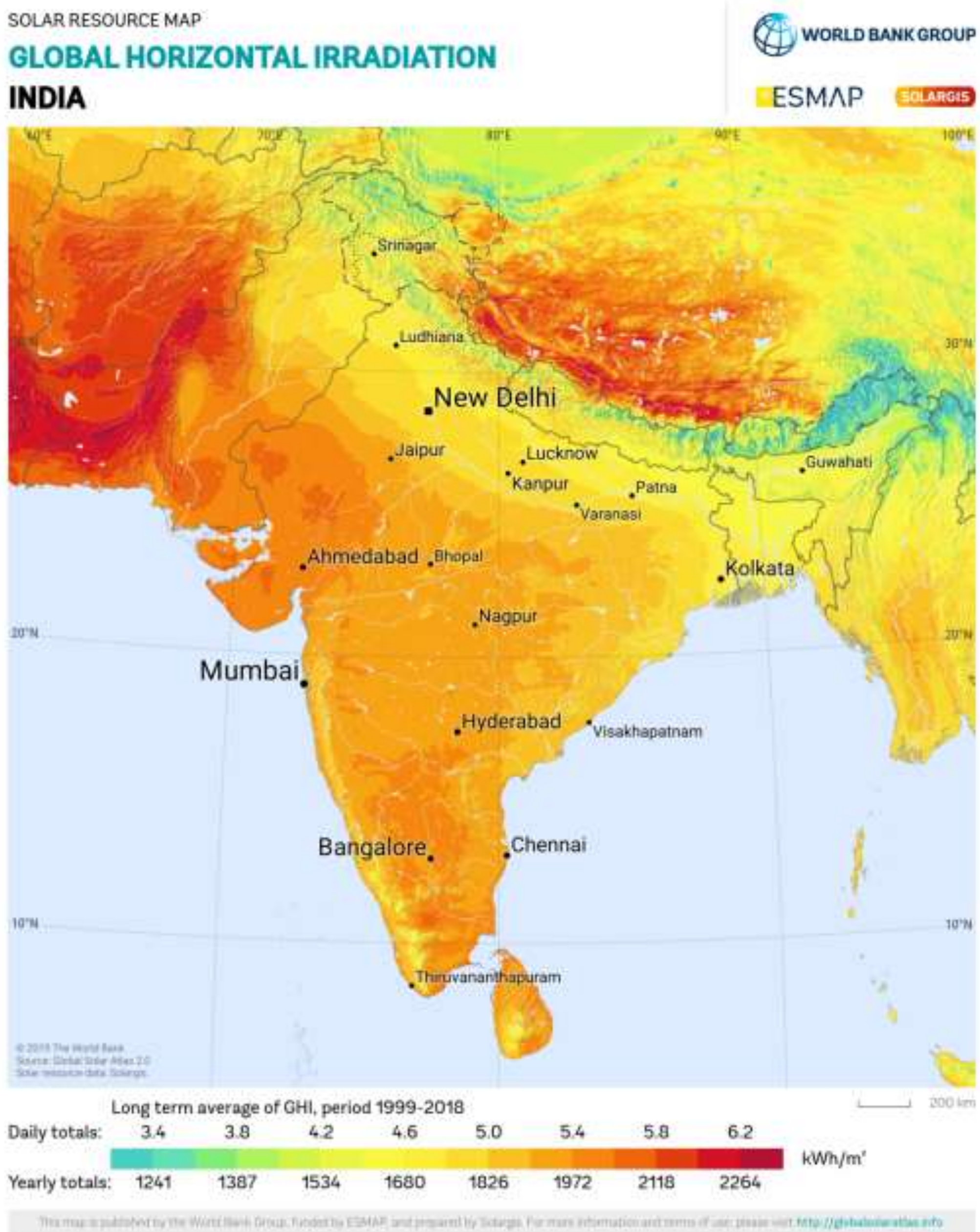
Renewable Energy Sources

Chapter:2: Solar Energy


- The industrial ages gave us the understanding of sunlight as an energy source. India is endowed with vast solar energy potential.
- About 5,000 trillion kWh per year energy is incident over India's land area with most parts receiving 4-7 kWh per sq. m per day.
- Solar photovoltaics power can effectively be harnessed providing huge scalability in India. Solar also provides the ability to generate power on a distributed basis and enables rapid capacity addition with short lead times


SOLAR RESOURCE MAP
GLOBAL HORIZONTAL IRRADIATION
INDIA
WORLD BANK GROUP
ESMAP
SOLARGIS
Srinagar
Ludhiana
New Delhi
Jaipur
Lucknow
Kanpur
Patna
Varanasi
Guwahati
Ahmedabad
Bhopal
Kolkata
Nagpur
Mumbai
Hyderabad
Visakhapatnam
Bangalore
Chennai
Thiruvananthapuram
20°N
10°N
Long term average of GHI, period 1999-2018
Daily totals: 3.4 3.8 4.2 4.6 5.0 5.4 5.8 6.2
kWh/m²
Yearly totals: 1241 1387 1534 1680 1826 1972 2118 2264
200 km

The Sun

- The Sun is at the centre of our solar system. It is a yellow dwarf star, with a hot ball of glowing gases. Its gravity holds the solar system together and it keeps everything from the biggest planets to the smallest particles of debris in its orbit.
- Electric currents in the Sun generate a magnetic field that is carried out through the solar system by the solar wind.

Structure of the Sun

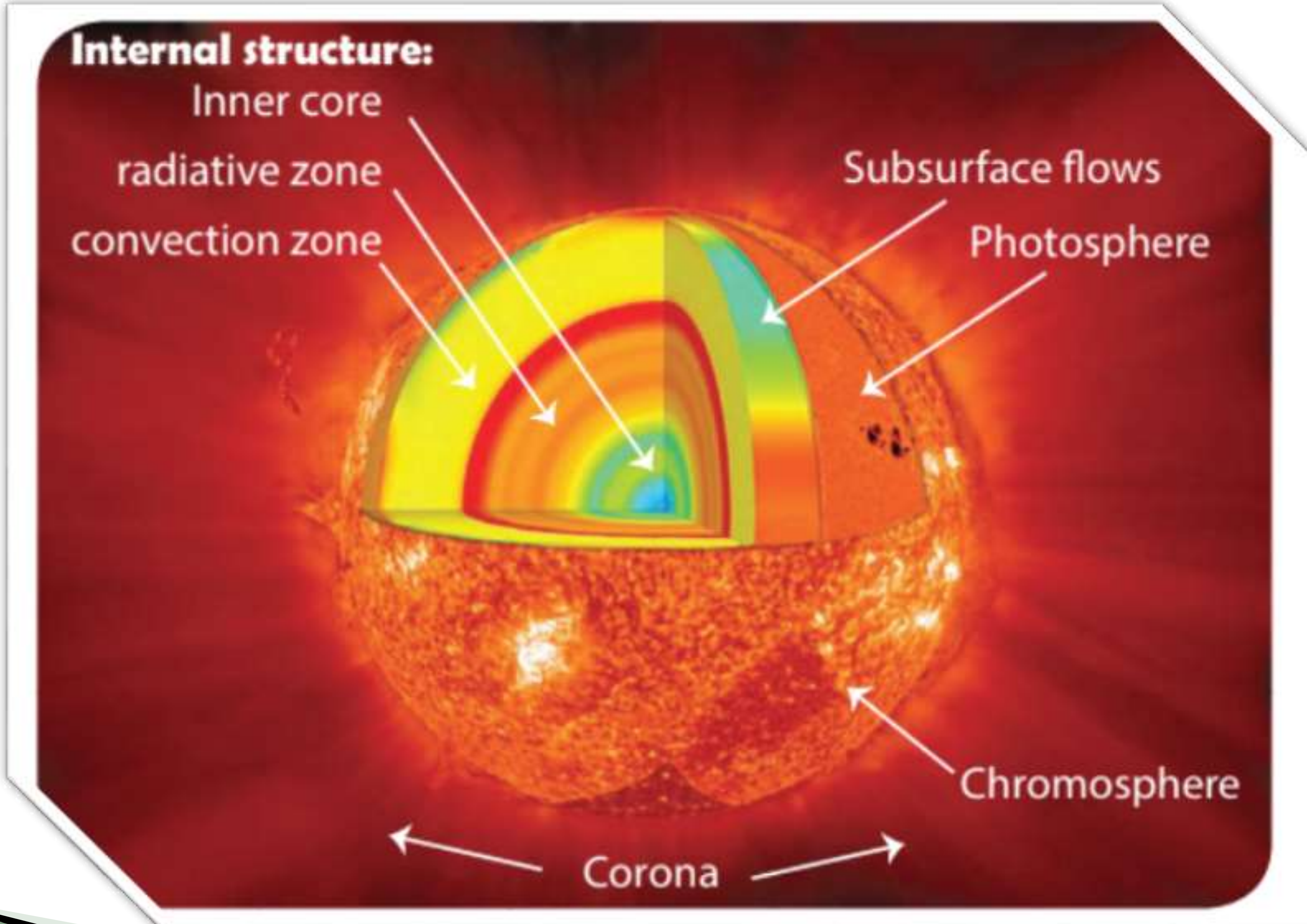
By mass, the Sun is made up of about

- 70.6% hydrogen,
- 27.4% helium and
- 2% other gases.

- The Sun's enormous mass is held together by gravitational attraction, producing immense pressure and temperature at its core.

There are three main layers in the Sun's interior:

- the core,
- the radiative zone, and
- the convective zone


Internal structure:
Inner core
radiative zone
convection zone
Subsurface flows
Photosphere
Chromosphere
Corona

- The core is at the centre. It is the hottest region, where the nuclear fusion reaction to give the sun power.
- Moving outward next come the radiative (or radiation) zone. Its name is derived from the way energy is carried outward through this layer, carried by photons as thermal radiation.
- The third and final region of the solar interior is named the convective (or convection) zone. It is also named after the dominant mode of energy flow in this layer.
- The boundary between the Sun's interior and the solar atmosphere is called the Photosphere. It is what we see as the visible ‘surface’ of the Sun.

Sun has an atmosphere?

- The lower region of the solar atmosphere is called the Chromosphere.
- Its name is derived from the Greek word chroma (meaning colour), for it appears bright red when viewed during a solar eclipse.
- A thin transition region, where temperature rises sharply, separates the chromospheres from the vast corona above. The uppermost portion of the Sun's atmosphere is called the corona, and is surprisingly much hotter than the Sun's surface (photosphere).
- The upper corona gradually turns into the solar wind. Solar wind is a flow of plasma that moves outward through our solar system into interstellar space.

Sun has six regions:

- the core,
- the radioactive zone,
- and the convective zone in the interior;

- The photosphere;
- the chromospheres;
- and the corona.

- The temperature of the sun’s surface is about 5,500°C to 6,000°C

- At the core, the temperature is about 15 million°C, which is sufficient to sustain thermonuclear fusion.
- This is a process in which atoms combine to form larger atoms and in this process, released staggering amounts of energy. Specifically, in the Sun’s core, hydrogen atoms fuse to make helium.

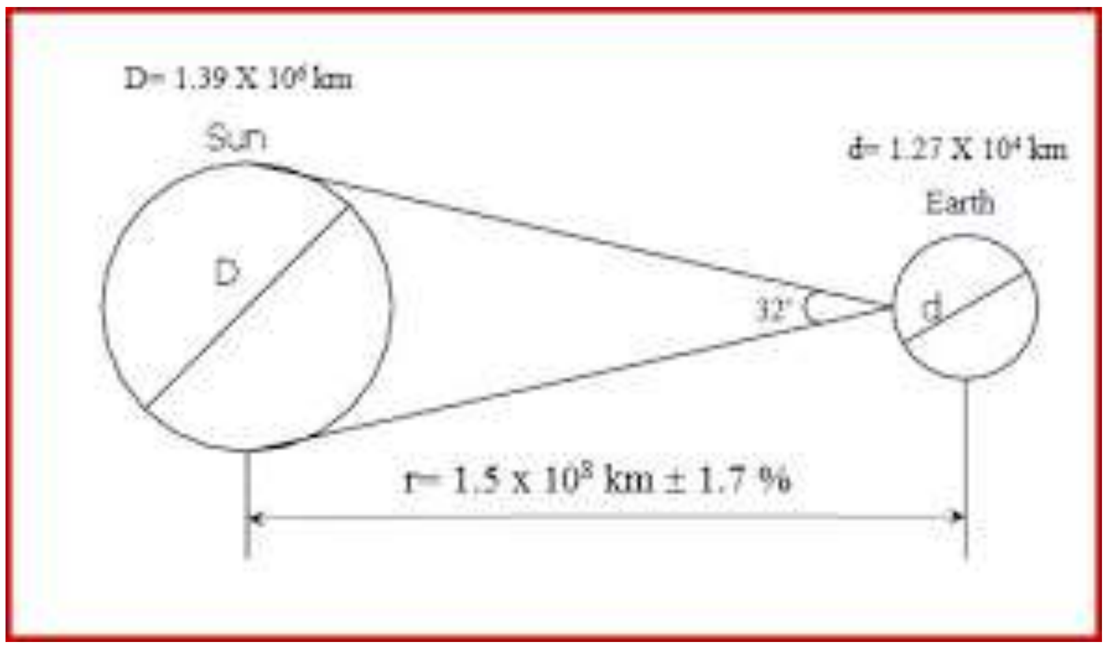
Source of Energy

$H+H+H+H=He$

$E=mc^2$

Sun Earth Geometric Relation

For practical purpose we consider Earth as a sphere of a dia. of 12,800 km. The Earth makes one rotation about its axis every 24 hours and complete one revolution about the SUN is 365.25 days .It is inclined at an angle of 23.5°. As a result the length of day and night keep changing.

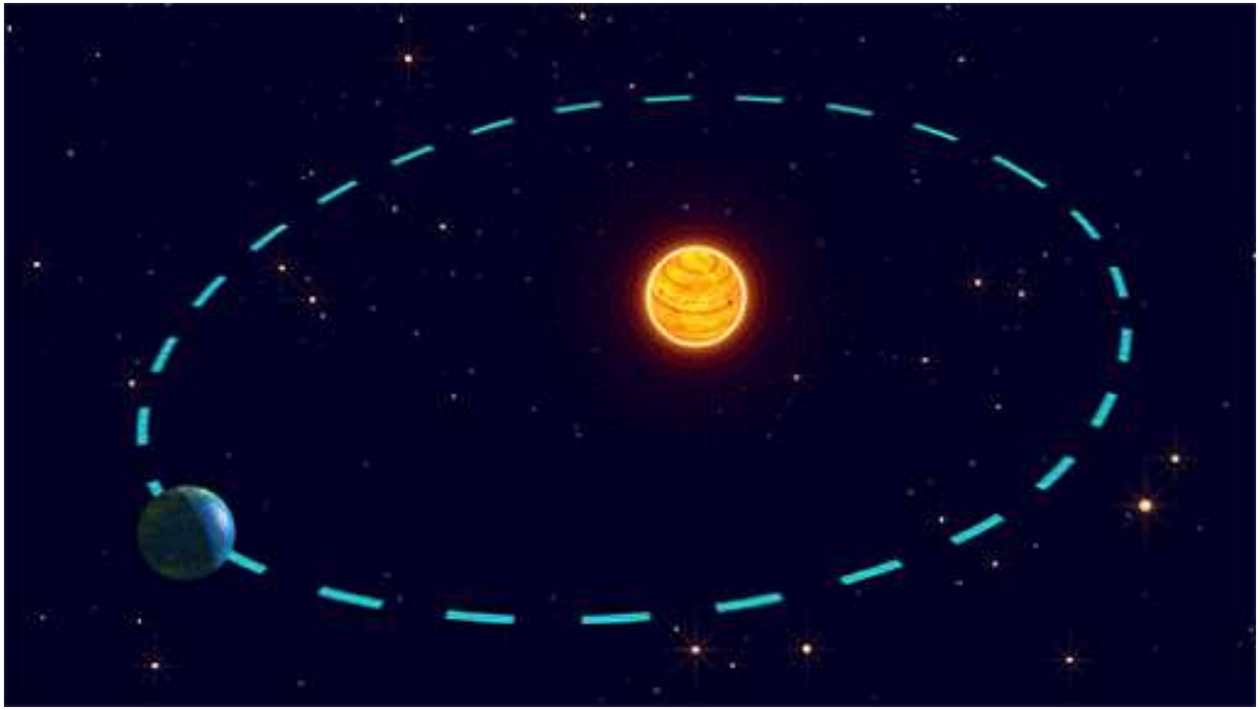


Heating of Earth

INSOLATION

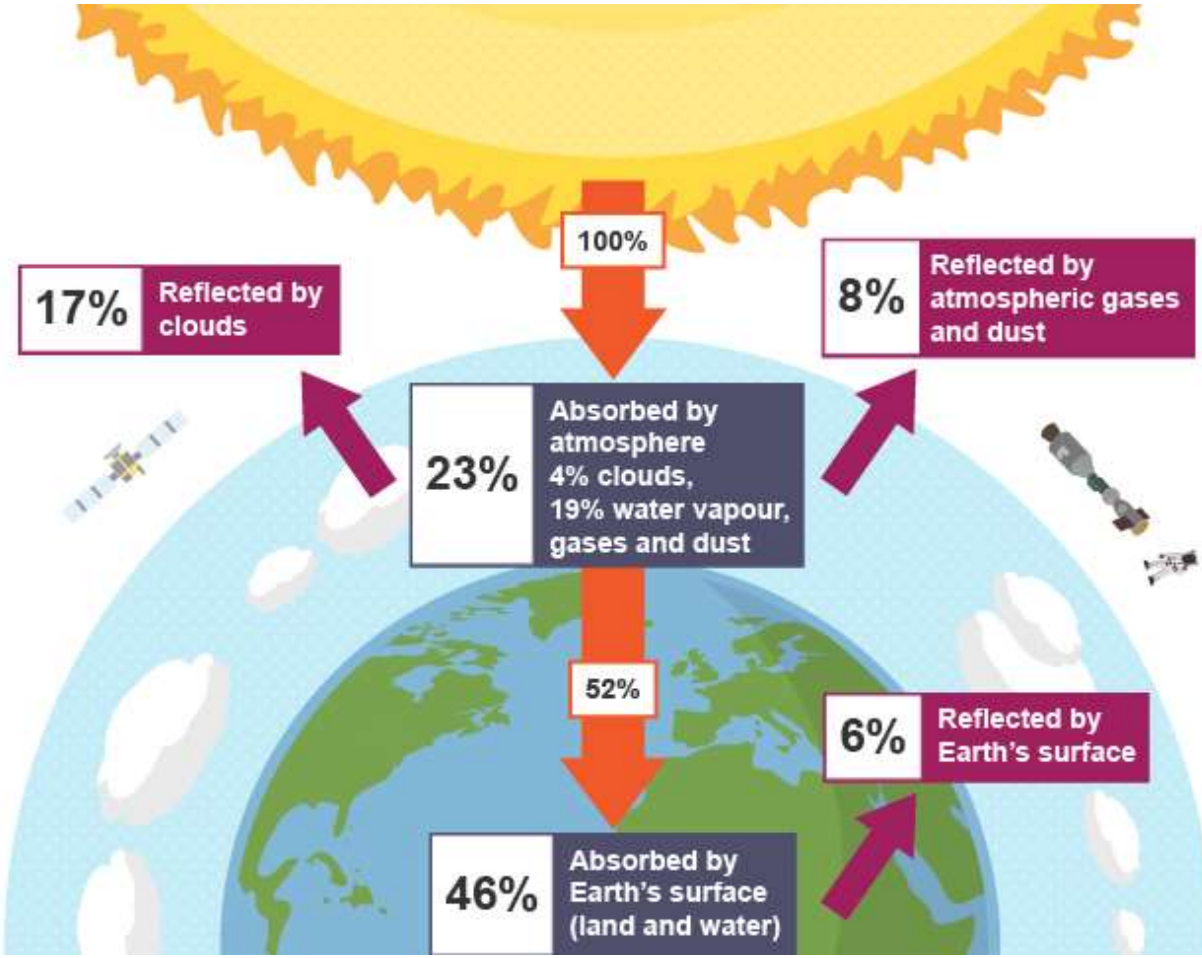
- The earth's surface receives most of its energy in short wavelengths. The energy received by the earth is known as incoming solar radiation which in short is termed as insolation.
- As the earth is a geoid resembling a sphere, the sun's rays fall obliquely at the top of the atmosphere and the earth intercepts a very small portion of the sun's energy. On an average the earth receives 1.94 calories per sq. cm per minute at the top of its atmosphere

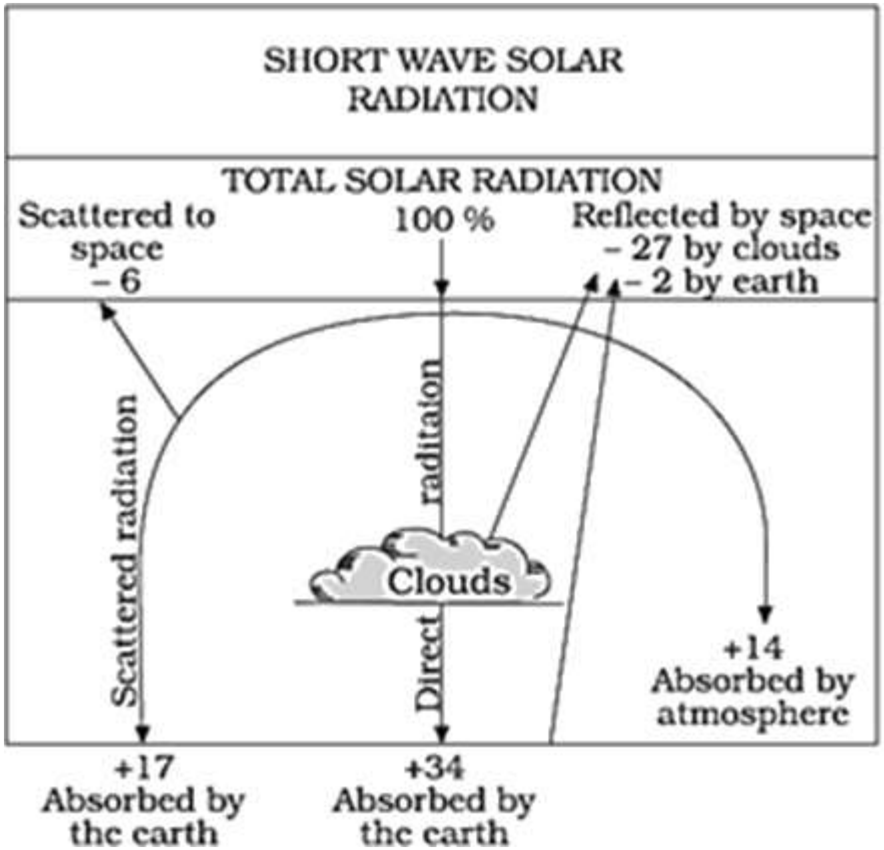
- The solar output received at the top of the atmosphere varies slightly in a year due to the variations in the distance between the earth and the sun.
- During its revolution around the sun, the earth is farthest from the sun (152 million km) on 4th July. This position of the earth is called aphelion.
- On 3rd January, the earth is the nearest to the sun (147 million km). This position is called perihelion

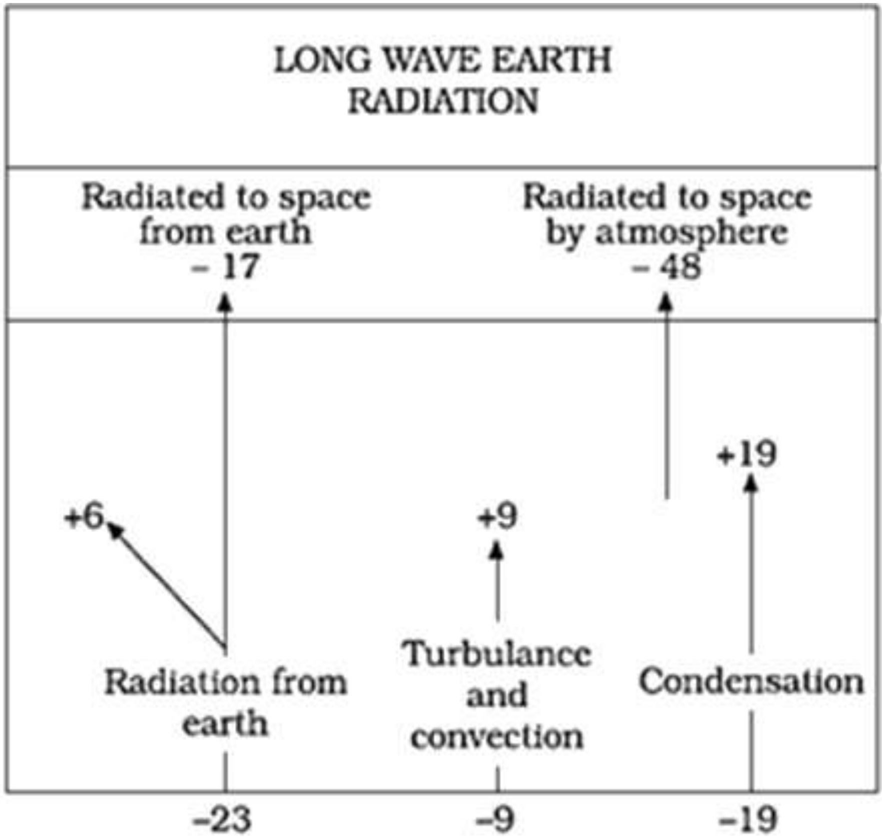


- The insolation received at the surface varies from about 320 Watt/m2 in the tropics to about 70 Watt/m2 in the poles.
- Maximum insolation is received over the subtropical deserts, where the cloudiness is the least.
- Equator receives comparatively less insolation than the tropics.
- Generally, at the same latitude the insolation is more over the continent than over the oceans. In winter, the middle and higher latitudes receive less radiation than in summer.

Heat Budget

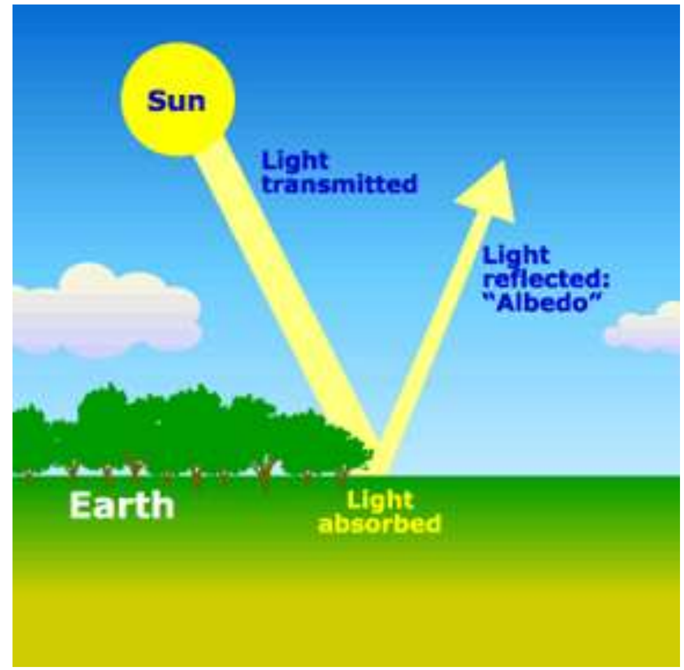

100%
17%
Reflected by clouds
8%
Reflected by atmospheric gases and dust
23%
Absorbed by atmosphere
4% clouds,
19% water vapour, gases and dust
52%
6%
Reflected by Earth's surface
46%
Absorbed by Earth's surface (land and water)


SHORT WAVE SOLAR RADIATION
TOTAL SOLAR RADIATION
Scattered to space
– 6
100 %
Reflected by space
– 27 by clouds
– 2 by earth
Scattered radiation
Direct raditaion
Clouds
+14
Absorbed by atmosphere
+17
Absorbed by the earth
+34
Absorbed by the earth


LONG WAVE EARTH RADIATION
Radiated to space from earth
– 17
Radiated to space by atmosphere
– 48
+6
+9
+19
Radiation from earth
Turbulance and convection
Condensation
–23
–9
–19

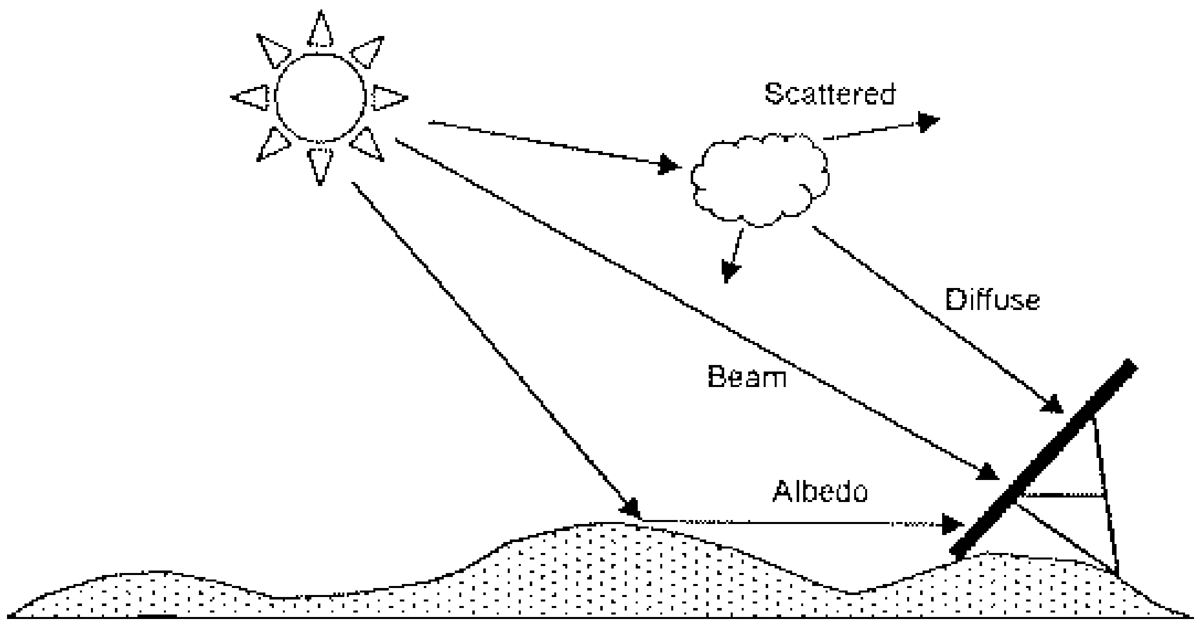
ALBEDO

Ratio between the total solar radiation falling upon a surface and the amount reflected
Represents as %
Earth’s avg. Albedo = 35%
Lowest- dark soil
highest - snowfall



surface	Albedo
Fresh snow	80%-90%
Desert	35-45%
Grasses	26%
Crops	15%
Brick - concrete	10-20%

Direct and Diffused Radiation



- the beam radiation that we have just seen the solar radiation that does not get absorbed or
- scattered. So, but reaches the ground directly from the sun. It produces shadow when
- interrupted by an opaque object. The diffusive radiation is the one; the solar radiation
- received after its direction has been changed by reflection and scattering in the atmosphere.

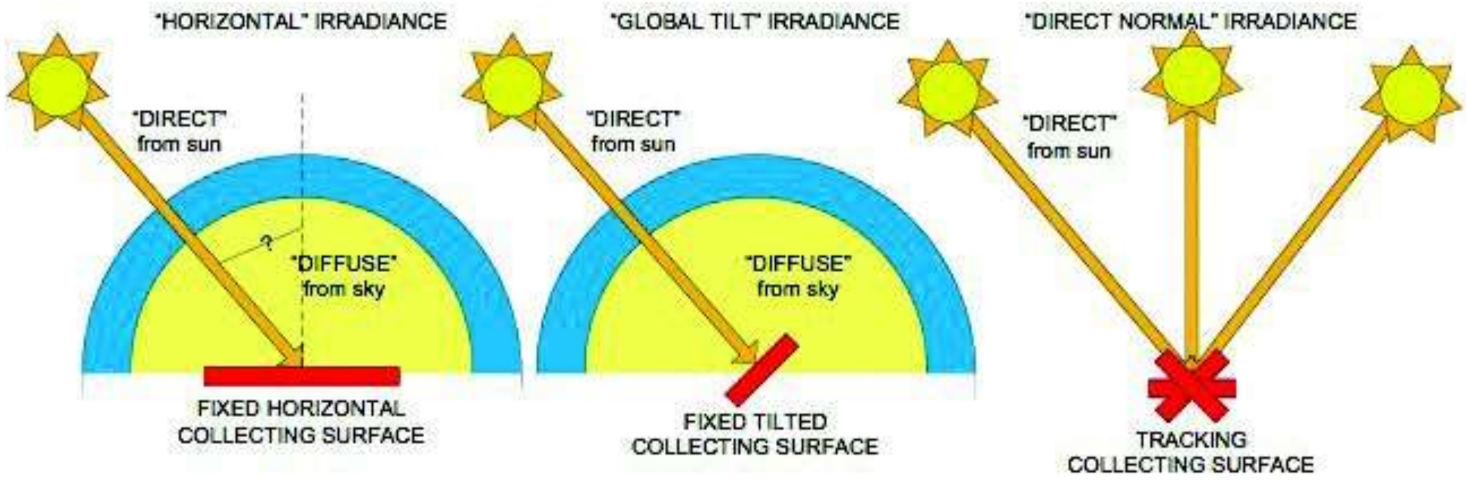
Basic Terminology

- The amount of radiant energy emitted by the **sun** is called **solar radiation**, While **solar irradiation** refers to the amount of **solar radiation** received from the **Sun** per unit area which is expressed in (kW/ m^2).
- So, if we take instant energy that is Joule per meter square obtained by integrating a irradiance over a specified time interval.

- We can do it by day or we can do it per hour and the second if you are doing that is instant
- then specifically for solar irradiance. This is called insulation. So, if you integrate it over a day or hour, this is called insulation. So, we use the symbol H for a day and I for a insulation for an hour.
- it can be given as watt per meter square as a flux which is nothing but radiant energy falling on a surface per unit area or we can give them in terms of Joules per meter square day or hour instead of joule per second meter square.

- So, the measurement of some of the direct and diffusive radiation is called the global solar irradiance. So, this is beam and this is scattered diffusive radiation.
- This is albedo. Either it can reach earth’s surface or it can go back to space as well.

- **Direct Normal Irradiance (DNI)** is the amount of solar radiation received per unit area by a given surface that is always held perpendicular to the incoming rays. The amount of irradiance can be maximized by keeping the receiving and electricity-generating surface - the PV module - on optimal track with the movement of the sun and thus of the sun rays.

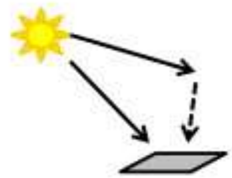


"HORIZONTAL" IRRADIANCE
"DIRECT" from sun
"DIFFUSE" from sky
?
FIXED HORIZONTAL COLLECTING SURFACE
"GLOBAL TILT" IRRADIANCE
"DIRECT" from sun
"DIFFUSE" from sky
FIXED TILTED COLLECTING SURFACE
"DIRECT NORMAL" IRRADIANCE
"DIRECT" from sun
TRACKING COLLECTING SURFACE

Measuring light from different sources

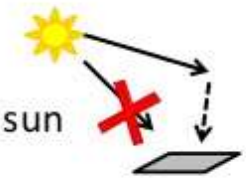
GHI = Global horizontal irradiance

- Light coming from all parts of the sky
- Measured on a horizontal surface



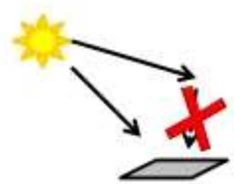
DHI = Diffuse horizontal irradiance

- Light not coming directly from the sun
- Measured on a horizontal surface



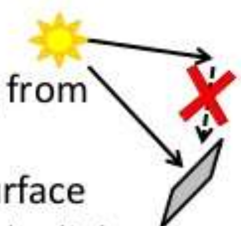
DirHI = Direct horizontal irradiance

- Light only coming from the sun
- Measured on a horizontal surface



DNI = Direct normal irradiance

- Light only coming from the sun
- Measured on a surface perpendicular to the light



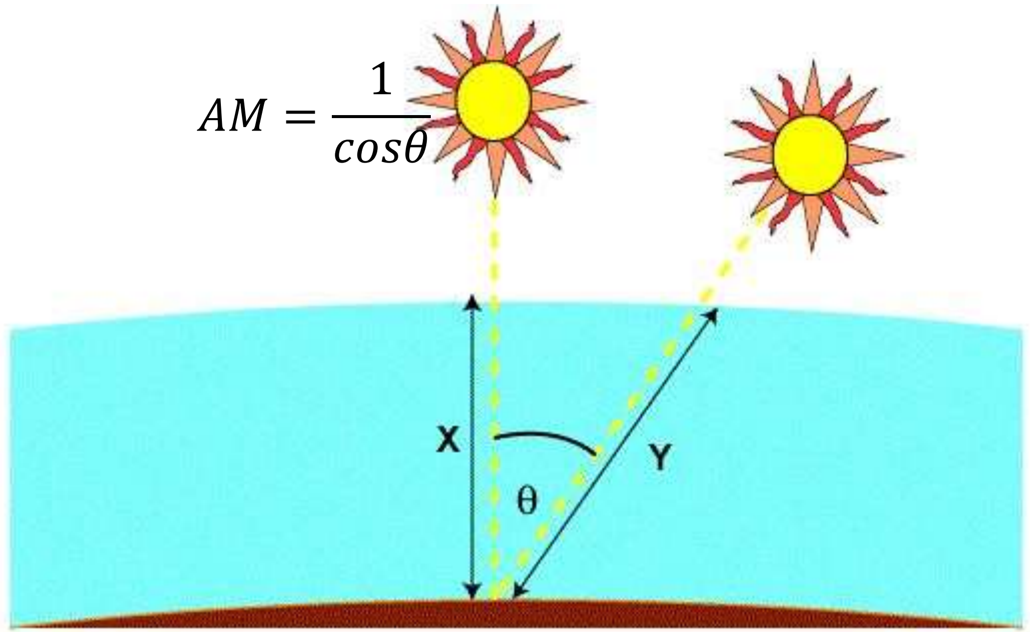
Air Mass

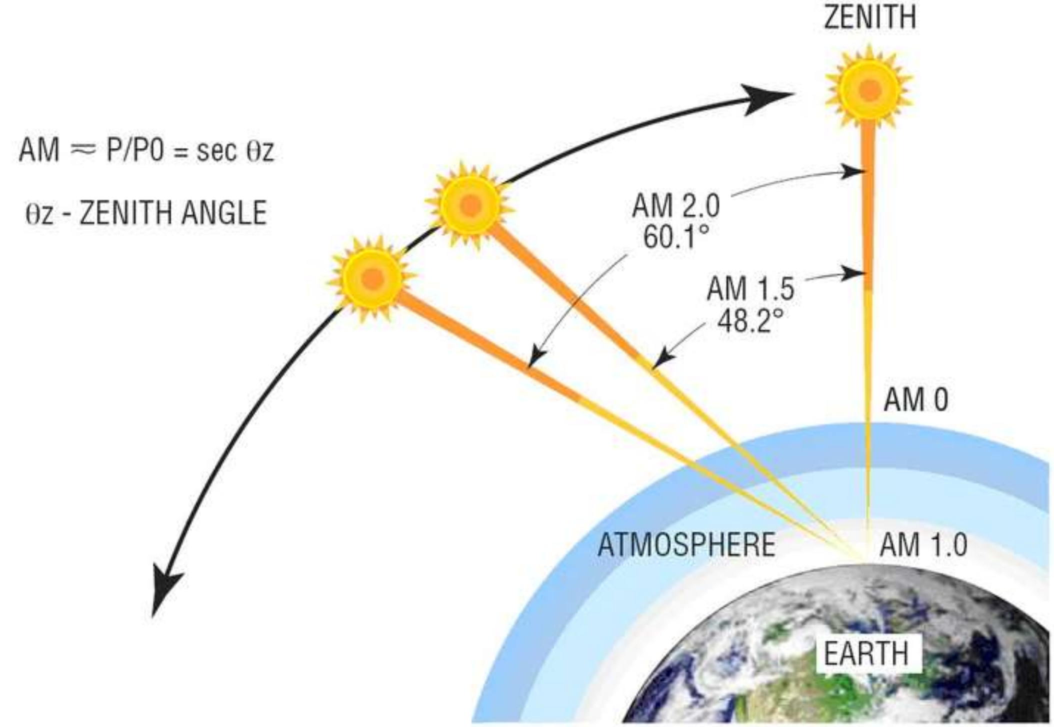
- ***Air mass*** is often used as a measure of a distance travelled by beam radiation through the atmosphere before it reaches a location on the earth's surface**.**
  - Air Mass zero (AM0) corresponds to extraterrestrial radiations,
    Air Mass one (AM1) corresponds to the case of the Sun at its zenith,
    Air Mass two (AM2) corresponds ti the case of a zenith angle of 60°.

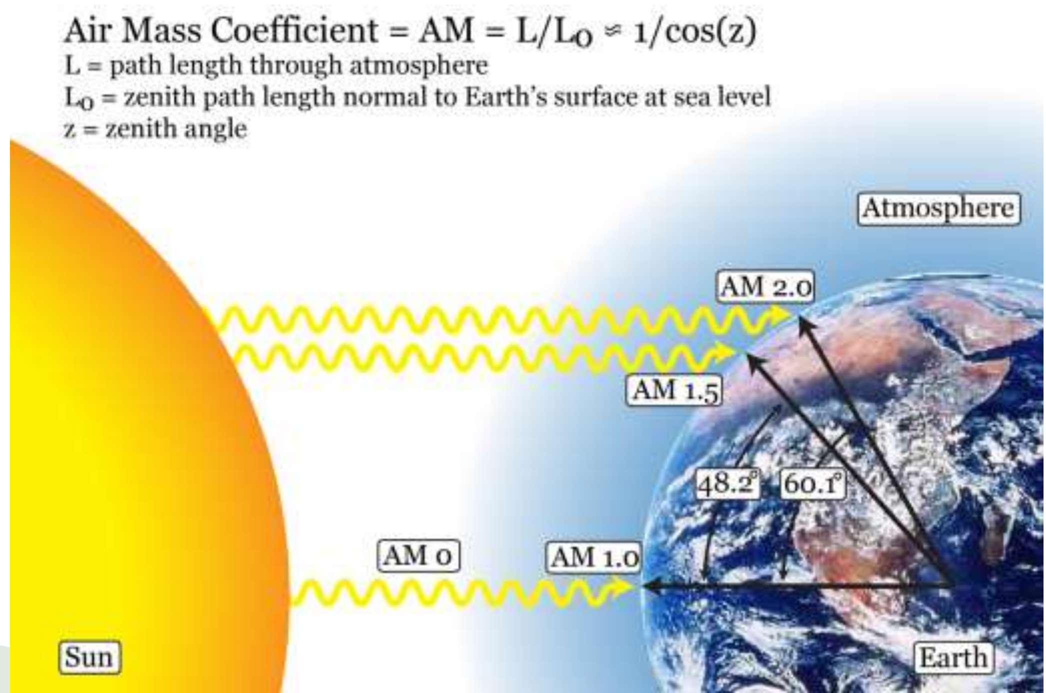
Air Mass

- The Air Mass is defined as the mass of the atmosphere through which the beam radiation passes to the mass it would pass through if the Sun is directly overhead (at zenith). The Air Mass quantifies the reduction in the power of light as it passes through the atmosphere and is absorbed by air and dust.

$$AM = \frac{1}{cos\theta}$$




ZENITH
AM ≈ P/P0 = sec θz
θz - ZENITH ANGLE
AM 2.0
60.1°
AM 1.5
48.2°
AM 0
ATMOSPHERE
AM 1.0
EARTH


Air Mass Coefficient = AM = L/L$_O$ ≈ 1/cos(z)
L = path length through atmosphere
L$_O$ = zenith path length normal to Earth's surface at sea level
z = zenith angle
Atmosphere
AM 2.0
AM 1.5
48.2°
60.1°
AM 0
AM 1.0
Sun
Earth

Radiation Measuring Instruments

- The most commonly used instruments to measure solar radiation today are based on either the thermoelectric or the photoelectric effects.
- The thermoelectric effect is achieved using a thermopile that comprises collections of thermocouples, which consist of dissimilar metals mechanically joined together. They produce a small current proportional to their temperature.

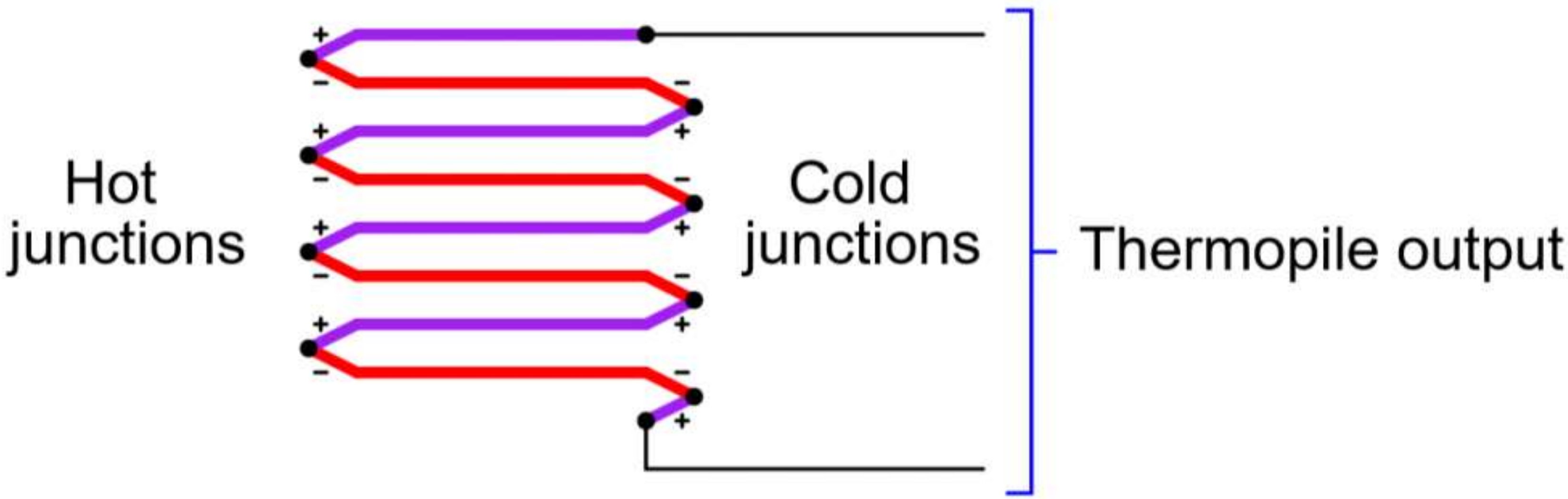


Figure- Thermopile

- When thermopiles are appropriately arranged and coated with a dull black finish, they serve as nearly perfect blackbody detectors that absorb energy across the entire range of the solar spectrum. The hot junction is attached to one side of a thin metallic plate.
- The other side of the plate is blackened to be highly absorptive when exposed to the Sun’s radiation. The cold junction is exposed to a cold cavity within the instrument. The output is compensated electrically for the cavity temperature.
- The amount of insolation is related to the elevated temperature achieved by the hot junction and the electromagnetic force generated. The response is linearized and calibrated so that the output voltage can be readily converted to the radiative flux.

Pyranometer

- To measure global or diffuse radiation

Pyrheliometer

- To measure beam radiation

Sunshine Recorder

- To measure bright Sunshine or duration in hours

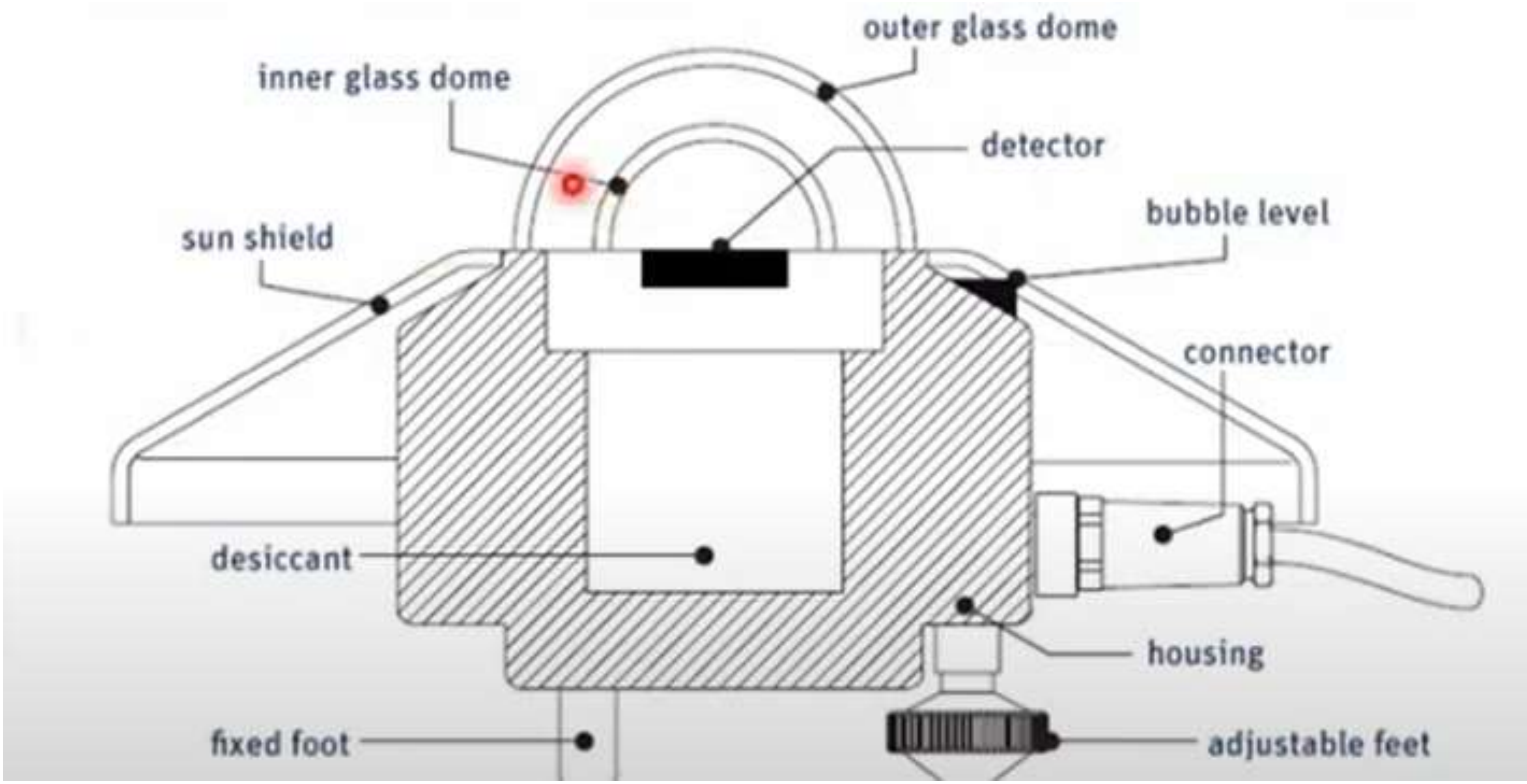
Pyrgeometer

- To measure terrestrial radiation

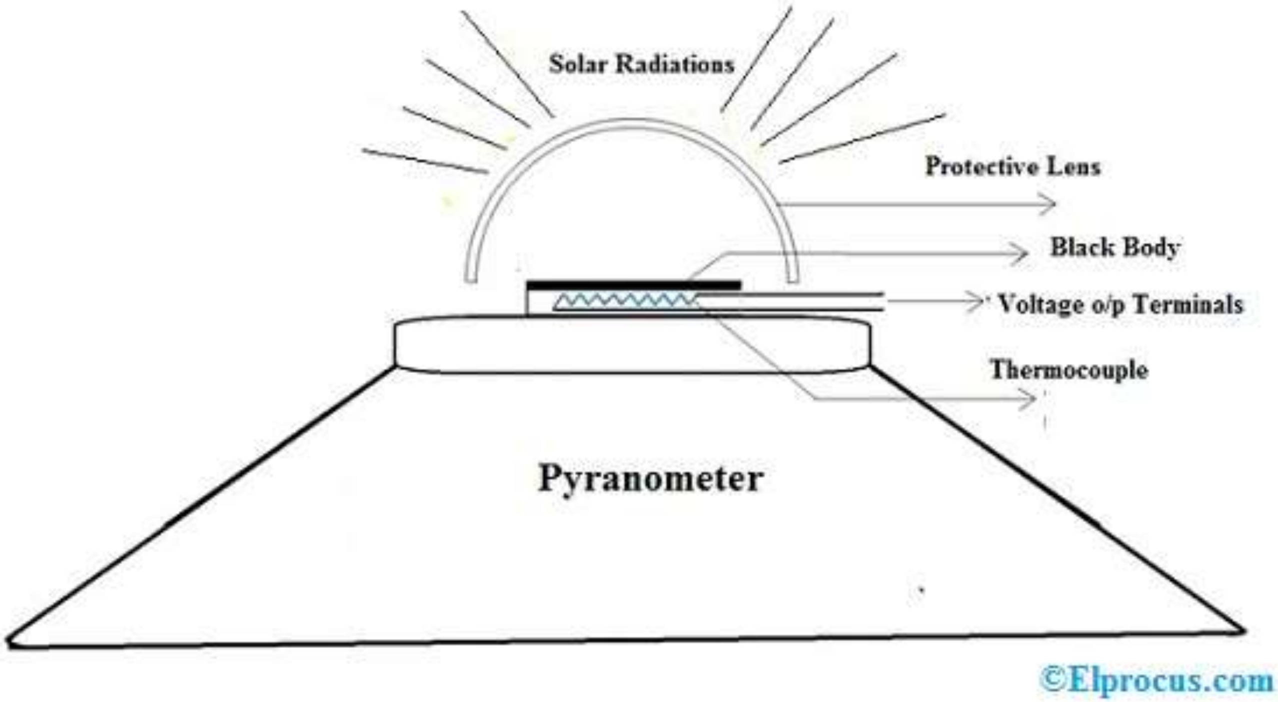
Pyranometer

- Pyranometer: Measures either Global or Diffuse radiation falling on a horizontal surface over a hemispherical field of view. The hot junction of thermopile is connected to the black surface; while cold junctions are locate under guard plate so that they do not receive radiation directly. It has an accuracy of ±2%.

- the temperature difference derived between the radiation-sensing element (the hot junction) and the reflecting surface (the cold junction) that serves as a temperature reference point is expressed by a thermopile as a thermo electromotive force.



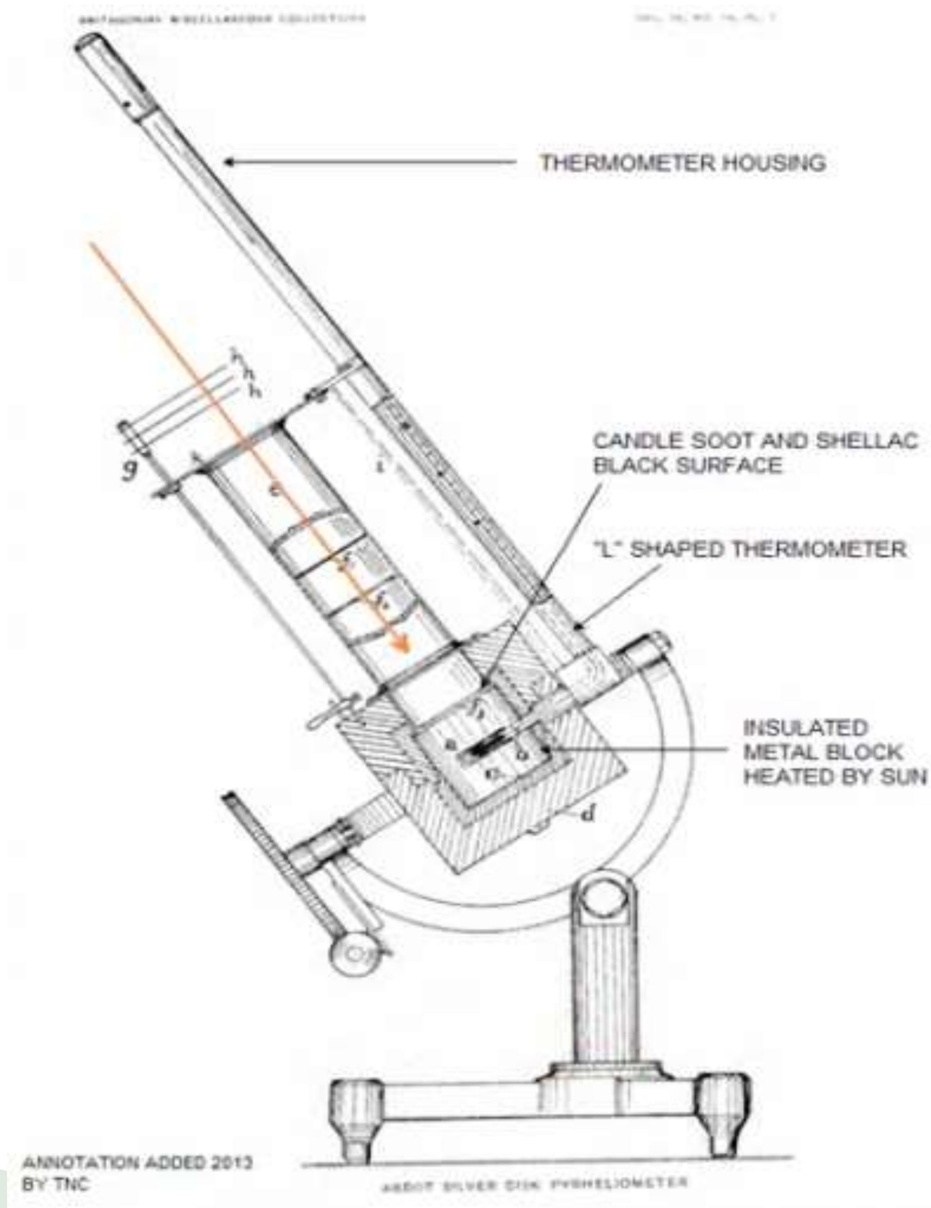
outer glass dome
inner glass dome
detector
bubble level
sun shield
connector
desiccant
housing
fixed foot
adjustable feet

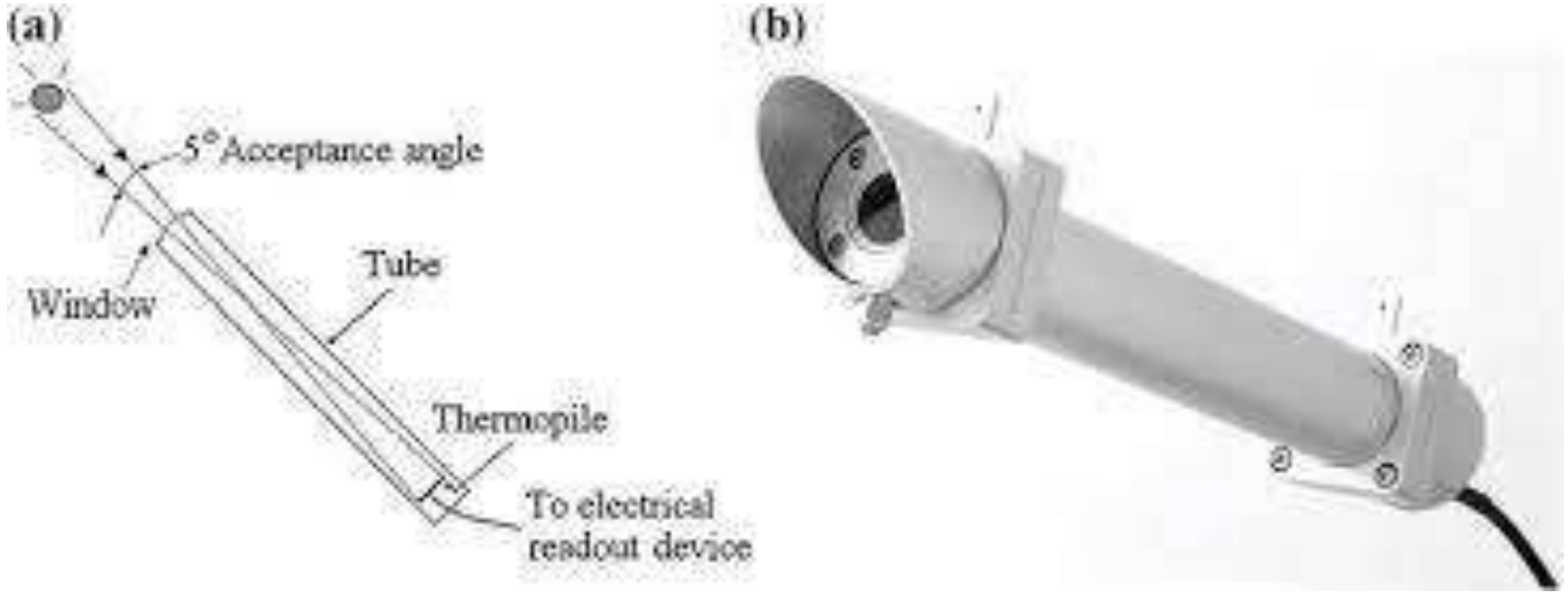

Solar Radiations
Protective Lens
Black Body
Voltage o/p Terminals
Thermocouple
Pyranometer
©Elprocus.com

Shading Ring- Diffused Rdiation

Pyrheliometer– Construction

1) Collimator Tube
2) Black Absorber Plate
3) Baffles
4) Thermopile
5) Pivot for 2 axis Rotation

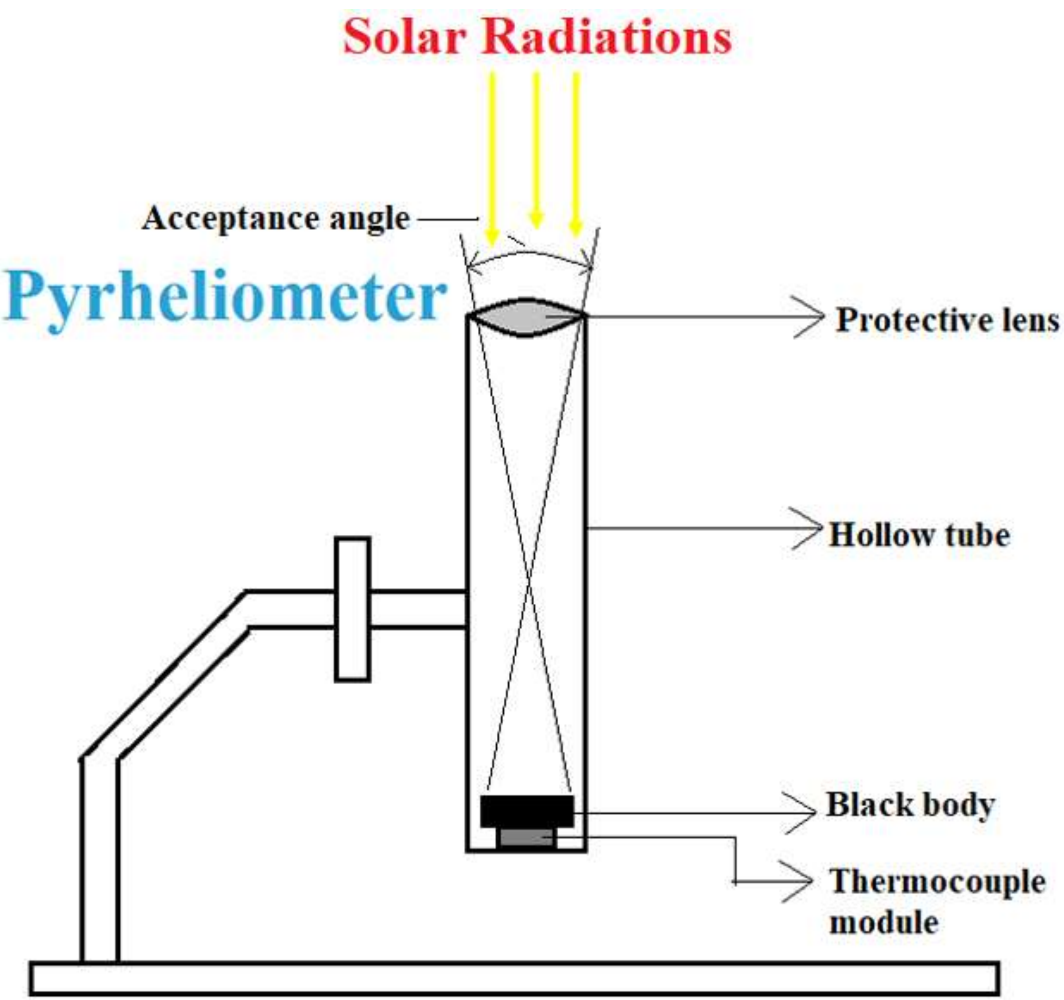



(a)
5° Acceptance angle
Tube
Window
Thermopile
To electrical
readout device
(b)

Working

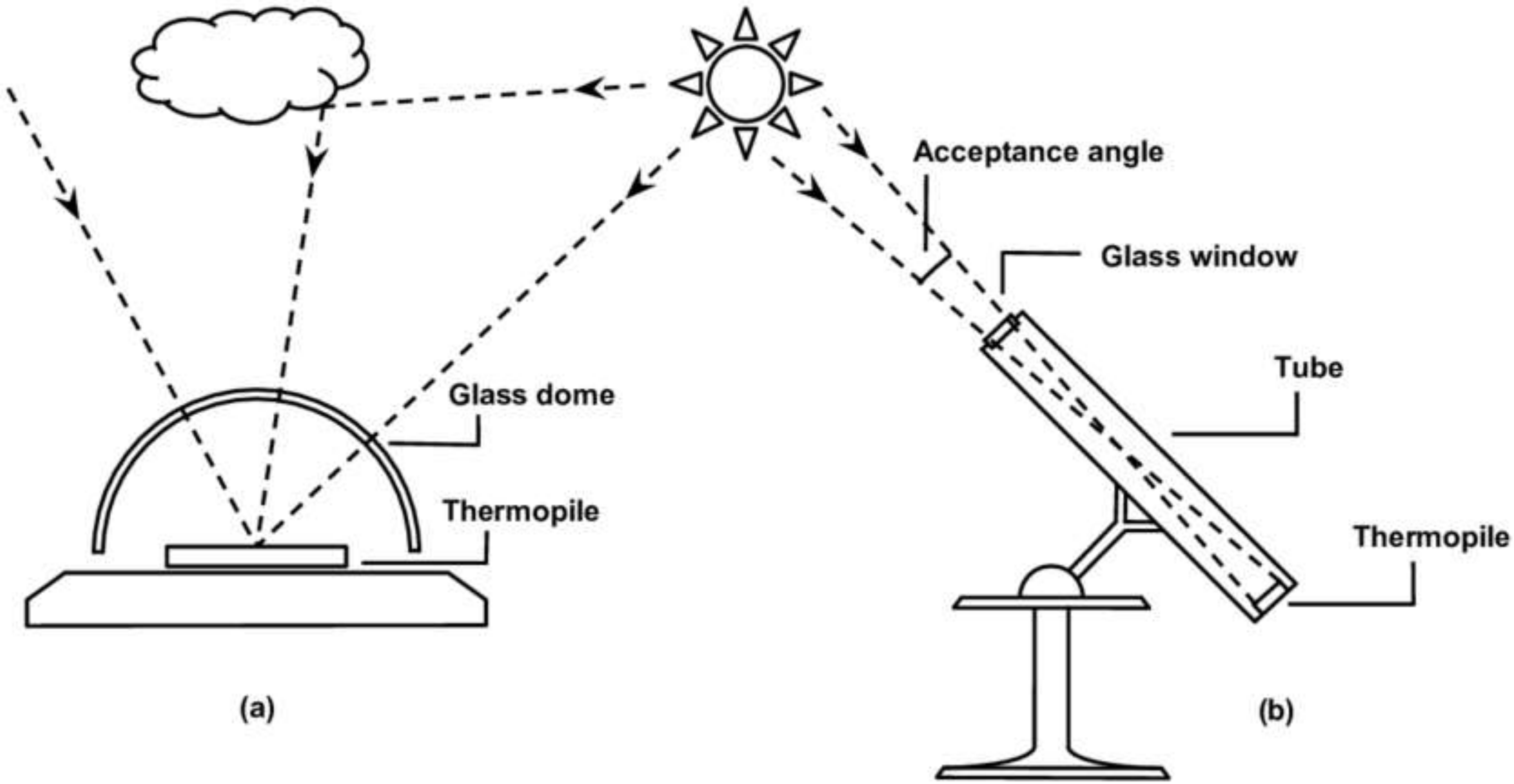
- It measures beam radiation falling on a surface normal to the Sun's rays. The absorber plate is kept at the base of a collimating tube. The alignment of the tube is in the direction of the Sun's rays with the help of two-axis mechanism and an alignment indicator.

Pyrheliometer

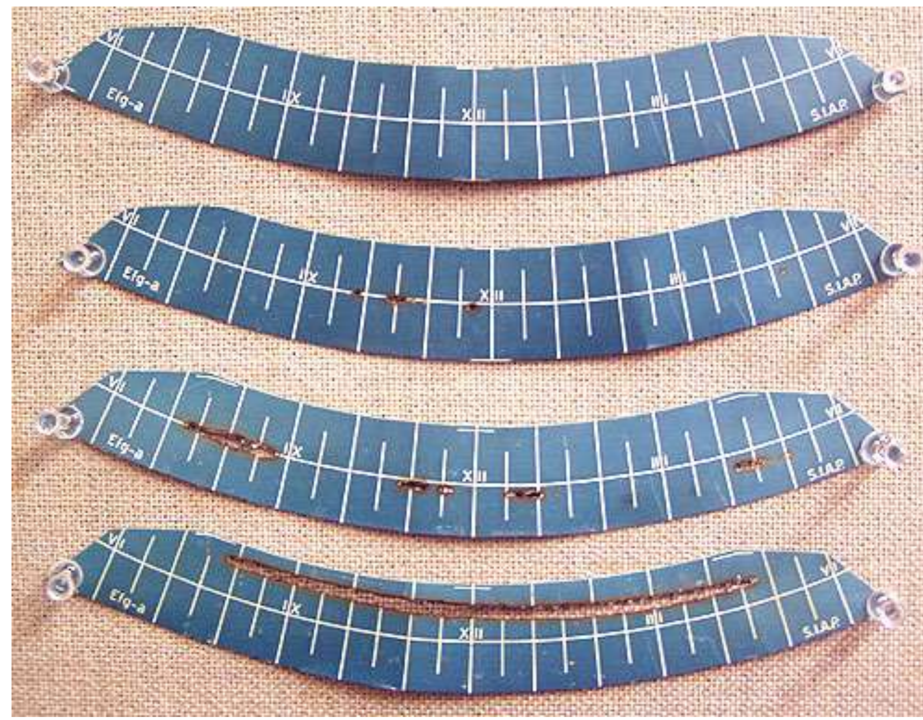


- A pyrheliometer is used to measure direct solar radiation from the Sun and its marginal periphery.
- To measure direct solar radiation correctly, its receiving surface must be arranged to be normal to the solar direction. For this reason, the instrument is usually mounted on a Sun-tracking device called an equatorial mount.
- This is a reliable instrument used to observe direct solar radiation, and has long been accepted as a working standard. However, its manual operation requires experience

Comparision



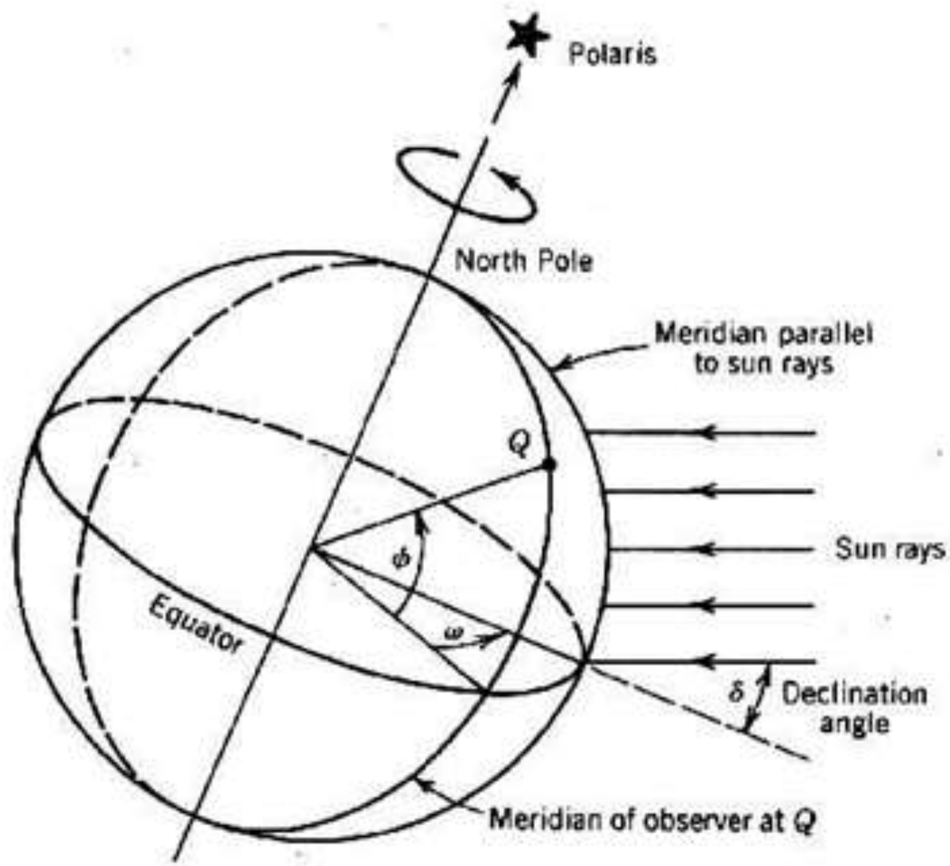
Sunshine Recorder



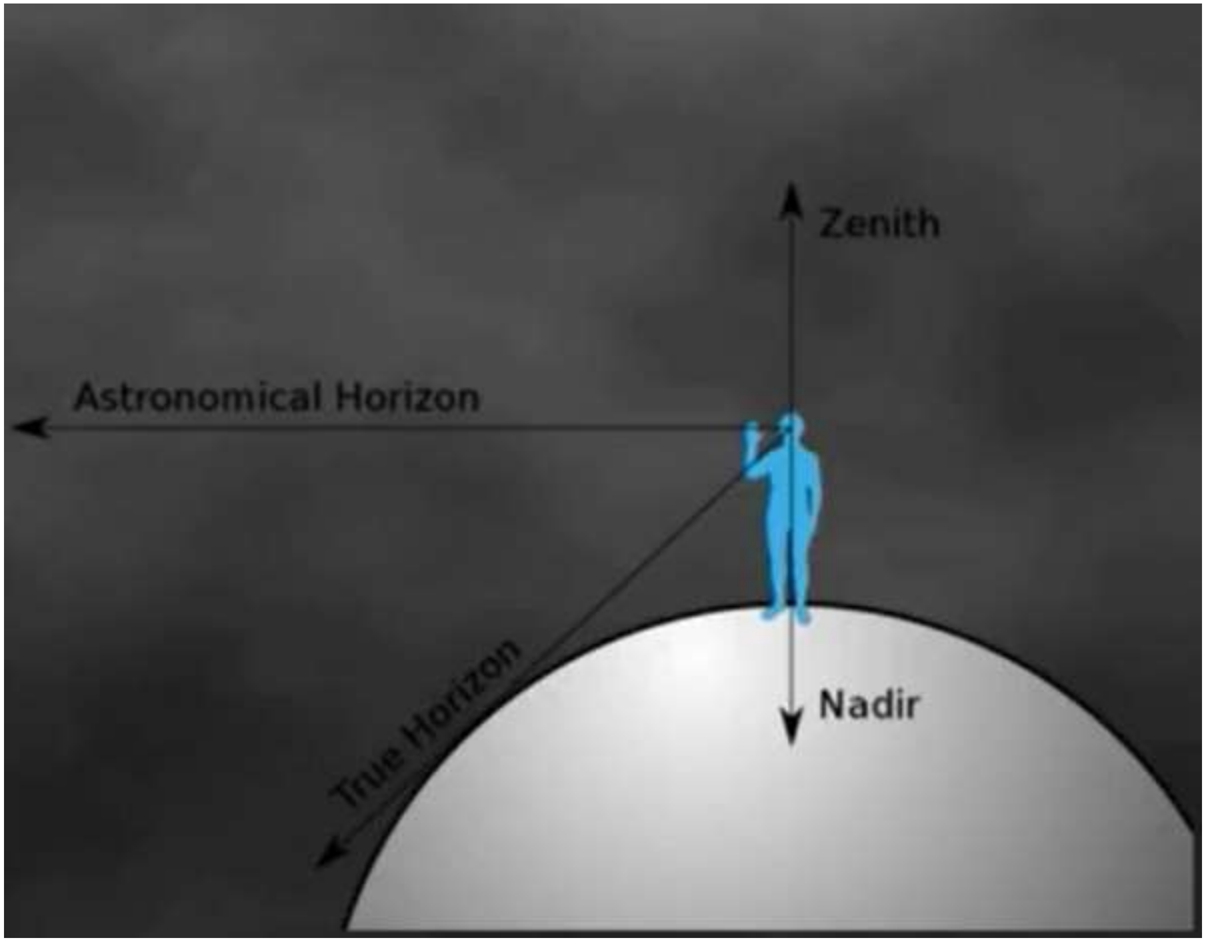
- The duration of bright Sunshine in a day is measured by means of a Sunshine recorder.
- Whenever there is bright Sunshine, the image formed is intense enough to burn a spot on the card strip.
- The Burnt trace whose length is proportional to the duration of Sunshine. The duration of bright Sunshine in a day is measured by means of Sun shine recorder.
- The Sun’s rays are focused by a glass sphere to a point on a card strip held in a groove in spherical bowl mounted concentrically with the sphere.

SOLAR RADIATION GEOMETRY

Equator And Polar Axis

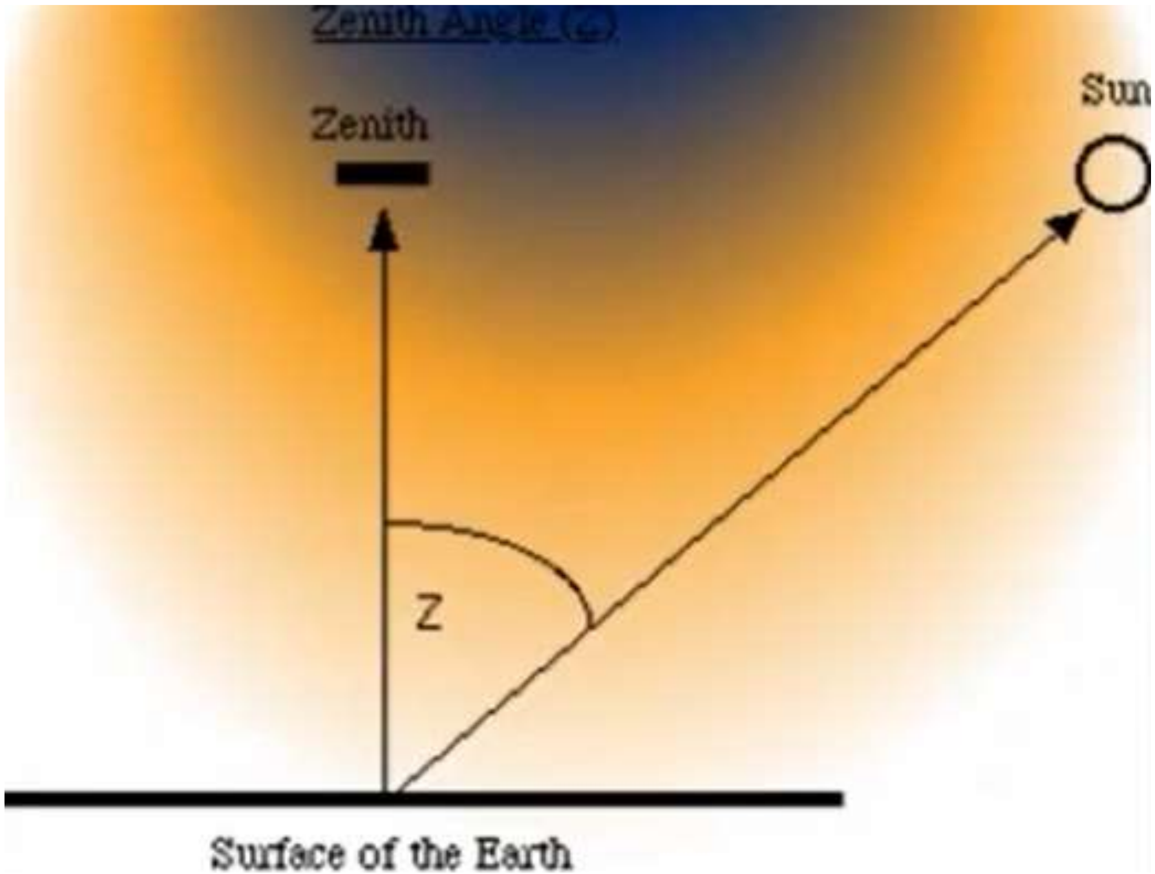


Zenith, Nadir and Horizon



- ZENITH : it is imaginary point above particular location exactly opposite to gravity (Nadir)
- HORIZON: it is the apparent which separates earth and sky

Zenith Angle

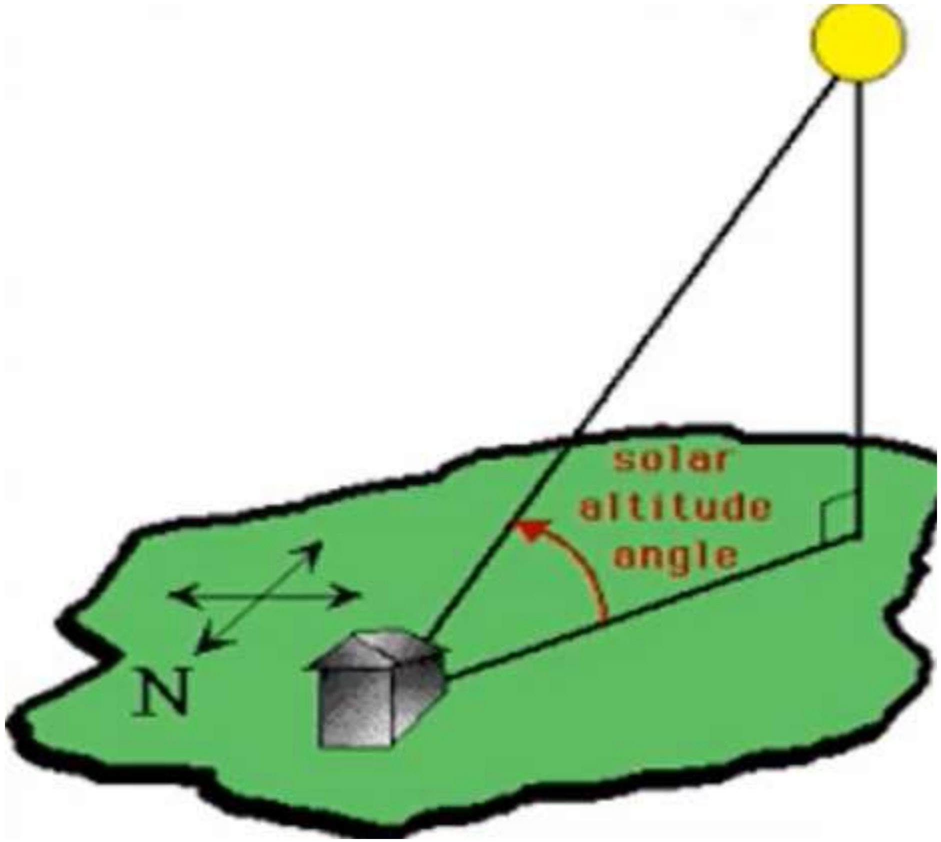


- Angle between Sun and the Vertical.

- It is similar to elevation angle but it is measured from Vertical Rather then Horizontal

Zenith Angle=90^{o}-Elevation Angle

Solar Altitude angle



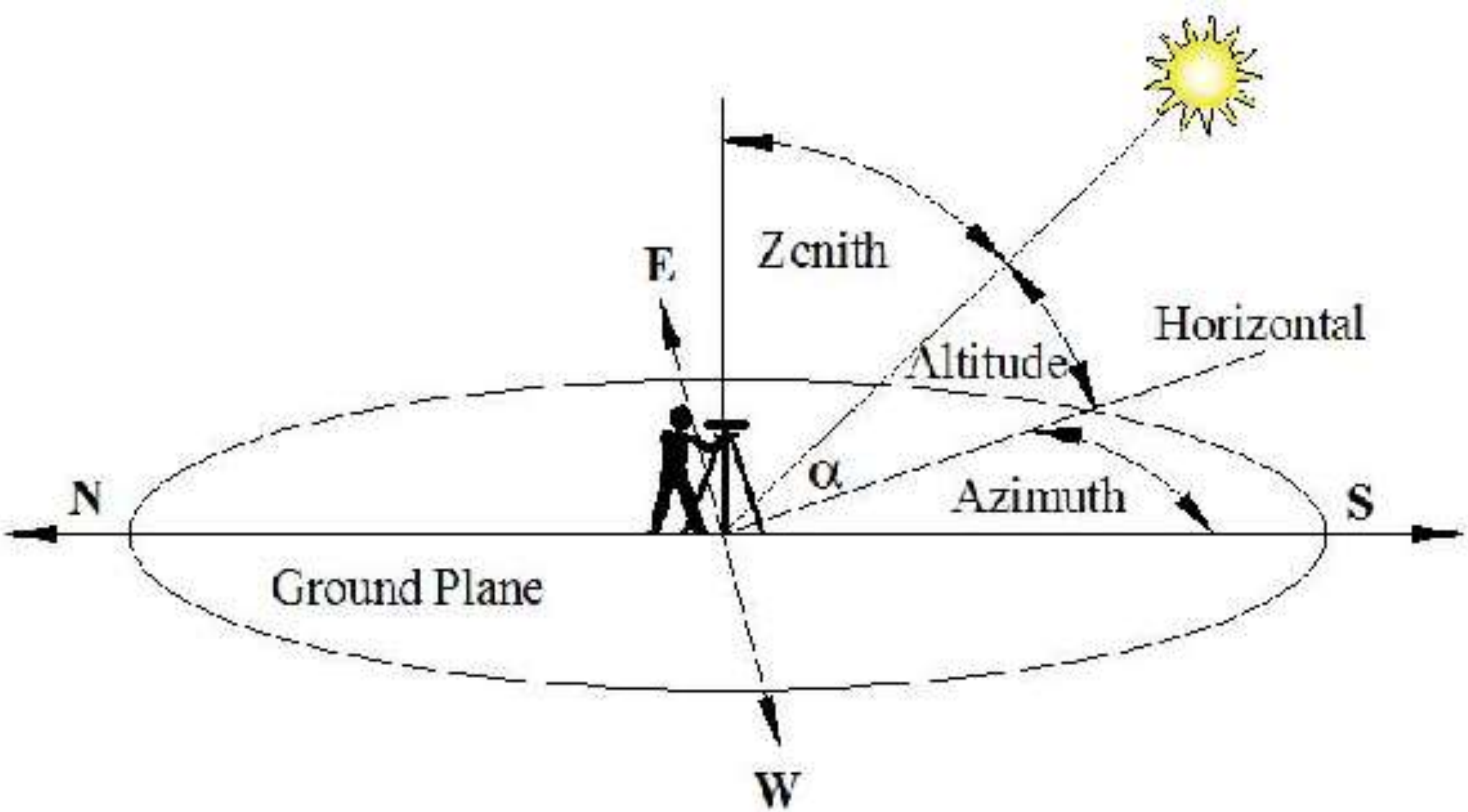
- Angle of Sun relative to earth Horizon, and measured in degree.
- Altitude zero at Sunrise and Sunset and 90 degree at noon at latitude near equator

- Angle Between 2 Lines

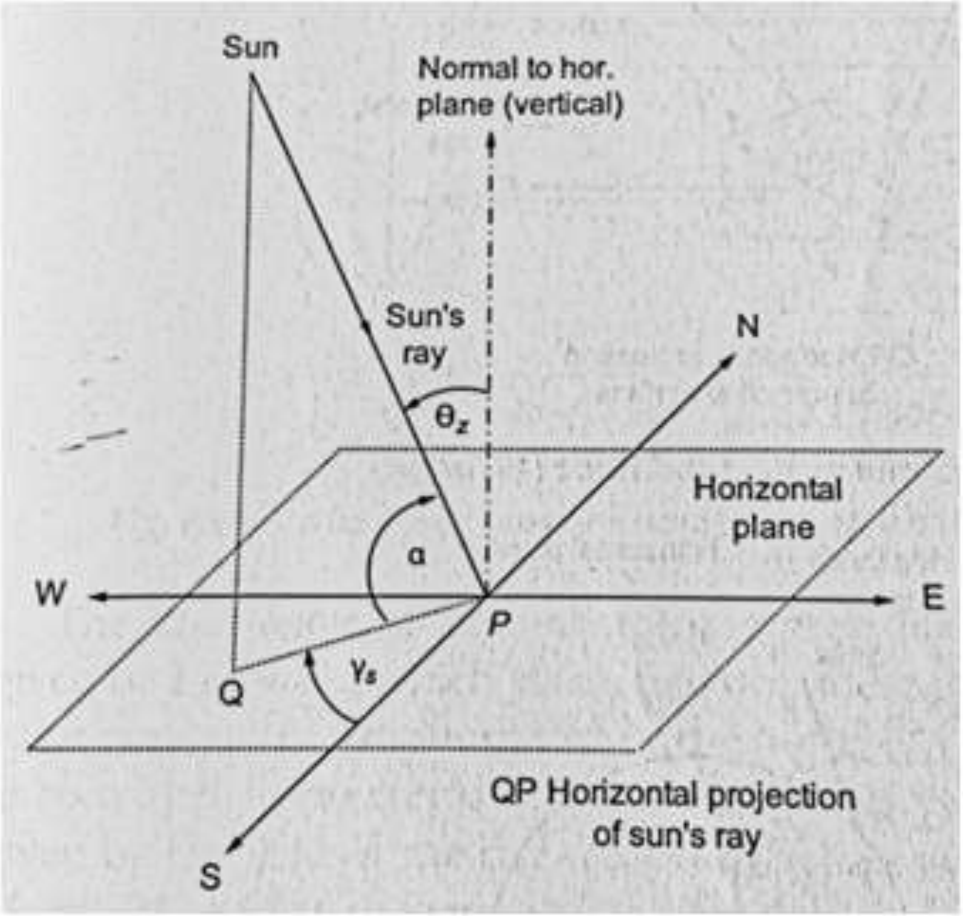
1) Line Joining Sun and Location of Earth
2) Line joining location and the point of projections of sun on horizontal plane of earth

Solar Azimuth Angle

- It is the angle made in the horizontal plane between the horizontal line due south and the projection of the line of sight of the Sun on the horizontal plane



Zenith
E
Horizontal
Altitude
α
N
Azimuth
S
Ground Plane
W



Sun
Normal to hor.
plane (vertical)
Sun's
ray
N
θ_z
Horizontal
plane
α
W
E
P
γ_s
Q
QP Horizontal projection
of sun's ray
S

Hour Angle (ω)

- The hour angle is the angular distance between the meridian of the observer and the meridian whose plane contains the Sun.
- To describe the earth's rotation about its polar axis, the concept of the hour angle is used.
- the hour angle is zero at solar noon (when the Sun reaches its highest point in the sky). At this time, the Sun is said to be 'due south' (or 'due north', in the Southern Hemisphere) since the meridian plane of the observer contains the Sun.

- The hour angle increases by 15° every hour. An expression to calculate the hour angle from solar time is,

$$\omega = 15 \times (t_s - 12); \text{ (in degrees)}$$

Where, t_s is the solar time in hours.

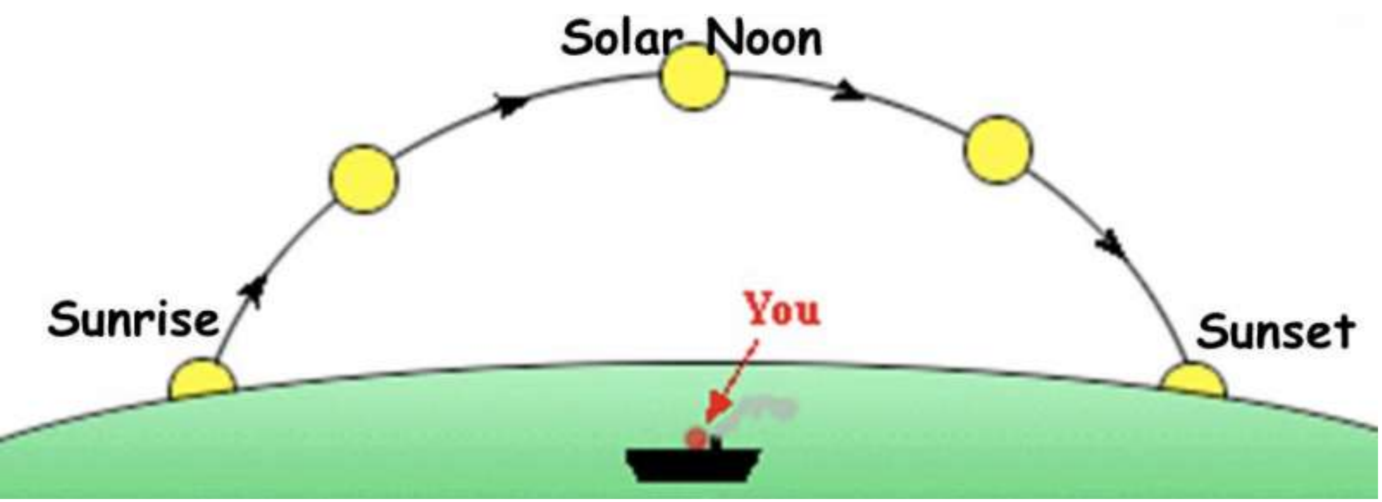
Hour angle (ω) can be calculated simply as follows:

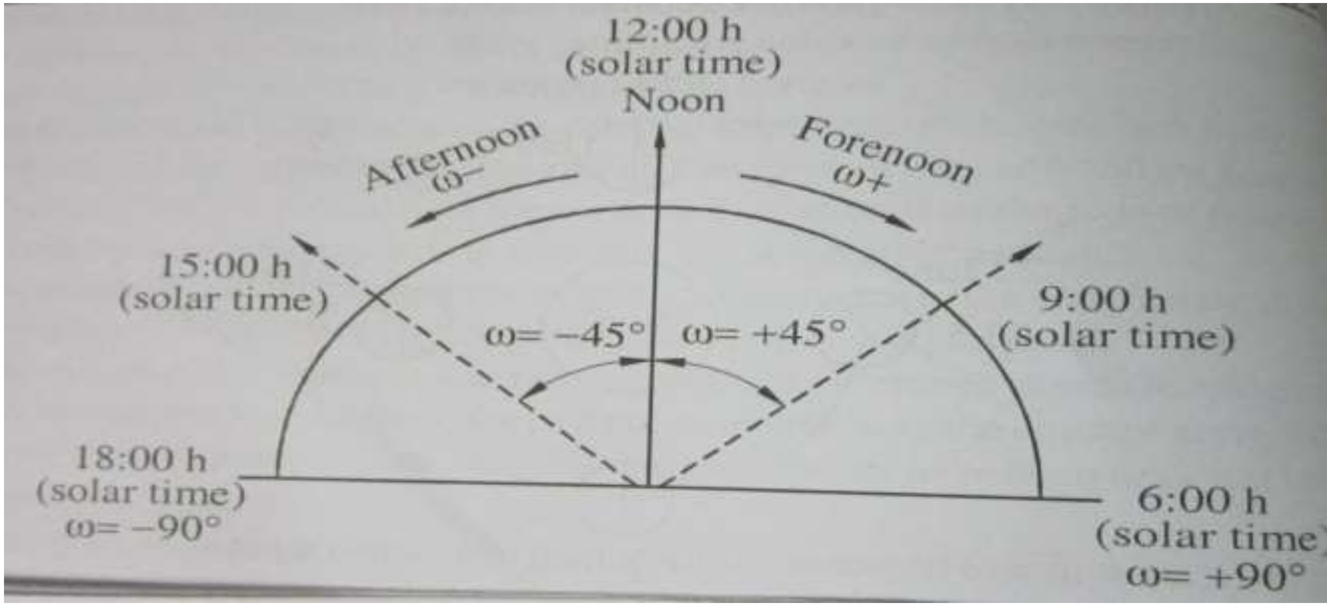
- Since the earth makes one revolution on its axis in 24 h, then 15 minutes will be equal to 15/60 = 1/4 min.

Therefore,

$$\omega = 1/4 \times t_m; \text{ (in degrees)}$$

Where, tm is the time in minutes after local solar noon


Solar Noon
Sunrise
You
Sunset


12:00 h
(solar time)
Noon
Afternoon
ω−
Forenoon
ω+
15:00 h
(solar time)
9:00 h
(solar time)
ω= −45°
ω= +45°
18:00 h
(solar time)
ω= −90°
6:00 h
(solar time)
ω= +90°

Local apparent time (Local Solar Time)

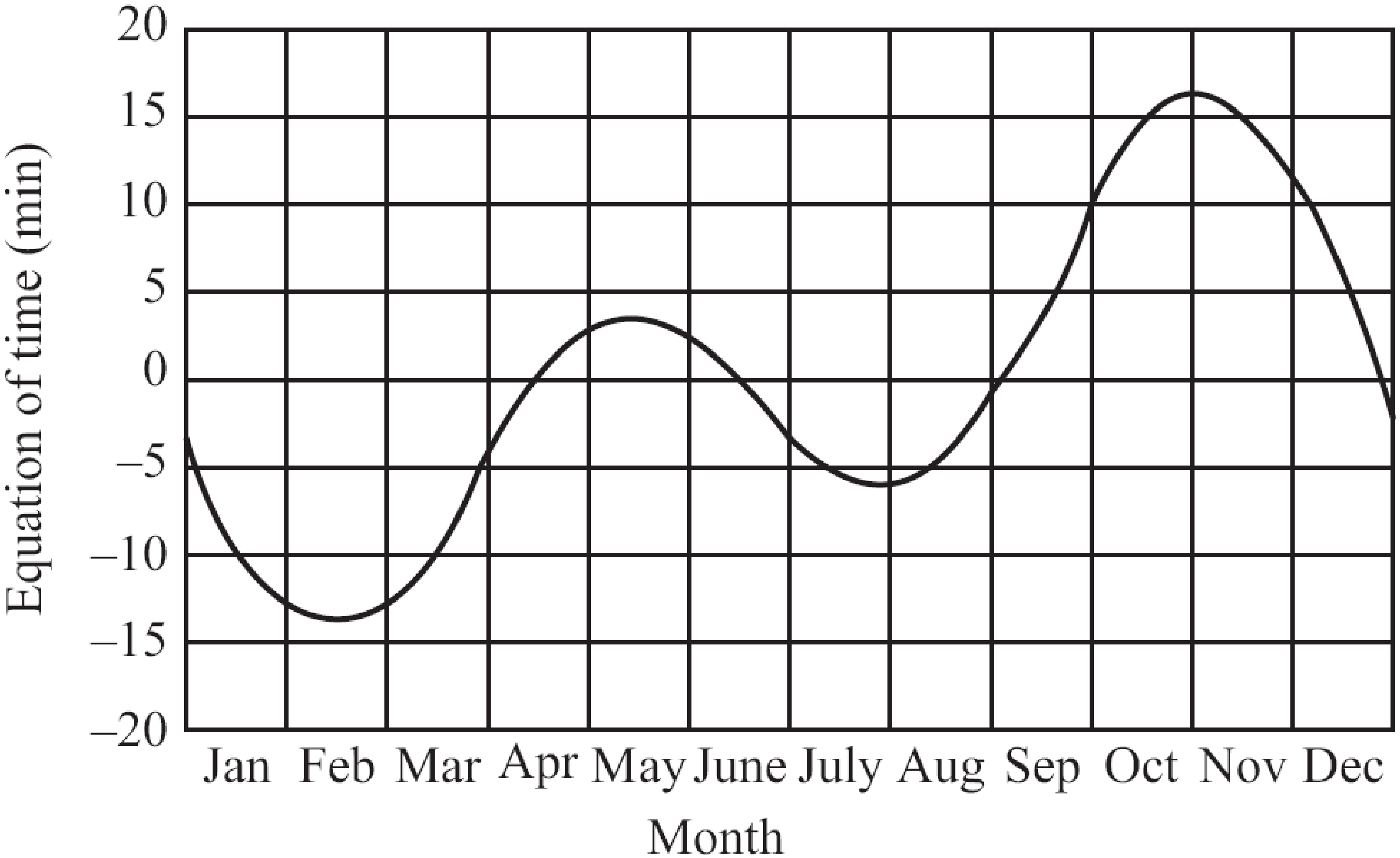
- Time used for calculating Hour Angle
- It is not same as local clock time.
- It can be obtained from local time observed on a clock by applying two corrections.

1)due to difference between longitude of location and meridian on which the standard time is determined. This correction has magnitude of 4 minutes for each degree difference in longitude.

2) Equation of time Correction, Which is required due to fact that earth orbit and rate of rotation are subject to certain fluctuations.

LAT = Standard time ± 4(Standard time longitude – longitude of location) + (Equation of time correction)

- Standard time: As observed on clock.
- Standard time longitude: 82.50^{o}E for India.
- Longitude of location: Any location in India.
- ‘+’ Sign for Western Hemisphere,
- ‘-’ Sign for Eastern Hemisphere


20
15
10
5
0
–5
–10
–15
–20
Equation of time (min)
Jan Feb Mar Apr May June July Aug Sep Oct Nov Dec
Month

Example 1

- Determine LAT corresponding to 13:50 IST on July 1 at Delhi($28^o35'$N, $77^o12'$ E). The equation of time correction on July 1 is -4 minutes. In India the standard time is based on $82^o30'$E

LAT = Standard time ± 4(Standard time longitude – longitude of location) + (Equation of time correction)

- 13.50 h– 4[(82.50)–(77.2)]min+(–4 min)
- 13.50 h– 4(82.50)–(77.2)min–4 min
- 13.50 h– 21.20 min– 4 min
- 13.50 h–25.20 min
- 13.50 h– 0.42 h
- 13.08 h
- 13 h 4 min 48 s

Declination Angle

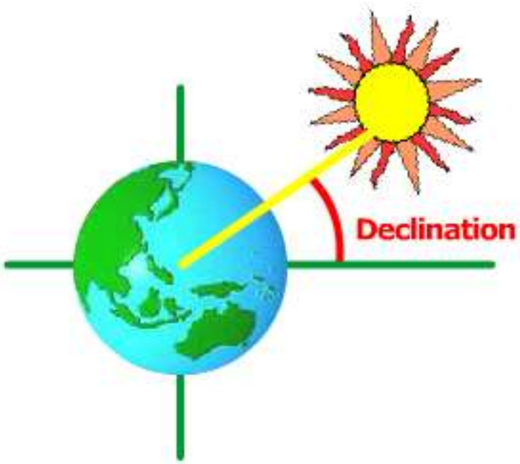
- It is the angle made line joining the centres of the Sun and the earth with the projection of this line on the equatorial plane.

$$\delta = 23.45 * Sin\left[\frac{360}{365}(n + 284)\right]$$

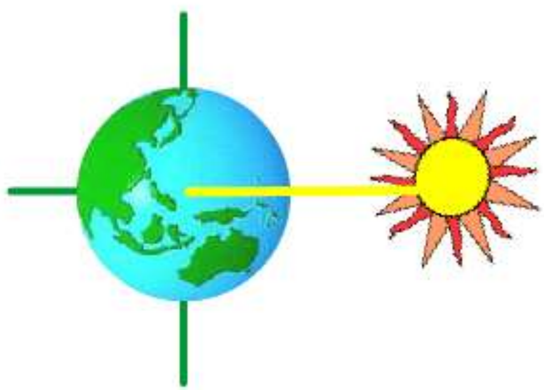
Where, n=day of the year.

- Its maximum value is $+23.5^0$ on June 21 and minimum value is (-23.5^0) on Dec 21. It is zero on the two equinox days of March 21 and September 22

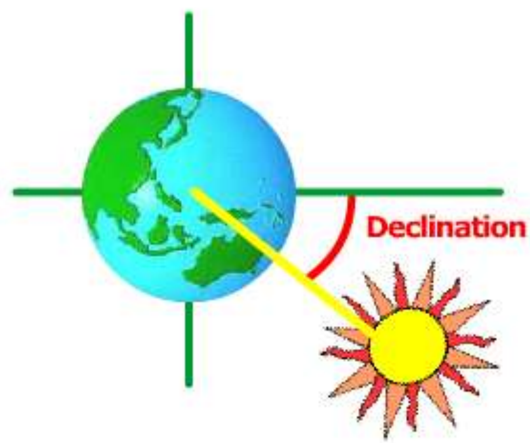
Summer solstice in the northern hemisphere. The declination angle (δ) is at its maximum and is 23.45º.



Spring equinox in the northern hemisphere and autumn equinox in the southern hemisphere. The declination angle (δ) is 0º.



Winter solstice in the northern hemisphere and summer solstice in the southern hemisphere. The declination angle (δ) is -23.45º.



Latitude Angle (ø)

- It is angle made by the radial line joining the location to the centre of the earth with the projection of the line on the equatorial plane. Its value is measured +90 N to -90 S.
- The intersection of the equatorial plane with the surface of the earth forms the equator and is designated as 0° latitude.

SUNRISE, SUNSET AND DAY LENGTH

- Time of Sunrise, Sunset and Duration of the length depend upon the latitude of the location and the month in the year

- At sunrise and sunset, the sunlight is parallel to the ground surface with a zenith angle of 90^{o}.

- Hour angle pertaining to sunrise and sunset obtained through

$$\cos\omega_s = -\tan \phi \tan \delta$$

$$\omega_s = \cos^{-1}(-\tan \phi \tan \delta)$$

- Value is positive for sunrise and negative for sunset. Total angle between sunrise and sunset is given by

$$2\omega_s = 2\cos^{-1}(-\tan \phi \tan \delta)$$

- Since 15 degree of hour angle corresponds to one hour, the corresponding day length(T_d) in hours is given by

$$T_d = 2/15 \cos^{-1} (-\tan \phi \tan \delta)$$

Empirical Equation for Estimating the availability of Solar Radiation

- The measurement of solar radiation at every location is not feasible.

- Empirical equation by utilizing the metrological data like the number of sunshine hours, day length and number of clear days.

$$H_g/H_c = a+b(D_L/D_{max})$$

- H_g= Monthly average of daily global radiation on a Horizontal surface at a given location, $MJ/m^2/day$.
- H_c= Monthly average of daily global radiation on a Horizontal surface at a given location on a clear sky day, $MJ/m^2/day$.
- D_L = Monthly Average Measured solar day length, in hours.
- D_{max} = monthly average of longest day length, in hours
- a,b = constant for the location

- It is difficult to define a clear sky day, so it was proposed that H_c should be replaced by H_o.
- H_o is the monthly average of daily extraterrestrial radiation that would fall on a horizontal surface at the given location.

$$H_g/H_o = a+b(D_L/D_{max})$$

$$H_o = 24/\text{pie}\ I_{sc}(1+0.033 \cos 360n/365)(\omega_s \sin \phi \sin \delta + \cos \phi \cos\delta \sin \omega_s)$$

I_{sc}= solar constant per hour=1367 W/m^2

Example 2

At Nagpur the following observations were made:

- Theoretical Maximum possible Sunshine hours= 9.5 h
- Average measured length of day during april= 9.0 h
- Solar radiation for a clear day H_o= 2100 KJ/m^2/day
- a=0.27, b= 0.50
- Calculate the average daily global radiation

$$H_g/H_o = a+b(D_L/D_{max})$$

$$H_g = H_o\ [a+b(D_L/D_{max})]$$

$$=2100[0.27+0.50(9.0/9.5)]$$

$$=1554\ kj/m^2/day$$

SOLAR COLLECTOR

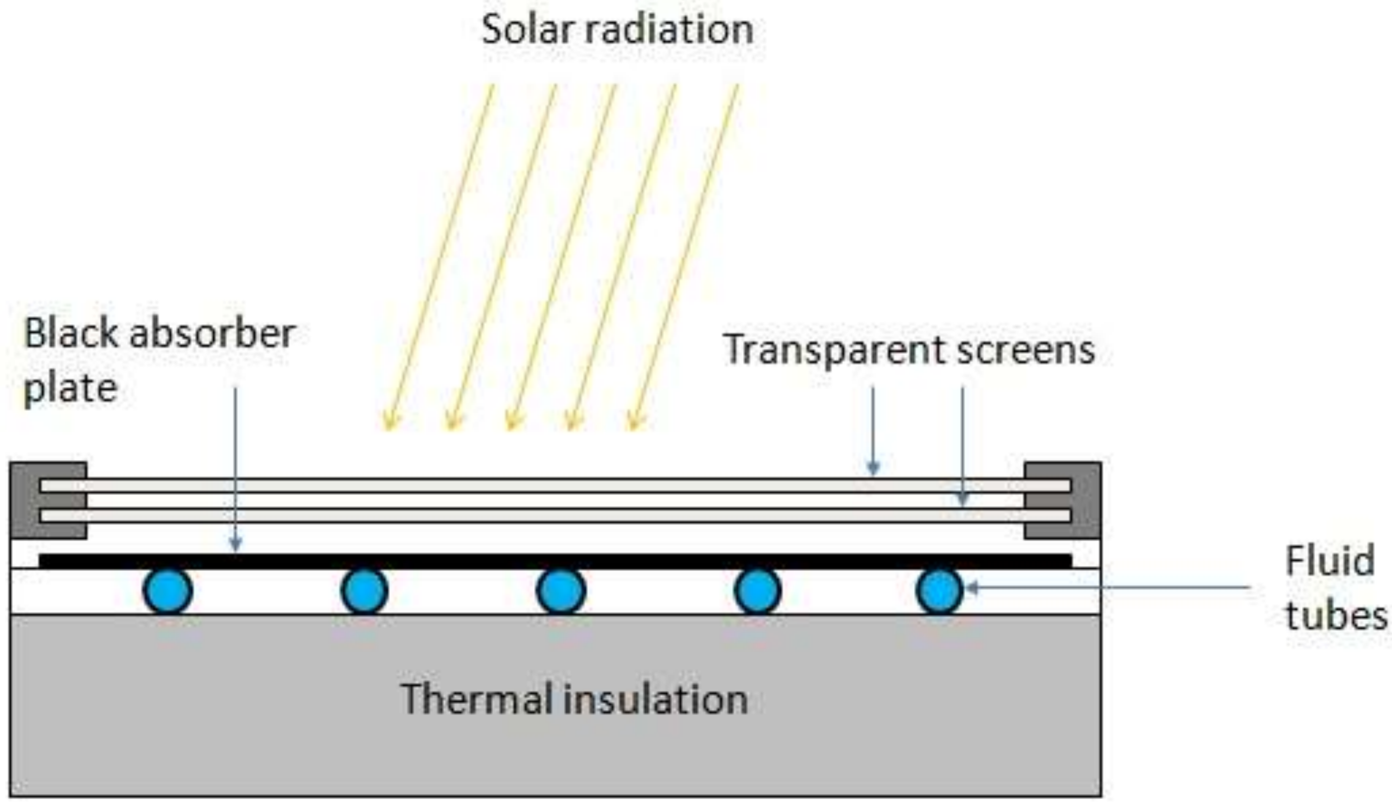
- Solar energy collector is a device which absorbs the incoming solar radiation, converts it into heat, and transfers this heat to a fluid (usually air, water, or oil) flowing through the collector.
- Solar energy collectors are special kind of heat exchangers that transform solar radiation energy into internal energy of the transport medium.
- The major component of any solar system is the solar collector.

- The solar energy, thus, collected is carried from the circulating fluid either directly to the hot water or space conditioning equipment or to a thermal energy storage tank, from which it can be drawn for use at night and/or cloudy days.
- The amount of heat energy produced by a solar collector depends on the type of collector, its working surface direction towards the Sun, meteorological conditions of the location, and many other factors.

Classification

- Solar collectors
  - Non-concentrating type (Flat plate collector)
  - Concentrating type
    - Focus type
      - Line focus (one axis tracking)
        - (a) Cylindrical parabolic concentrator
        - (b) Fixed mirror solar concentrator
        - (c) Linear Fresnel lens collector
      - Point focus (two axis tracking)
        - (a) Paraboloidal dish collector
        - (b) Hemispherical bowl mirror concentrator
        - (c) Circular Fresnel lens conc.
        - (d) Central tower receiver
    - Non-focus type
      - (a) Modified flat plate collector
      - (b) Compound Parabolic Concentrating (CPC) type

Flat Plate Collector



- In the flat plate collector. all the major components are absorber plate, cover glass, insulation housing and the working fluid.
- absorber plate is usually made of copper and coated to increase the absorption of solar radiation. So in that case we call it as a selective surfaces normally it is a black surface.

- Selective surface to increase the absorption and to decrease the emission and it may be flat because the name says it as a flat plate collector but it may be flat or corrugated or grooved with tubes, fins or passages attached to it.
- So it is not always possible to have a flat plate collector It is based on the application or what type of absorb what type of fluid passages you want to use it.
- And then the plate thickness normally of plate thickness that is delta p which is normally 0.2 to 0.7mm.

Liquid-type Flat Plate Collector

In general it consists of:

- Glazing: One or more covers of transparent material like glass, plastics, etc. Glazing may be left out for some low temperature applications.
- Absorber: A plate with tubes or passages attached to it for the passage of working fluid. The absorber is usually painted flat black or electroplated with a selective absorber. eg. Copper.

- Header or manifolds: To facilitate the flow or heat transfer fluid.
- Insulation: To minimize heat loss from the back and the sides. (2.5 to 8cm thick layer of glass wool)
- Container: It is box or casing type.

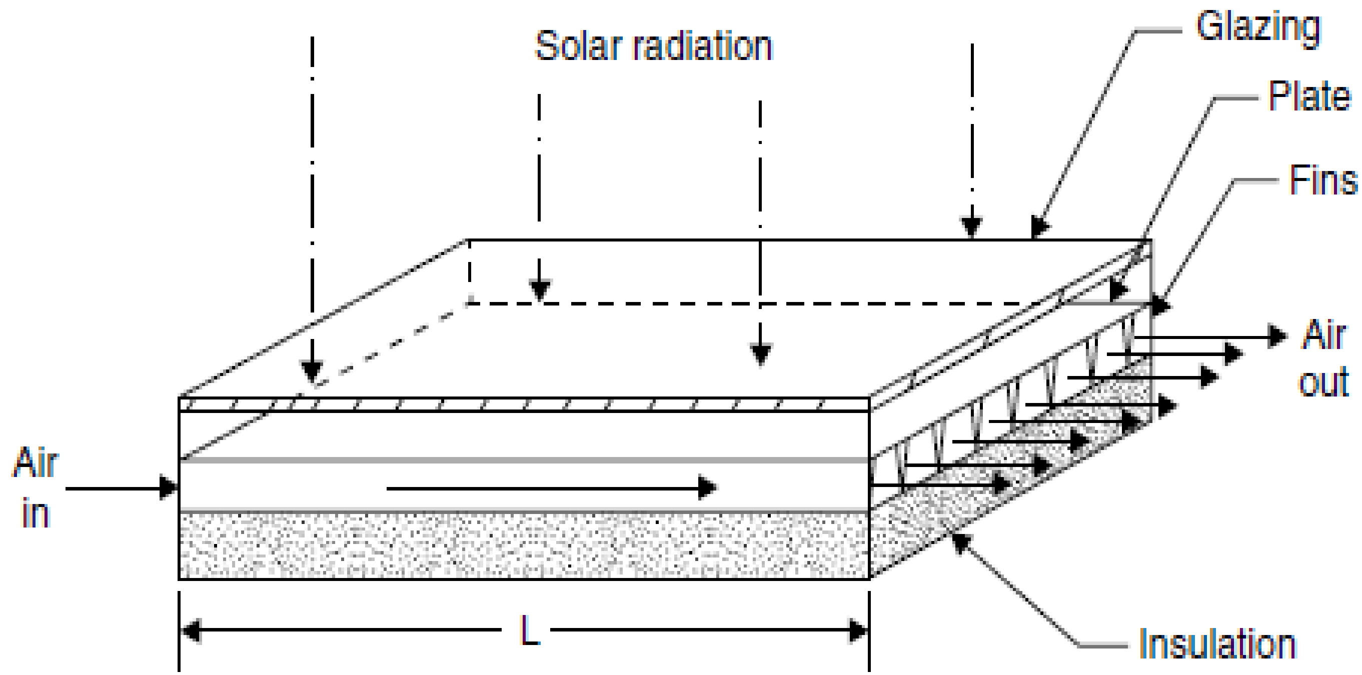
- Liquid heating collectors are used for heating water and non-freezing aqueous solution and occasionally for non-aqueous heat transfer fluids. Typically a metal plate, usually of copper, steel or aluminium material with tubing of copper in thermal contact with the plates, is most commonly used material. The absorber plate is usually made from metal sheet 1 to2mm in thickness.
- Tube: They are soldered or clamped or bind to bottom of absorber plate from 5 to 15cm. And its diameter is about 1.0 to 1.5 cm. In some other type of design of liquid collector we can found, the arrangement of tubes are attached to the absorber plate.

- *Disadvantage of flat plate collector*: Large heat loss area because of the absence of optical concentration and hence it cannot attain high temp.

Air type flat plat collector

- Air type collectors are more commonly used for agricultural drying and space heating applications. Their basic advantages are low sensitivity to leakages and no need for an additional heat exchanger for drying and space heating applications.
- However, because of the low heat capacity of the air and the low convection heat transfer coefficient between the absorber and the air, a larger heat transfer area and higher flow rates are needed.

Air type flat plat collector



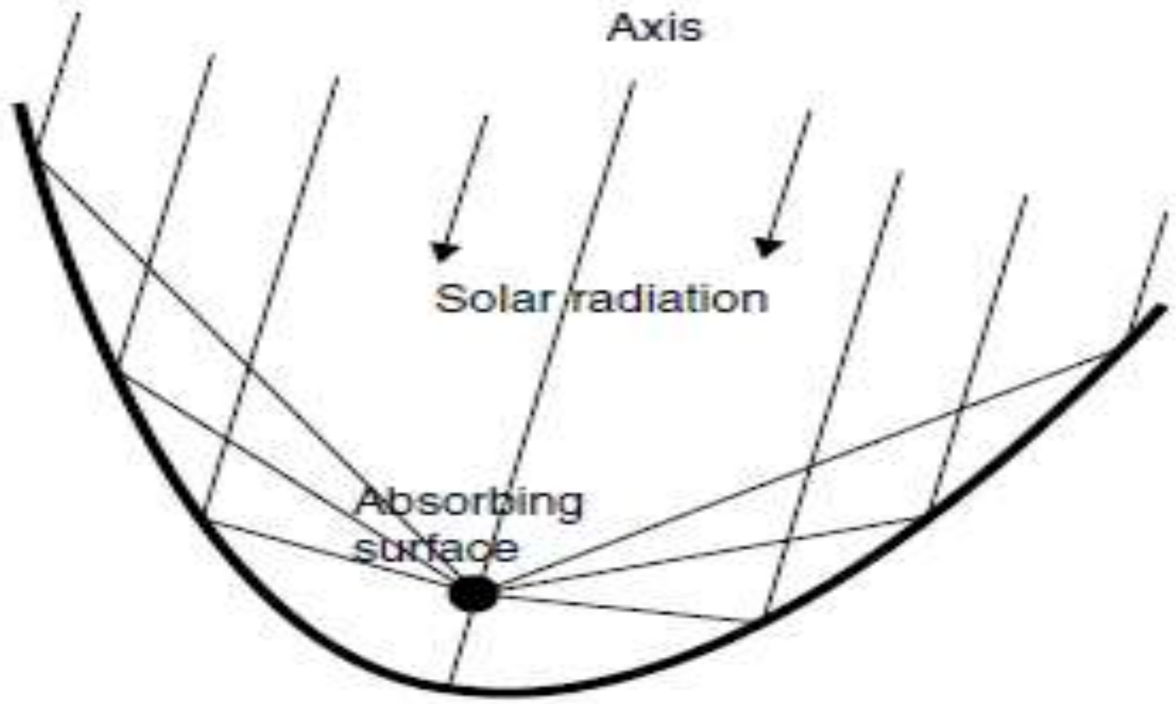
Concentrating type collector (Focusing type)

- They usually have concave reflecting surface to intercept and focus the Sun's beam radiation to a smaller receiving area, thereby increasing the radiation flux. In other words, concentrating solar collectors use shaped mirrors or lenses to provide higher temperatures than the flat plate collectors.

- Concentrating collector is a device to collect solar energy with high intensity of solar radiation on the energy absorbing surface.
- Such collectors use optical system in the form of reflectors or refractors.
- These collectors are used for medium (100-300^{o} C) and high-temperature (above 300^{o}C) applications such as steam production for the generation of electricity.

- The high temperature is achieved at absorber because of reflecting arrangement provided for concentrating the radiation at required location using mirrors and lenses.

- These collectors require tracking to follow the Sun because of optical system.
- The tracking rate depends on the degree of concentration ratio and needs frequent adjustment for system having high concentration ratio.
- The efficiency of these collectors lies between 50-70%.
- The collectors need more maintenance than FPC because of its optical system.
- The concentrating collectors are classified on the basis of reflector used; concentration ratio and tracking method adopted.


Axis
Solar radiation
Absorbing
surface

Concentration ratio

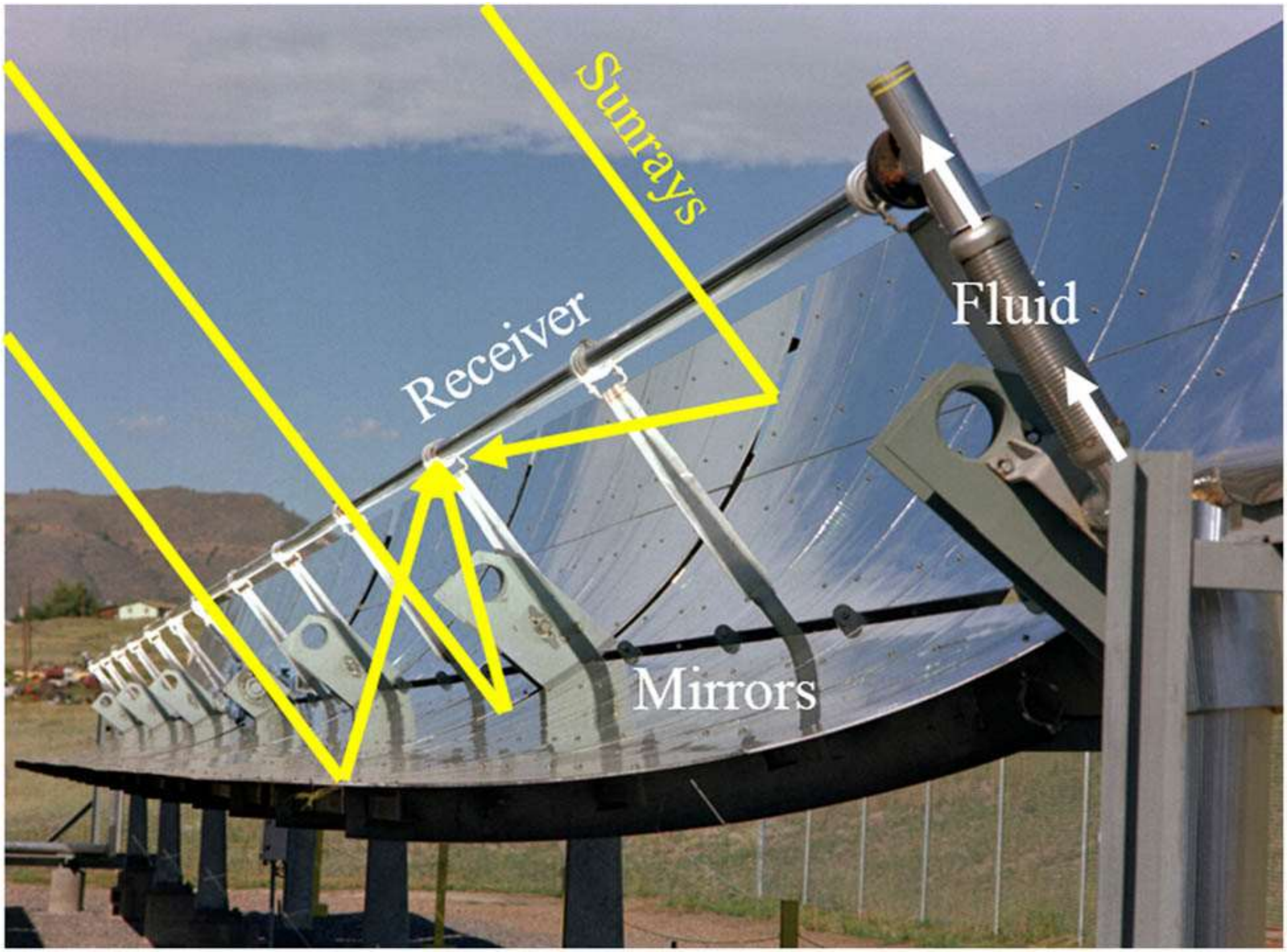
- It is the ratio of effective area of the plane opening of the concentrator through which the solar radiation passes to the surface area of the absorber.

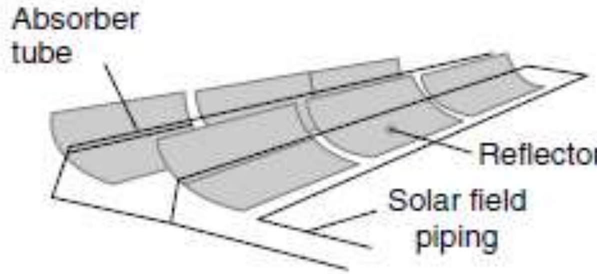
Compound Parabolic Solar Collector

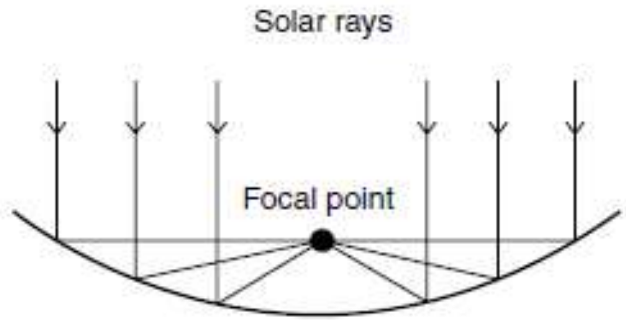
- Compound Parabolic Concentrator (CPC) is a special type of solar collector fabricated in the shape of two meeting parabolas. It belongs to the non-imaging family, but is consider among the collector having the highest possible concentrating ratio.

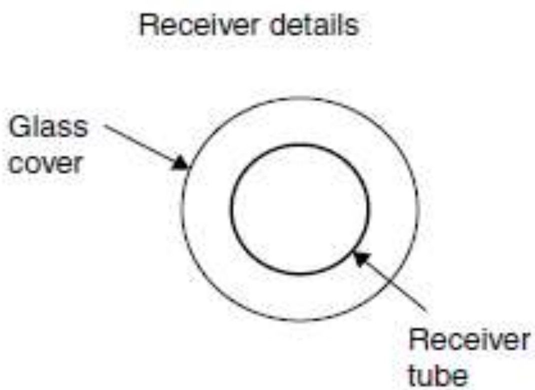
- These collectors are line focusing type. The compound parabolic collectors have two parabolic surfaces to concentrate the solar radiation to the absorber placed at bottom. These collectors have high concentration ratio and concentrator is moving to track the Sun.

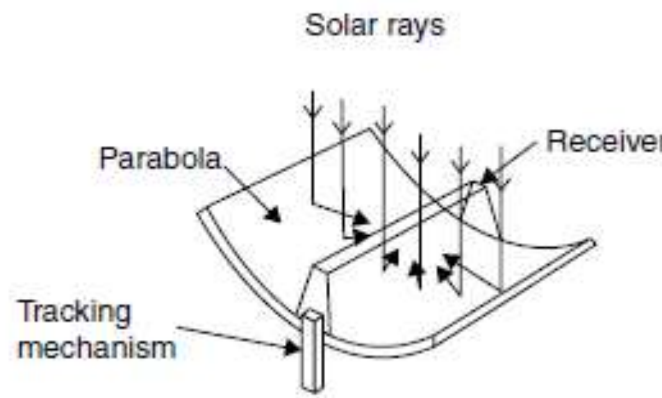
Parabolic Trough Collector




Absorber tube
Reflector
Solar field piping


Solar rays
Focal point


Receiver details
Glass cover
Receiver tube


Solar rays
Parabola
Receiver
Tracking mechanism

- The troughs concentrate Sunlight onto a receiver tube, placed along the focal line of the trough.
- The temperature at the absorber tube is obtained at nearly 400^{o} C.
- The absorber in these collectors is moving to receive the reflected radiations by reflector, while the concentrators (trough) remains fixed.

- Because of its parabolic shape, it can focus the Sun at 30 to 100 times its normal intensity (concentration ratio) on a receiver.
- The heat transfer medium carries the heat at one central place for further utilization.