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Department of Electrical and Electronic Engineering
EEE: Renewable Energy Technology Laboratory

Title: Measurement of Global Solar Irradiance using Pyranometer.

Abstract:

In this experiment students will learn about the global irradiance and its components. They will also learn about various equipment to measure solar irradiance. An experiment will be performed with Pyranometer to measure the global irradiance hence they will learn about the measurement process using Pyranometer.

Introduction:

A number of radiation parameters are needed for the design, sizing, performance evaluation and research of solar energy applications. These include total solar radiation, beam radiation, diffuse radiation and sunshine duration. Various types of equipment measure the instantaneous and long-term integrated values of beam, diffuse and total radiation incident on a surface. This equipment usually employs the thermoelectric and photovoltaic effects to measure the radiation. In this experiment, students will use Pyranometer to measure the global irradiance.

Theory and Methodology:

The solar heat reaching the earth's surface is reduced below the extraterrestrial normal radiation (1383 W/m^2) because a large part of it is scattered, reflected back out into space and absorbed by the atmosphere. As a result of the atmospheric interaction with the solar radiation, a portion of the originally collimated rays becomes scattered or non-directional. Some of this scattered radiation reached the earth's surface from the entire sky vault. This is called the *diffuse radiation*. The solar heat that comes directly through the atmosphere is termed *direct* or *beam radiation*.

The insolation received by a surface on earth is the sum of diffuse radiation and the normal component of beam radiation. The solar heat at any point on earth depends on

i. The ozone layer thickness
ii. The distance traveled through the atmosphere to reach that point
iii. The amount of haze in the air (dust particles, water vapor, etc.)
iv. The extent of the cloud cover

The earth is surrounded by atmosphere that contains various gaseous constituents, suspended dust and other minute solid and liquid particulate matter and clouds of various types. As the solar radiation travels through the earth's atmosphere, waves of very short length, such as X rays and gamma rays, are absorbed in the ionosphere at extremely high altitude. The waves of relatively longer length, mostly in the ultraviolet range, are then absorbed by the layer of ozone (O_3), located about 15-40 km above the earth's surface. In the lower atmosphere, bands of solar radiation in the infrared range are absorbed by water vapor and carbon dioxide. In the long-wavelength region, since the extraterrestrial radiation is low and the H_2O and CO_2 absorption are strong, little solar energy reaches the ground.

Therefore, the solar radiation is depleted during its passage though the atmosphere before reaching the earth's surface. The reduction of intensity with increasing zenith angle of the sun is generally assumed to be directly proportional to the increase in air mass, an assumption that considers the atmosphere to be unstraified with regard to absorbing or scattering impurities.

The degree of attenuation of solar radiation travelling through the earth's atmosphere depends on the length of the path and the characteristics of the medium traversed. In solar radiation calculations, one standard air mass is defined as the length of the path traversed in reaching the sea level when the sun is at its zenith (the vertical at the point of observation). The air mass is related to the zenith angle (figure 1), without considering the earth's curvature, by the equation below.

$$m = \frac{AB}{BC} = \frac{1}{cos\varphi} \tag{i}$$

Therefore, at sea level when the sun is directly overhead, i.e. when $\varphi = 0^{\circ}$, m =1 (air mass one); and when $\varphi = 60^{\circ}$, we get m=2 (air mass two).

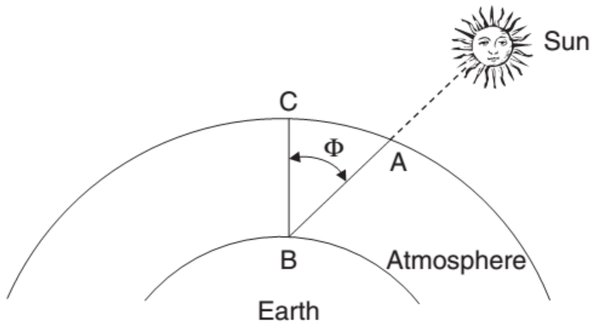


Figure.1: Air mass definition

Similarly, the solar radiation outside the earth's atmosphere is at air mass zero.

There are basically two types of solar radiation measuring instruments: The Pyranometer and the Pyrheliometer. The former is used to measure total (beam and diffuse) radiation within its hemispherical field of view, whereas the latter is an instrument used for measuring the beam radiation at normal incidence. The pyranometer can also measure the diffuse solar radiation if the sensing element is shaded from the beam radiation. For this purpose, a shadow band is mounted with its axis tilted at an angle equal to the latitude of the location plus the declination for the day of measurement. Since the shadow band hides a considerable portion of the sky, the measurements require corrections for that part of diffuse radiation obstructed by the band. Pyrhelimeters are sued to measure direct solar irradiance, required primarily to predict the performance of concentrating solar collectors. Diffuse radiation is blocked by mounting the sensor element at the bottom of a tube pointing directly at the sun. Therefore, a two-axis sun-tracking system is required to measure the beam radiation.

Figure 2: Photograph of a pyranometer

Finally, sunshine duration is required to estimate the total solar irradiation. The duration of sunshine is defined as the time during which the sunshine is intense enough to cast a shadow.

Also, the duration of sunshine has been defined by the World Meteorological Organization as the time during which the beam solar irradiance exceeds the level of 120 W/m^2. Two types of sunshine recorders are used: the focusing type and a type based on the photoelectric effect. The focusing type consists of a solid glass sphere, approximately 10 cm in diameter, mounted concentrically in a section of a spherical bowl whose diameter is such that the sun's rays can be focused on a special card with time marking, held in place by grooves in the bowl. The record card is burned whenever bright sunshine exists. Thus, the portion of the burned trace provides the duration of sunshine for the day. The sunshine recorder based on the photoelectric effect consists of two photovoltaic cells, with one cell exposed to the beam solar radiation and the other cell shaded from it by a shading ring. The radiation difference between the two cells is a measure of the duration of sunshine.

Operating Principle:

A thin absorbing surface is shielded from heat losses and connected to thermocouples. The surface temperature reached is proportional to the incident flux.

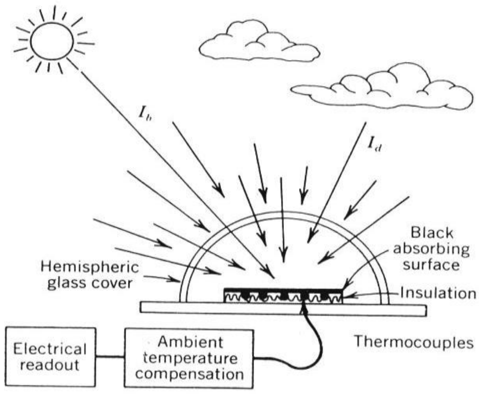


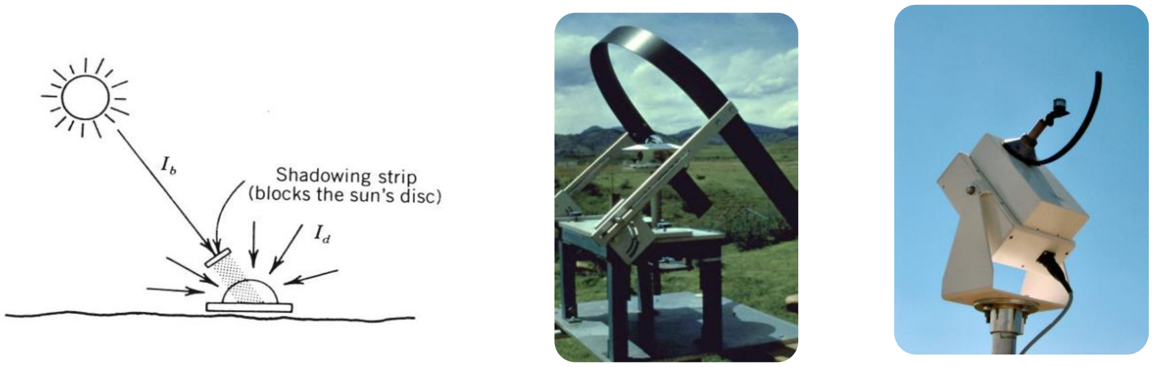
Figure 3: Internal Structure of a Pyranometer

Pyranometers are usually placed flat, where they measure horizontal global irradiance.

$$I_{t,h} = I_b \cos\theta_z + I_{d,h} \quad \text{(ii)}$$

In order to obtain a measure of the diffuse radiation at a site, a shadow-band pyranometer can be used, which blocks the Sun's beam to measure only diffuse radiation. This allows calculation of the beam radiation intensity:

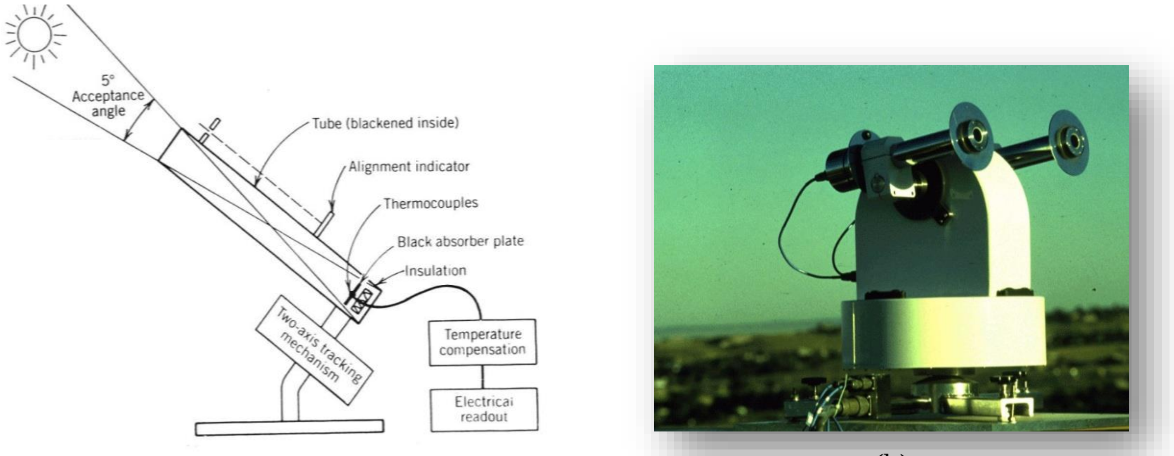
$$I_b = \frac{I_{t,h} - I_{d,h}}{\cos\theta_z} \quad \text{(iii)}$$



(a) (b) (c)

Figure 4: (a) Internal Structure of shadow-band pyranometer (b) Fixed Shadowband (c) Rotating Shadowband

Beam radiation can be measured directly using a normal-incidence pyrheilometer (NIP), which attempts to eliminate diffuse radiation. The NIP must be aligned to point at the Sun. TO simplify operation of the NIP, an acceptance cone of ~%5^0 is used for incident radiation. The NIP will therefore tend to overestimate the value of I_b.



(a) (b)

Figure 5: (a) Internal structure of pyrheliometer (b) Normal-incidence pyrheliometer (NIP)

Pre-Lab Homework:

Students should read the theory before coming to lab.

Apparatus:

1. Pyranometer
2. Ammeter or Clamp meter
3. Lux meter
4. Voltmeter
5. Light Set

Circuit Diagram:

Light Source **Lux Meter** **Pyranometer**

Figure 6: Complete experimental setup (Actual Image will be added later)

Experimental Procedure:

1. Construct the circuit as shown in Figure 6.
2. Initially keep the light at deem position and measure the light intensity using Lux meter and output reading of the pyranometer.
3. Gradually increase the intensity of the light and measure the corresponding reading of the pyranometer.
4. Record at least five values and fill up the following data table.

Data Table:

No.	Light Intensity (w/m^2)	Output reading of Pyranometer
1	0 (Short Circuit)	
2		
3		
4		
5		

Questions for report writing:

1. Define beam and diffuse radiation.
2. Discuss the operating principle of a pyranometer.
3. Why normal-incidence pyrheliometer overestimate the value of beam radiation?

Reference(s):

[1] Gilbert M. Masters, "Renewable and Efficient Electric Power System," Wiley, 2004
[2] Kalogirou, Soteris A. Solar energy engineering: processes and systems. Academic Press, 2009.