EXPERIMENT 1a: Measurement of solar radiation and duration of sunshine

AIM:

1. To measure hourly values of global and diffuse radiation incident on a horizontal surface on a clear day using shaded and unshaded pyranometers and to compare these with values calculated from ASHRAE correlations.
2. To measure the beam normal radiation using pyrheliometer and compare it with that calculated from global and diffuse radiation measured by pyranometer.
3. Introduction to sunshine recorder.

THEORY:

For a clear cloudless day, the global radiation (I_g) reaching a horizontal surface on earth is given by,

$$I_g = I_{bn} \cdot \cos\theta_z + I_d, \qquad (1)$$

As per ASHRAE correlation,

$$I_{bn} = A \cdot \exp(-B/\cos\theta_z)$$

$$I_d = C \cdot I_{bn} \qquad (2)$$

$$\cos\theta_z = \cos\delta \cdot \cos\phi \cdot \cos\omega + \sin\delta \cdot \sin\phi \qquad (3)$$

A, *B* and *C* are constants, appropriate values of which have to be used from table. δ, ϕ, and ω are declination, latitude and hour angle, respectively.

APPARATUS:

Pyranometers (with and without shading ring), pyrheliometer, and sunshine recorder.

PROCEDURE:

1. Check the levelling of the raised platforms and mount the pyranometers and pyrheliometer.
2. Level these instruments with the help of attached spirit levels. Adjust the shading ring corresponding to the latitude (of the place) and declination (of the day of the experiment).
3. Record the output of the pyranometers and pyrheliometer with the help of readout devices.

RESULTS:

Use the appropriate calibration constants to calculate:

1. global and diffuse radiation from pyranometer readings and
2. direct normal radiation from pyrheliometer readings.

Compare these with each other as well as with theoretically calculated values based on ASHRAE model.

PRECAUTION:

The instruments must be levelled properly. The shading ring needs to be adjusted correctly.

EXPERIMENT 1b : Measurement of solar radiation and reflectivity

AIM:

1. To measure infrared (IR) radiation and ultraviolet (UV) radiation and find out their percent fraction in the global radiation measured by pyranometer.
2. To measure reflectivity of samples using albedometer.

APPARATUS:

Infrared radiometer, ultraviolet radiometer, albedometer, and readout devices.

PROCEDURE:

1. Check the levelling of the raised platforms and mount the IR and UV meters. Level these instruments with the help of attached spirit levels. Record the output with the help of readout devices.
2. Adjust the albedometer and take readings with upper and lower pyranometers for different samples at different angles of incidence.

RESULTS:

1. Use the appropriate calibration constants to calculate the IR and UV share in the global radiation.
2. Calculate and report reflectivity of different samples at different angles of incidence.

DETAILS OF RADIATION-MEASURING INSTRUMENTS

SOLAR RADIOMETRY:

The objective of solar radiometry is to measure instantaneous or integrated values of direct, diffuse and total solar radiation incident on a surface. Quite a few instruments have been designed to measure and to study the behaviour of solar radiation. Among the few accurate instruments, the pyranometers, pyrheliometers and sunshine recorders are widely used.

PYRANOMETER:

It is an instrument for measuring global or diffuse solar radiation incident on a horizontal surface. Essentially it consists of a circular (25mm diameter) blackened surface supported inside a relatively massive, well-polished case. It is protected from the weather by two concentric glass domes (30 and 50 mm in diameter) having excellent transmission characteristics for solar radiation. When exposed to solar radiation, the temperature of blackened surface rises till its rate of heat gain is balanced by rate of heat loss. A thermopile, with hot junctions attached to the blackened surface and with cold junctions prevented from receiving radiation, sets up an e.m.f. and is measured by a recorder.

For measuring diffuse radiation, the blackened surface and two glass domes are shaded by a ring from direct sunshine. The shading ring is a semicircular frame fixed in such a fashion that it's plane is parallel to the plane of the path of sun's daily movement across the sky. The pyranometer is mounted at the center of the shading ring.

PYRHELIOMETER:

It is an instrument to measure beam radiation only. Similar to pyranometer, it operates on thermopile effect. The difference is that the blackened disc is located at the base of a tube whose axis is aligned with the direction of sun's rays. Thus the diffuse radiation is blocked. Essentially it consists of a collimating tube blackened on the inside. The tube contains a number of optical diaphragms, behind these lies the detector, which is a multijunction thermopile coated with Parson's black. Direct solar radiation is measured by attaching the instrument to an electrically driven equatorial movement, for tracking the sun.

SUNSHINE RECORDER:

The sunshine recorder consists of a glass sphere mounted in a brass bowl with grooves for holding the recorder cards. The instrument is mounted on a marble base fixed to a raised platform. The glass sphere acts as a lens and produces an image of the sun on a strip of standard treated paper. The solar image burns a mark on the paper and the length of the burned portions of the paper provides an index of duration of bright sunshine.

INFRARED RADIOMETER:

The precision Infrared Radiometer, Pyrgeometer, is an instrument designed for the measurement of (unidirectional) global incoming or outgoing long-wave terrestrial radiation. For the measurement of long-wave radiation in general, and for the isolation of this flux from the solar short-wave radiation in daytime, the instrument is fitted with a broadband infrared transmitting hemisphere (30 mm diameter) of silicon, which is cemented into a removable collar on the instrument case. On the inner surface of the hemisphere is a vacuum-deposited interference filter. The composite envelope transmission exhibits a sharp transition between about 3.0 and 4.0 μm from complete opaqueness to maximum infrared transmittance. The main band, with the typical interference modulation pattern superimposed, has a general transmittance of about 50 % decreasing, with increasing wavelength, to 31 – 40 % around 50 μm. Tests have demonstrated that this coated hemisphere does not exhibit significant transmission of short wavelength sunlight. Absorption and re-emission effects are small and have been discussed by a number of investigators. A thermistor for measurement of the hemisphere temperature has been incorporated in the instrument.

The PIR has a temperature compensation circuit for the thermopile's response variation with temperature as in the Eppley PSP pyranometer. In addition, a thermistor-battery-resistance circuit is incorporated to precisely compensate for emitted radiation. The reason for this capability is to allow for the separation of the signal due to incoming radiation. The thermopile output signal (when used for the measurement of infrared radiation) is representative of net radiation flux at the receiver surface, where;

$R_{net} = R_{in} - R_{out}$

R_{in} (the desired measurement quantity) can be directly measured if the portion of the signal due to R_{out} can be removed as can be seen from;
$R_{in} = R_{net} + R_{out}$

Where R_{out} is essentially dependent on the temperature of the receiver. A voltage, controlled by a thermistor which senses thermopile temperature continuously, is introduced (added) between the thermopile output and the instrument output. The circuit is simple, consisting of a selected thermistor, a 1.35 V battery, a shunt resistor, a series resistor and a variable resistor (potentiometer) is used to precisely set the thermopile sensitivity. The electrical circuit is shown in the attached Wiring Diagram.
The convention for the measurement of the various output quantities relates to the circuit components and the relevant pins on the instrument connector. There are three output functions of the overall thermopile circuitry.

1. The **thermopile output** between pins A and C. Note that the thermopile temperature compensation circuit is in parallel with the thermopile signal and is always in the circuit. When the signal across pins A and C is divided by the sensitivity, the result is the net radiation at the thermopile.

2. The **pyrgeometer output** between pins A and B. This is the normal instrument output function for use when only a single output will be measured. The signal at this output is that which relates to the incoming radiation only, which is usually the desired measurement result. Dividing the signal across pins A and B by the sensitivity yields the incoming radiation value. Note that pin A is negative and pin B is positive.

$$R_{in} = V_{A\text{-}B} \;/\; s$$

   Where $V_{A\text{-}B}$ is the signal voltage measured across pins A and B and S is the sensitivity of the instrument given on the calibration certificate.

3. The **compensation output** may be measured across pins B and C. This output is the signal generated by the radiation compensation circuit and added to the thermopile signal to produce the pyrgeometer output. It offers a method of checking the battery condition.

   In addition to the signal output there are two (2) thermistor temperature sensors available at the connector. The case (or body) thermistor, across pins D and E, is for measurement of the instrument case temperature. This is the temperature, which would be used to calculate the outgoing radiation when the thermopile output is used to measure signal output. Some investigators use this method while not using the battery circuit. The second thermistor, across pins F and G is the hemisphere (or dome) thermistor, which allows measurement of the temperature at the base of the silicon hemisphere. Some investigators use this temperature to apply corrections for dome heating or cooling. The temperature can be obtained from the table of resistance versus temperature.

$$T = 1 / \{c_1 + c_2 \cdot \ln (R_m) + c_3 \cdot (\ln(R_m))^3\}$$

Where T is the absolute temperature, Rm is the measured resistance of the thermistor in ohms (either case or hemisphere), ln indicates the natural logarithm and the values of the constants are;

$c_1 =$ 0.0010295 $= 1.0295 \times 10^{-3}$
$c_2 =$ 0.0002391 $= 2.391 \times 10^{-4}$
$c_3 =$ 0.0000001568 $= 1.568 \times 10^{-7}$

To obtain the temperature in ºC subtract 273.15 from the calculated temperature.

Calibration constant: 3.77 x 10 $^{-6}$ V/W m^{-2}

ULTRAVIOLET RADIOMETER:

The Eppley Ultraviolet Radiometer consists essentially of a selenium barrier-layer photoelectric cell with a sealed-in quartz window, a bandpass filter to restrict the wavelength response of the photocell to the designed range, generally 295-385 nm (i.e. adhering closely to the generally accepted limits for solar ultraviolet radiation reaching the earth's surface, even at altitudes as high a 15,000 feet) and virgin teflon diffusing disk. The purpose of this disk is twofold, viz. to reduce the light intensity at the filtered photocell (and thus to increase its stability with exposure time) and also to improve the adherence of the instrument to the Lambert cosine law (and is shaped with this object in view). The disk is nearly uniformly diffusing over the wavelength range of interest, as well as geometrically within the system. The terminals of the photocell are connected through a precision resistor and the signal measured as a voltage drop across this resistor. By this method, the photometric flux is only of the order 1-2 foot candles and the current flowing in the circuit is restricted to only a few microamp in the extreme, thus satisfying the two conditions for best photocell stability. The whole arrangement is mounted in a painted brass tube; the diffusing disk is removable, but its seating is weatherproofed through the incorporation of an O-ring seal; the tube-stand assembly similarly employs this type of seal. A desiccator is installed in the base of the tube opposite the connector. A circular spirit level is provided on the stand which also contains levelling screws and mounting holes.

Calibration constant: 2.01 x 10 $^{-3}$ V/W m^{-2}

ALBEDOMETER:

The pyranometer CM 11 is designed for measuring the irradiance (radiant-flux, watt/m^2) on a plane surface, which results from the direct solar radiation and from the diffuse radiation incident from the hemisphere above.

Because the CM 11 exhibits no tilt dependence it can measure solar radiation on surfaces inclined as well. In the inverted position reflected solar radiation can be measured. The albedometer CM 14 is based on two CM 11 sensors and is suitable for the measurement of net global radiation and/or albedo over surfaces of different nature. For measuring the diffuse component of solar radiation only, the direct solar component can be shielded semi-automatically from the pyranometer by the Kipp & Zonen shadow ring CM 121.

The CM 11 pyranometer complies with the specifications for ‘secondary standards’ the best of three classes, as published in the ‘Guide to meteorological Instruments and Methods of Observation’, Fifth Edition, 1983, of the World Meteorological Organization (WMO) – Geneva – Switzerland. The WMO classification list is adopted, improved and extended by the International Standard Organization ISO and published as ISO 9060. This standard is one of a series of standards specifying methods and instruments for the measurement of solar radiation. In this manual the specifications of accuracy are listed according the ISO list.

SPECIFICATIONS OF PYRANOMETER CM 11

Performance

Response Time (Time for 95 % response) **:** < 15 s

Zero off-set

Response to 200 $W.m.^{-2}$ net thermal radiation (ventilated) **:** + 7 W m^{-2}
Response to 5 K h^{-1} change in ambient temperature **:** ± 2 W m^{-2}

Non-stability (Percentage change responsitivity per year) **:** ± 0.5 %

Non-linearity **:** ± 0.6 %
Percentage deviation from the responsitivity at 500 Wm^{-2} due to the change in irradiance within 100 Wm^{-2}- to 1000 Wm^{-2}.

Directional response for beam radiation **:** ± 10 W m^{-2}
The range of errors caused by assuming that the normal incidence responsitivity is valid for all directions when measuring from any direction a beam radiation whose normal incidence irradiation is 1000 W m^{-2}

Spectral selectivity **:** ±2 %
Percentage deviation of the product of spectral absorptance and spectral transmittance from the corresponding mean within 0.35 μm and 1.5 μm

Temperature response **:** ±1%
Percentage deviation due to change in ambient temperature from –10 to +40ºC relative to 20ºC

Tilt Response **:** ±0.25%
Percentage deviation from the responsivity at 0º tilt (horizontal) due to change in tilt from 0º to 90º at 1000 $W.m^{-2}$ irradiance

Viewing angle **:** 2π sr

Irradiance **:** 0-1400 W/m^2 (max. 4000 W/m^2)

Spectral range:	50 % points	: 305-2800 nm
	95 % points	: 335-2200 nm
Sensitivity		: between 4 and 6 μV/W m^{-2}

Impedance	: 700-1500 Ω

Construction

Receiver Paint	: Carbon black

Glass domes**:** Schott K5 optical glass 2 mm thick, 30 mm and 50 mm outer diameter.

Desiccant	: Silica gel

Spirit level**:** Sensitivity 0.1 degree (bubble half out of the ring) Coincide with base of the instrument. Detector surface and base are coplanar within 0.1°

Materials**:** Anodized Aluminium case Stainless steel screws in stainless steel bushes. White plastic screen of ASA Drying Cartridge PMMA.

Weight	: 830 g
Cable Length	: 10 m

SPECIFICATIONS OF ALBEDO VERSION CM 14

1. The general specifications of the CM 11 pyranometer also apply to the albedometer CM 14.
2. Sensors of equal sensitivity.
3. Conical lower screen, which prevents illumination of the lower glass dome at sunrise and sunset.

Impedance	:	Depends on connection
Weight, including rod	:	1.9 kg
Cable length	:	10 m

ELECTRICAL CONNECTION CM 14

The CM 14 is provided with a 10 m cable with shield and five leads.

The colour code is	Red	:	+	upper sensor
	Blue	:	-	upper sensor
	Green	:	+	lower sensor
	Yellow	:	-	lower sensor
	White	:	case	

There are two modes of operating an albedometer:

1. With the sensors connected in anti-series, the net global radiation is measured.
2. When the outputs are recorded separately, the albedo can be calculated by dividing reflected by global radiation.