based on calculations and including several correction factors.

While solar irradiance is most commonly measured, a more common form of radiation data used in system design is the solar insolation. The solar insolation is the total amount of solar energy received at a particular location during a specified time period, often in units of $\text{kWh}/(\text{m}^2 \text{ day})$. While the units of solar insolation and solar irradiance are both a power density (for solar insolation the "hours" in the numerator are a time measurement as is the "day" in the denominator), solar insolation is quite different than the solar irradiance as the solar insolation is the instantaneous solar irradiance averaged over a given time period. Solar insolation data is commonly used for simple PV system design while solar irradiance is used in more complicated PV system performance which calculates the system performance at each point in the day. Solar insolation can also be expressed in units of MJ/m^2 per year and other units and conversions are given in the units page.

Solar radiation for a particular location can be given in several ways including:

- Typical mean year data for a particular location
- Average daily, monthly or yearly solar insolation for a given location
- Global isoflux contours either for a full year, a quarter year or a particular month
- Sunshine hours data
- Solar Insolation Based on Satellite Cloud-Cover Data
- Calculations of Solar Radiation

Global solar radiation

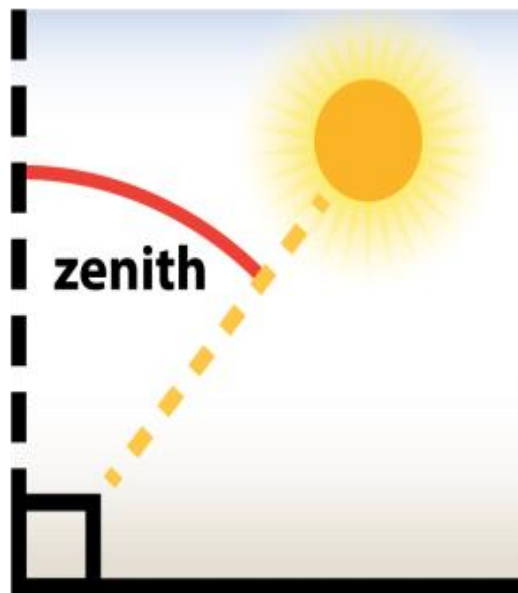
- Our sun outputs radiation over wavelengths from 0.15 to $4.0 \mu\text{m}$, which is called the solar spectrum. The measurement of the sun's radiation on the earth is referred to as global solar radiation. Sometimes called short-wave radiation, global solar radiation is both the

direct and diffuse **solar** radiation received from the hemisphere above the plane of the pyranometer.

- It is difficult to find an environmental process on the earth that isn't driven directly or indirectly by the sun's energy. Therefore, it is likely that global solar radiation affects the process you are researching.

Pyranometer

A pyranometer is a sensor that converts the global solar radiation it receives into an electrical signal that can be measured. Pyranometers measure a portion of the solar spectrum. As an example, the CMP21 Pyranometer measures wavelengths from 0.285 to 2.8 μm . A pyranometer does not respond to long-wave radiation. Instead, a pyrgeometer is used to measure long-wave radiation (4 to 100 μm).



Pyranometers must also account for the angle of the solar radiation, which is referred to as the cosine response. For example, 1000 W/m^2 received perpendicular to the sensor (that is, 0° from zenith) is measured as 1000 W/m^2 . However, 1000 W/m^2 received at an angle 60° from zenith is measured as 500 W/m^2 . Pyranometers that have diffusors instead of glass domes require precise diffusors to provide the correct cosine response.



A pyranometer with a diffusor

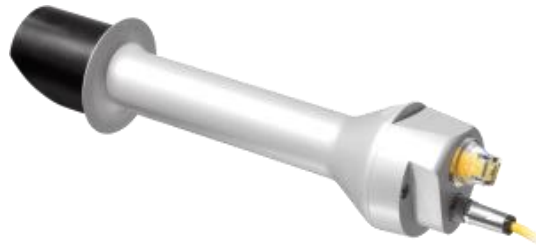
A pyranometer with a glass dome

A net radiometer measures incoming and outgoing short-wave radiation using two thermopile pyranometers, and it measures incoming and outgoing long-wave radiation using two pyrgeometers. These four measurements are frequently part of an energy budget. Energy budget assessments help us understand whether solar energy is being stored in the ground or lost from the ground, reflected, emitted back to space, or used to evaporate water.



A net radiometer

A pyrheliometer consists of a radiation-sensing element enclosed in a casing (collimation tube) that has a small aperture through which only the direct solar rays enter. Radiation bounced off a cloud or particle in the air does not make it through this small opening and collimation tube to the detector. To make measurements all day, a pyrheliometer needs to be pointed directly at the sun using a solar tracker.



A pyrhelimeter

How does a pyranometer measure global solar radiation

The most common types of pyranometers used for measuring global solar radiation are thermopiles and silicon photocells (Tanner, B. "Automated weather stations," 73-98). These pyranometer types are discussed below, along with their advantages and disadvantages.

There are also pyranometers on the market where short-wave radiation (W/m^2) is returned in digital format. This will require either a computer or data logger to read the serial data string (along with the appropriate interface data cable and communications software).

Thermopile pyranometers



Thermopile pyranometers use a series of thermoelectric junctions (multiple junctions of two dissimilar metals—thermocouple principle) to provide a signal of several $\mu\text{V/W/m}^2$ proportional to the temperature difference between a black absorbing surface and a reference. The reference may be either a white reflective surface or the internal portion of the sensor base. The thermopile pyranometer's black surface uniformly absorbs solar radiation across the solar spectrum.

The solar spectrum is the range of wavelengths of the light given off by the sun. Blue, white, yellow, and red stars each have different temperatures and therefore different solar spectrums.

The advantages of thermopile pyranometers relate to their broad usage and accuracy. A thermopile pyranometer's black surface uniformly absorbs solar radiation across the short-wave solar spectrum from 0.285 to 2.800 μm (such as with the CMP6 Pyranometer). The uniform spectral response allows thermopile pyranometers to measure the following: reflected solar radiation, radiation within canopies or greenhouses, and albedo (reflected:incident) when two are deployed as an up-facing/down-facing pair.

Although thermopile pyranometers can be the most accurate type of solar short-wave radiation sensors, they are typically significantly more expensive than silicon photocell pyranometers.

Silicon photocell pyranometers



Silicon photocell pyranometers produce a μA output current similar to how a solar panel converts the sun's energy into electricity. When the current passes through a shunt resistor (for example, 100 ohm), it is converted to a voltage signal with a sensitivity of several $\mu\text{V}/\text{W}/\text{m}^2$. A plastic diffuser is used to provide a uniform cosine response at varying sun angles.

The spectral response of silicon photocell pyranometers is limited to just a portion of the solar spectrum from 0.4 to 1.1 μm . Although these pyranometers only sample a portion of the short-wave radiation, they are calibrated to provide an output similar to thermopile sensors under clear, sunny skies. Silicon photocell pyranometers are often used in all sky conditions, but measurement errors are higher when clouds are present. The uniformity of the daylight spectrum under most sky conditions limits errors typically to less than $\pm 3\%$, with maximum errors of $\pm 10\%$. The error is usually positive under cloudy conditions.

Silicon photocell pyranometers are typically several times less expensive than thermopile pyranometers. For environmental researchers, the accuracy of silicon photocell pyranometers is often sufficient for their requirements.

The disadvantage of silicon photocell pyranometers is that their spectral response is limited to a smaller portion of the solar spectrum from 0.4 to 1.1 μm . These pyranometers perform their best when they are used to measure global solar radiation under the same clear sky conditions used to calibrate them. They should not be used within vegetation canopies or greenhouses, or to measure reflected radiation.

A Comparison of Pyranometers

The following graph shows a comparison between the measured output of an inexpensive silicon-cell pyranometer and a secondary-standard blackbody thermopile reference sensor on both sunny and overcast days:

