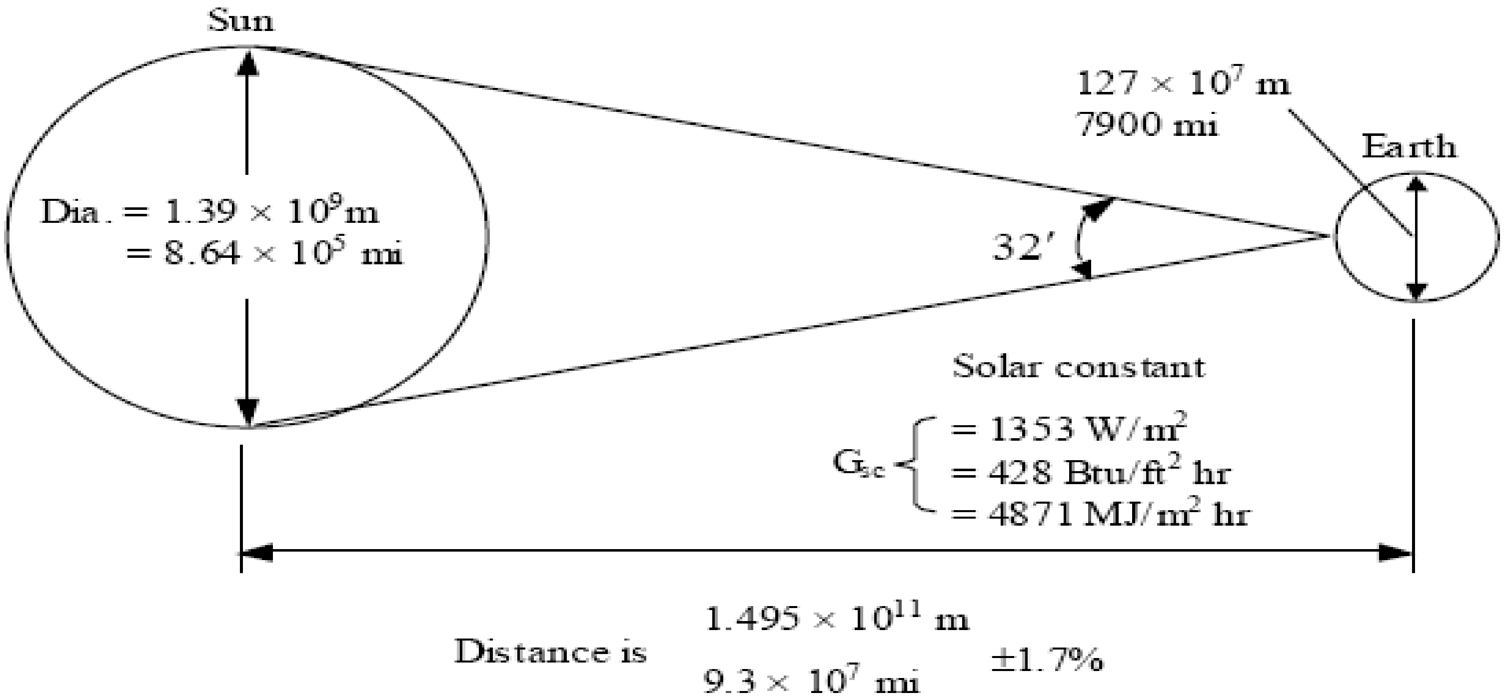
Solar Energy

Sun and Earth

- Diameter of sun = 1.39×10^9 m
- Average distance of sun from earth = 1.495×10^{11} m
- Temperature of sun = 8×10^6 to 40×10^6 K



RADIATION

- A perfect radiator emits energy form its surface at a rate

$Q = \sigma A T^4$ σ = Stefan Boltzmann Constant

$= 56.7 \times 10^{-9}\ W\ m^{-2}\ K^{-4}$

- A real body emits radiation at a rate

$Q = \varepsilon \sigma A T^4$

ε = Emissivity of the surface = $\dfrac{\textit{Radiation emission of a real body}}{\textit{Radiation emission of a Black Body}}$

Sun's Radiation

- Sun radiates energy of about 3.5 x 10^{23} kw into space ; 2 x 10^{14} kw energy reaches the earth.
- Sun subtends an angle of 32^{o} at the earth surface.
- Solar constant (I_{sc}): It is "The total energy received from the sun per unit time on a surface of unit area kept perpendicular to the radiation in space just outside the earth's atmosphere when the earth is at its mean distance from the sun."
- Its standard value is 1353 Wm^{-2}

Solar radiation at he earth's surface: (Terrestrial radiation)

- Solar radiation at he earth's surface:

The solar radiation that reaches the earth's surface after passing through the earth's atmosphere are called terrestrial radiation.

As solar radiation passes through the earths atmosphere it is reduced due to absorption (By ozone layer, water vapors and gases) and scattering by gases and particulate matter in atmosphere.

Solar radiation at he earth's surface: (Terrestrial radiation)

- Direct or Beam radiation: Solar radiation propagation in a straight line and received at the earth's surface without change of direction are called direct or beam radiation.
- Diffuse radiation: Solar radiation scattered by dust particles and air molecule when reaches to earth's surface is called diffused radiation.

Albedo

- Albedo: *Albedo* is the fraction of solar energy (shortwave radiation) reflected from the Earth back into space.
- The energy reflected back to the space by reflection from clouds, scattering by the atmospheric gases and dust particles and from the earth's surface is called albedo.

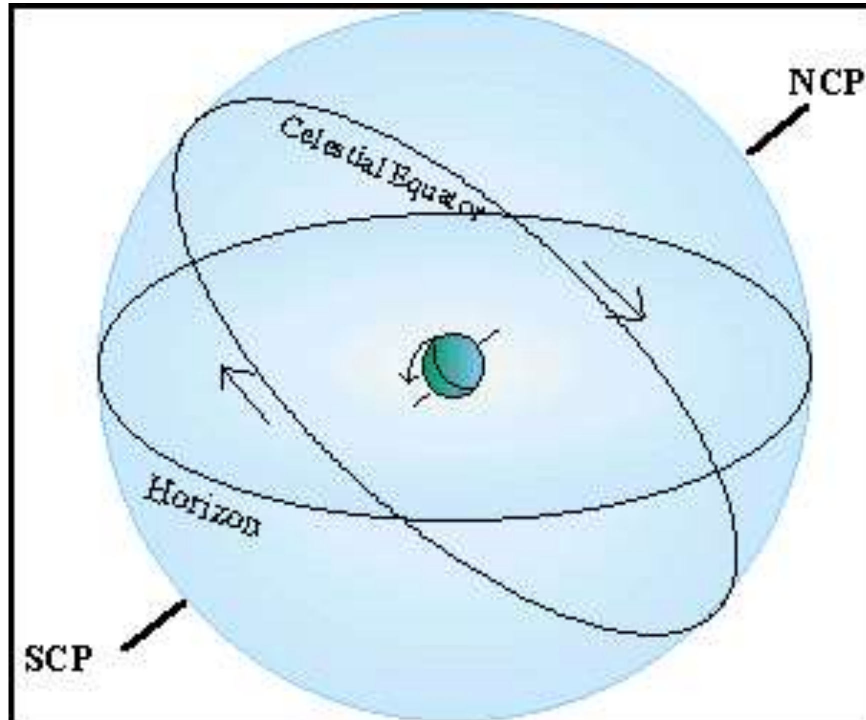
Air mass

- Air Mass: It is defined as the ratio of the path length through the atmosphere which the solar beam actually traverse up to the ground to the vertical path length through the atmosphere.

- Air mass m $= \dfrac{\text{Path length traversed by beam radiation}}{\text{Vertical path length of the atmosphere}}$

SOLAR GEOMETRY

- **Celestial Sphere:** The celestial sphere is an imaginary sphere of gigantic radius with the earth located at its center. The poles of the celestial sphere are aligned with the poles of the Earth. The celestial equator lies along the celestial sphere in the same plane that includes the Earth's equator.

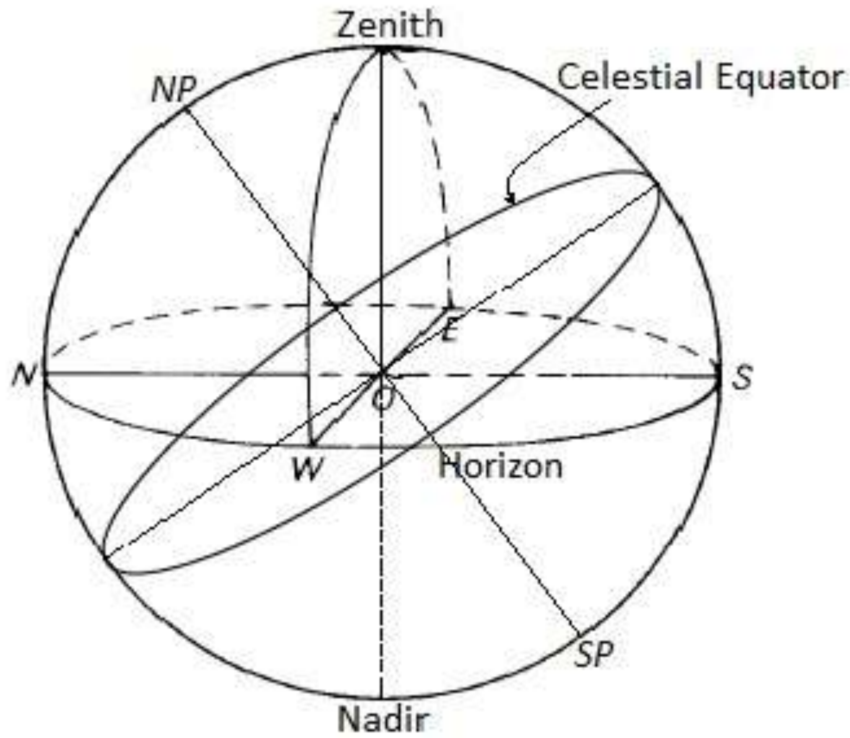


- SCP – South celestial Pole

Solar Geometry

Zenith: the point of the celestial sphere that is directly opposite the nadir and vertically above the observer

Nadir: It is the point on the celestial sphere diametrically opposite to the zenith.

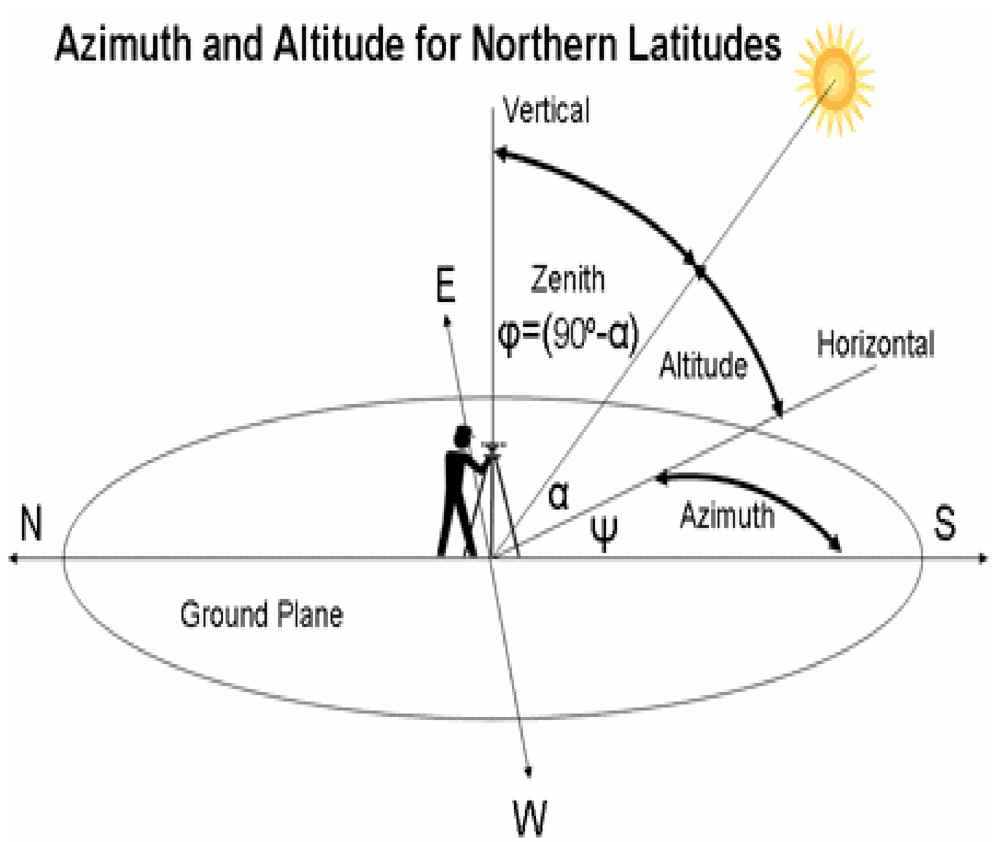


Earth sun angles

Altitude angle α : the angle between the sun's rays and its projection on a horizontal surface is known as inclination angle.

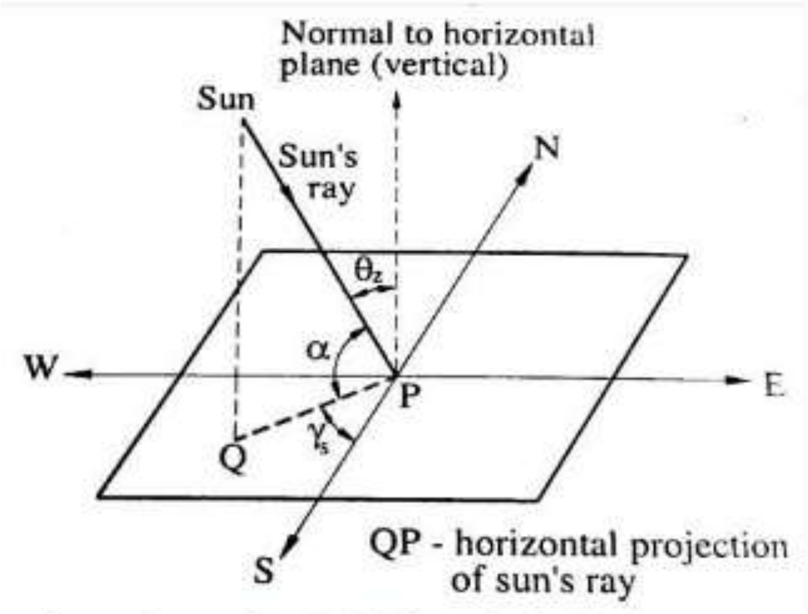
Zenith Angle ϕ : It is the angle between the sun's ray and the perpendicular to the horizontal plane . The zenith angle is complement of altitude angle.

Solar azimuth angle: It is the angle on a horizontal plane between the line due south and the projection of the sun's rays on the horizontal plane. It is considered as positive when it is measured from south towards west .



Sun Angle

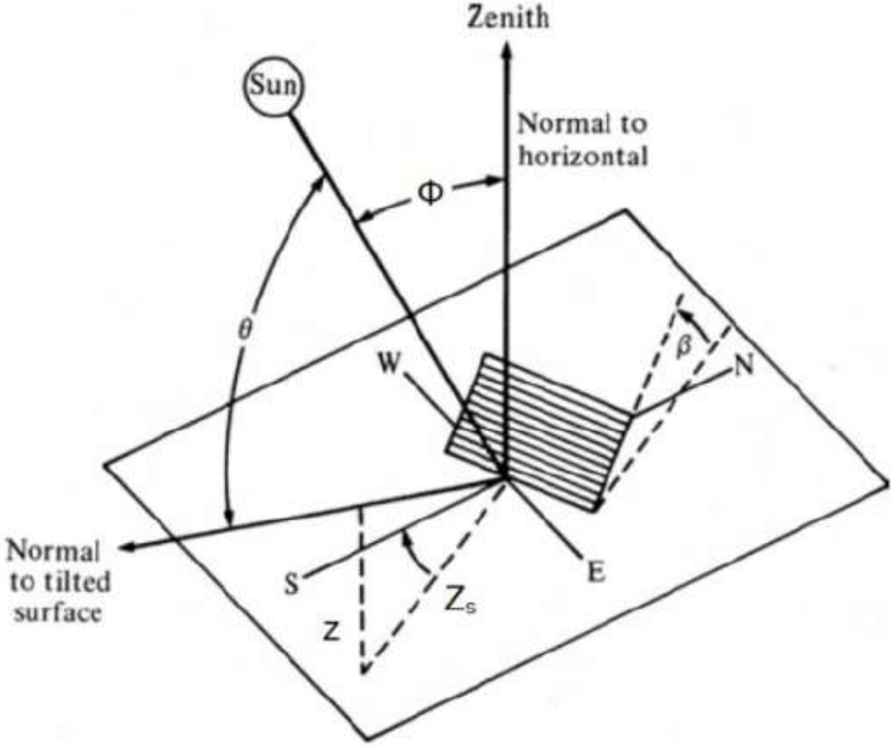
Sun Angle



1. Inclination Angle (Altitude) (α)
2. Zenith Angle (θ_z)
3. Solar Azimuth Angle (γ_s)

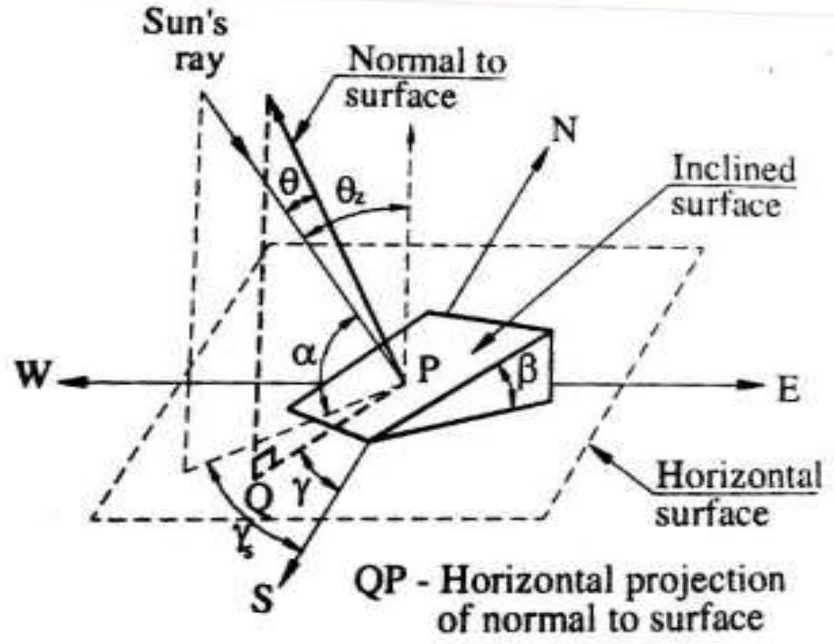
EARTH SUN ANGLES

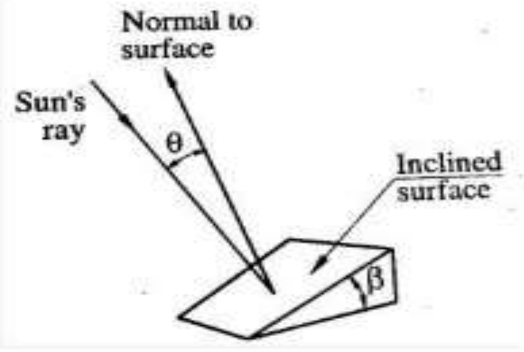
- Surface Azimuth angle (Z_s)It is the angle in the horizontal plane, between the line due south and the horizontal projection of the normal to the inclined plane surface



Earth sun angles

Surface Angle

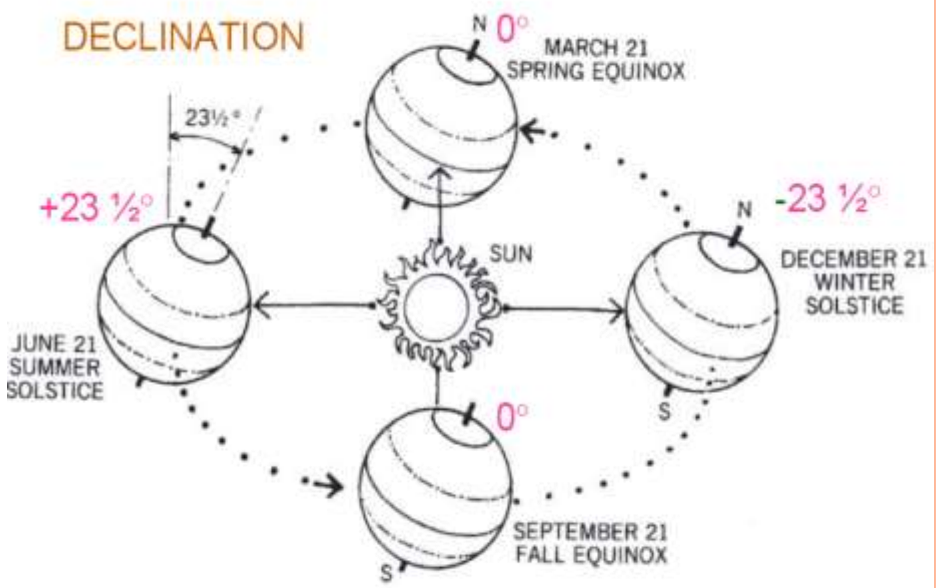




1. Surface Azimuth Angle (γ)
2. Tilt Angle or Slope (β)
3. Angle of Incidence (θ)

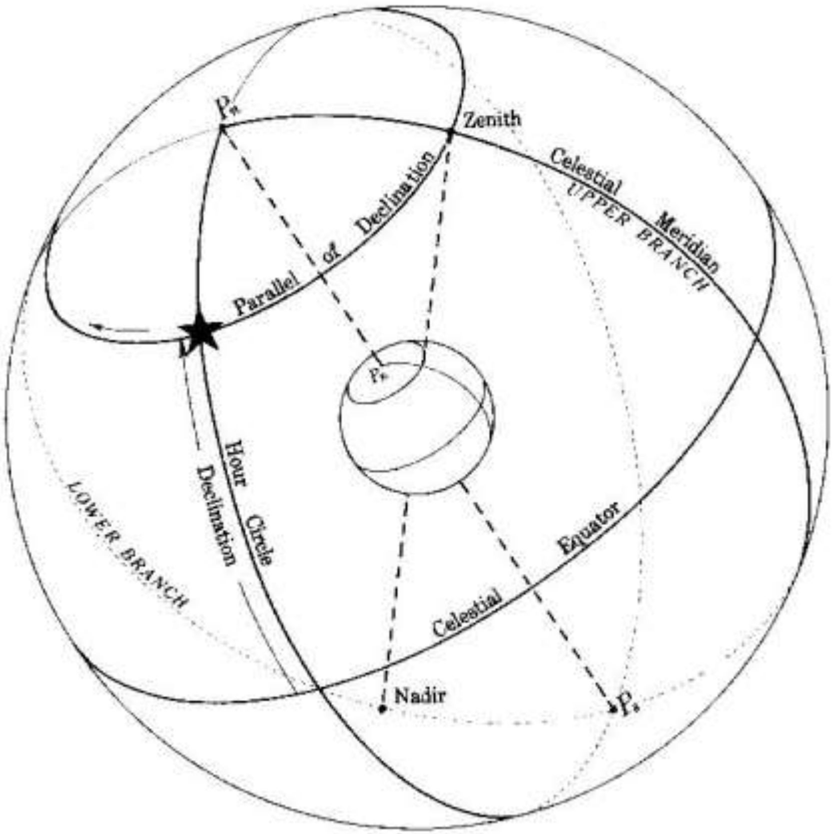
DECLINATION

- The earth's equator is tilted **23.45 degrees** with respect to the plane of the earth's orbit around the sun, so at various times during the year, as the earth orbits the sun, declination varies from **23.45 degrees** north to **23.45 degrees** south.



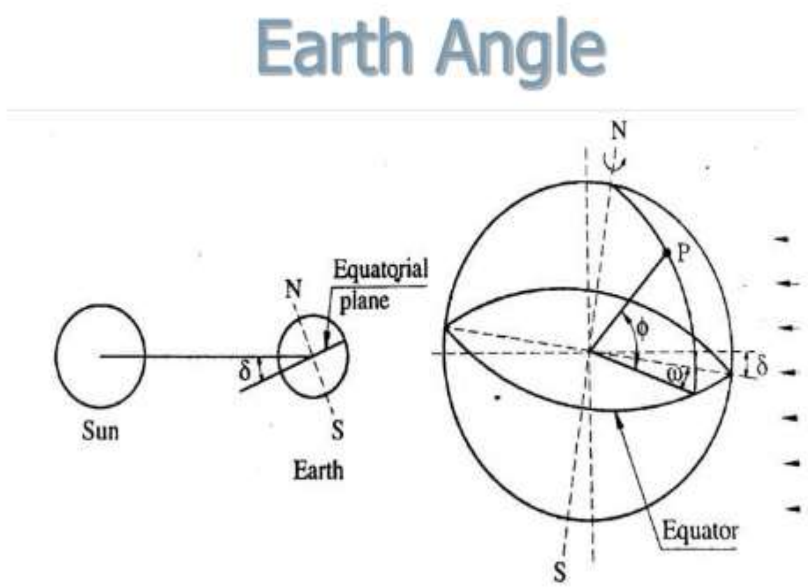
Hour circle

- In astronomy, the **hour circle** of a celestial object is the great circle through the object and the celestial poles. It is perpendicular to the celestial equator. The declination of an object as observed on the celestial sphere is the angle measured along the hour circle of that object to the celestial equator.
- In other words, it is analogous to meridians or longitudes on a globe. A meridian on the celestial sphere matches an hour circle at any time. So called because the angle between the planes of the hour circles (or the difference in longitudes) of two objects is sometimes measured in hours (or hours, minutes, and seconds), one revolution (360°) being equivalent to 24 hours, or 1 hour being equivalent to 15°.



Hour Angle

- In astronomy, **hour angle** is defined as the **angular** distance on the celestial sphere measured westward along the celestial equator from the meridian to the **hour** circle passing through a point.

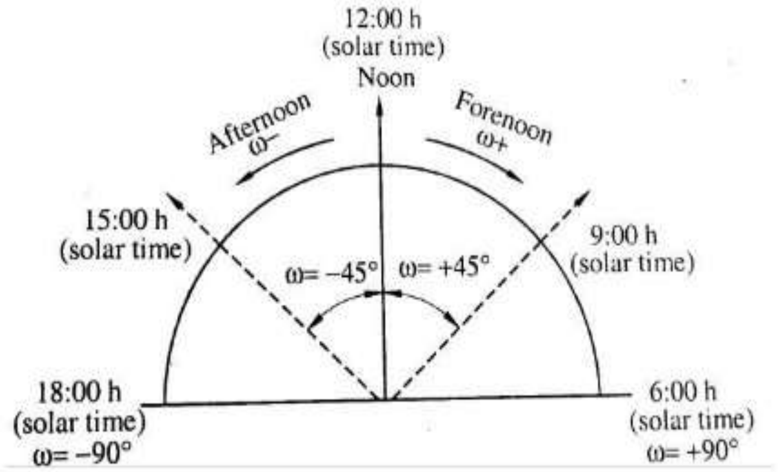


1. Angle of Latitude (Φ)
2. Declination (δ)
3. Hour Angle (ω)

Hour angle

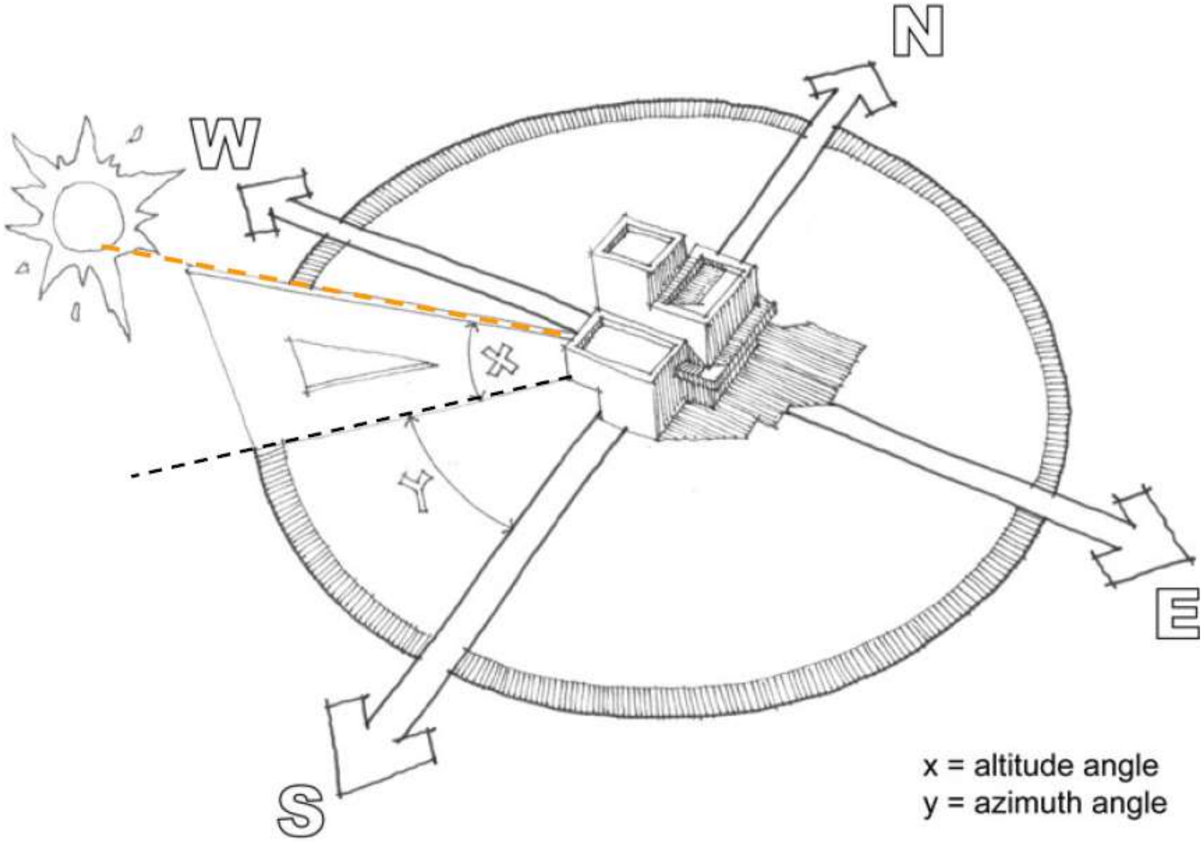
- It is the angle representing the position of the sun with respect to clock hour and with reference to sun's position at 12 noon.

3.Hour Angle (ω)



Inclination angle or Altitude angle

Altitude angle α : the angle between the sun's rays and its projection on a horizontal surface is known as inclination angle.



Solar Radiation Measurements

Solar Radiation Measurements

PYRANOMETER

A type of **actinometer** used to measure **broadband solar irradiance** on a **planar surface.**

It is a sensor that is designe measure the **solar radiatio flux density** (in **watts per metre square**) from a **field of view of 180 degrees**.

The name pyranometer has a **Greek origin**, "pyr" : "fire" and "ano" : "above, sky".

Instruments used to measure heating power of radiation, used in meteorology to measure solar radiation as pyrheliometers / pyranometers.

Solar Radiation Measurements

PYRANOMETER (contd.)

- Solar radiation spectrum : ~ 300 to 2,800 nm.
- Pyranometers have a spectral sensitivity that is as "flat" as possible.
- For Irradiance measurement : by definition – response to "beam" radiation varies with the cosine of angle of incidence.
- Thus, Pyranometer needs to have a so-called "directional response" or "cosine response" that is close to the ideal cosine characteristic.

Full response when solar radiation hits the sensor perpendicularly – normal to surface, sun at zenith

Zero response when sun is at the horizon (angle of incidence = zenith angle = 90°)

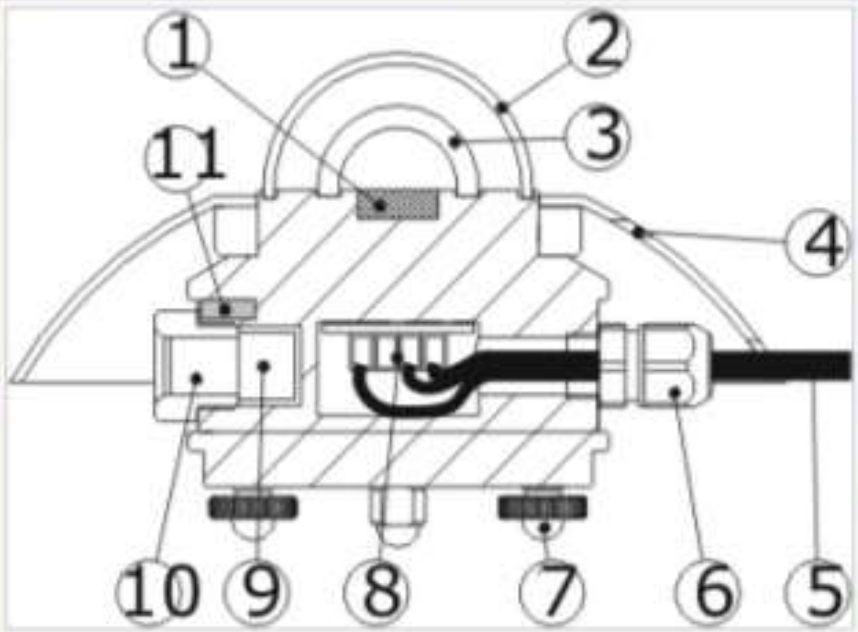
0.5 response at 60° angle of incidence.

Solar Radiation Measurements

PYRANOMETER (contd.)

MAIN COMPONENTS :

1. Thermopile Sensor with a Black Coating :
   1. absorbs all solar radiation,
   2. has a flat spectrum covering the 300 to 50,000 nanometer range,
   3. has a near-perfect cosine response.
2. Glass dome.
   1. limits the spectral response from 300 to 2,800 nanometers (cutting off the part above 2,800 nm), while preserving the 180 degrees field of view.
   2. shields the thermopile sensor from convection.

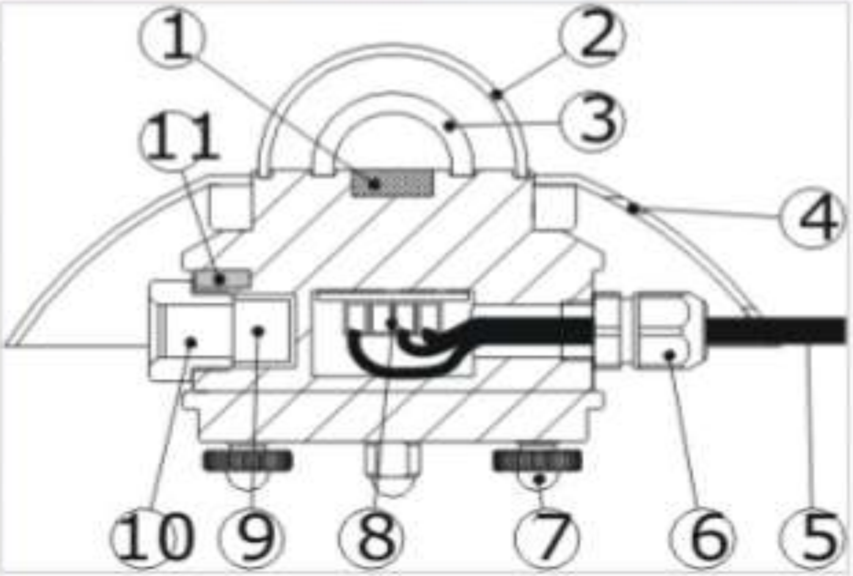


(1) sensor, (2, 3) glass domes, (5) cable, standard length 5 m, (9) desiccant.

Solar Radiation Measurements

PYRANOMETER (contd.)

3. **Black coating on the thermopile sensor :**
   1. absorbs solar radiation, which is converted to heat.
   2. The heat flows through the sensor to the pyranometer housing.
   3. The thermopile sensor generates a voltage output signal that is proportional to the solar radiation.



(1) sensor, (2, 3) glass domes, (5) cable, standard length 5 m, (9) desiccant.

Solar Radiation Measurements

PYRANOMETER (contd.)

APPLICATIONS :

Pyranometers are frequently used in

1. **Meteorology :** They can be seen in many meteorological stations - typically installed horizontally and next to solar panels - typically mounted with the sensor surface in the plane of the panel.
2. **Climatology**
3. **Solar Energy Studies**
4. **Building Physics**

STANDARDIZATION :

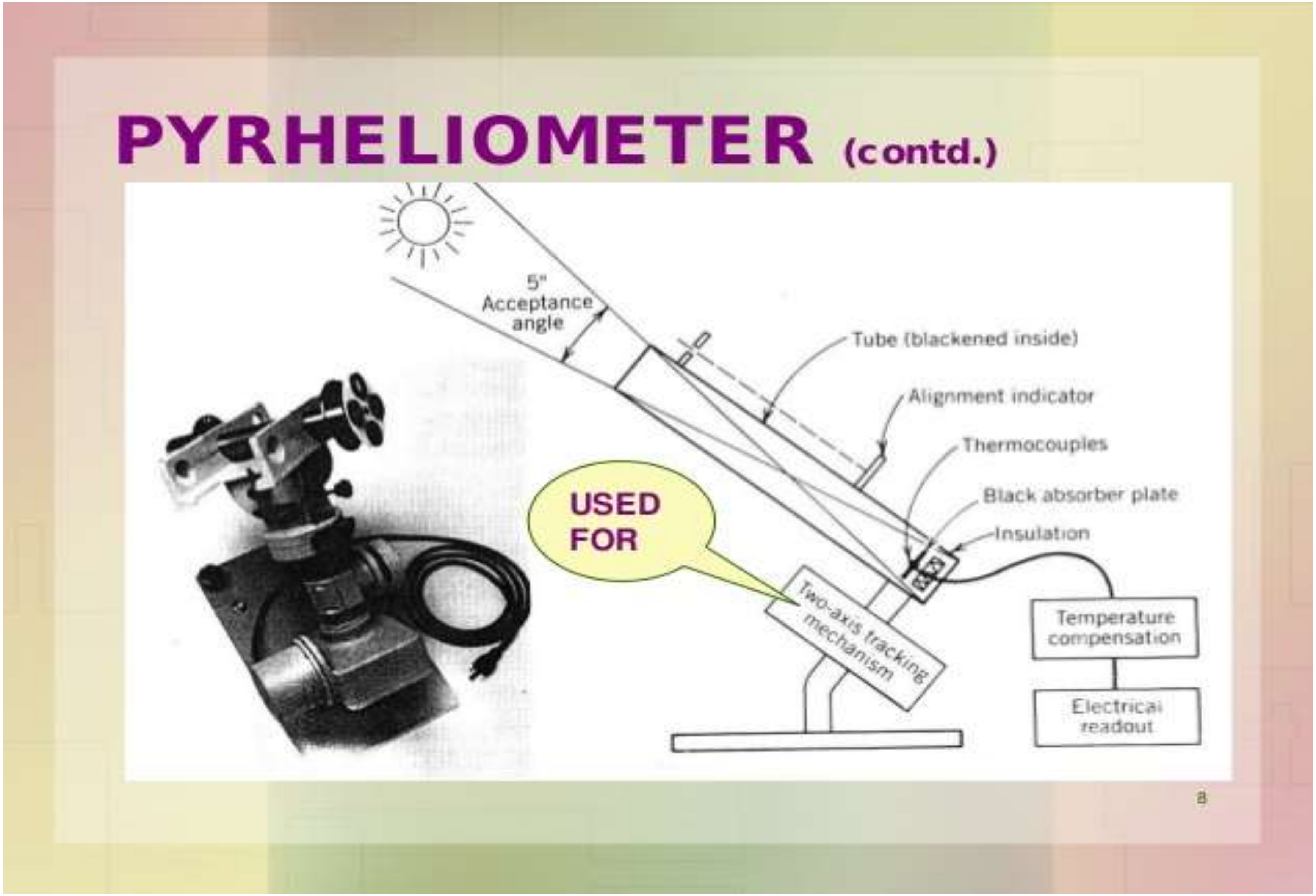
- Pyranometers are standardized according to the **ISO 9060** standard, that is also adopted by the **World Meteorological Organization (WMO)**.
- This standard discriminates **three classes**. The best is (confusingly) called **"secondary standard"** the second best **"first class"** and the last one **"second class"**
- Calibration is typically done relative to **World Radiometric Reference (WRR)**.

Solar Radiation Measurements

PYRHELIOMETER

- A pyrheliometer is an instrument for measurement of direct solar irradiance.
- It is used with a solar tracking system to keep the instrument aimed at the sun.
- A pyrheliometer is often used in the same setup with a pyranometer.

Solar Radiation Measurements



Solar Radiation Measurements

PYRHELIOMETER (contd.)

Pyrheliometer measurement specifications are subject to International Organization for Standardization (ISO) and World Meteorological Organization (WMO) standards.

Typical pyrheliometer measurement applications include :

1. scientific meteorological and climate observations,
2. material testing research
3. assessment of the efficiency of solar collectors and photovoltaic devices.

Solar Radiation Measurements

SUNSHINE RECORDER

A **sunshine recorder** is a device that **records the amount of sunshine at a given location**.

The results provide information about **the weather and climate of a geographical area**.

This information is useful in **meteorology, science, agriculture, tourism, and other fields**.

Solar Radiation Measurements

SUNSHINE RECORDER

There are **two basic types** of sunshine recorders.

- One type uses the **sun itself as a times scale** for the sunshine readings.
- The other type uses **some form of clock** for the **time scale**.

Older recorders required a human observer to interpret the results; recorded results might **differ among observers**. Modern sunshine recorders use **electronics and computers** for precise data that do not depend on a human interpreter. Newer recorders can also measure the **global and diffuse radiation**.

Solar Collectors

“Flat Plate Collector”

Introduction

- Incoming solar spectrum energy consist one third of infrared radiations.
- Characteristic of infrared radiation that whenever it falls on any object , it converts into heat.
- Solar collector is used collect that solar radiation & convert it into heat, & produced heat can be used for certain applications.

Solar collector

- A device designed to absorb incident solar radiation and to transfer the energy to a fluid passing in contact with it, usually liquid or air.

They can be classified in three groups:

- Flat-plate collectors,
- Evacuated-tube collectors
- Focusing collectors.

Flat – Plate Collector

fig: Flat-plate collectors

- A typical flat-plate collector is an insulated metal box with a glass or plastic cover (called the glazing) and a dark-colored absorber plate. These collectors heat liquid or air at temperatures less than 180°F.

- Temperature-
  Achieved upto 40-100^{0}c.

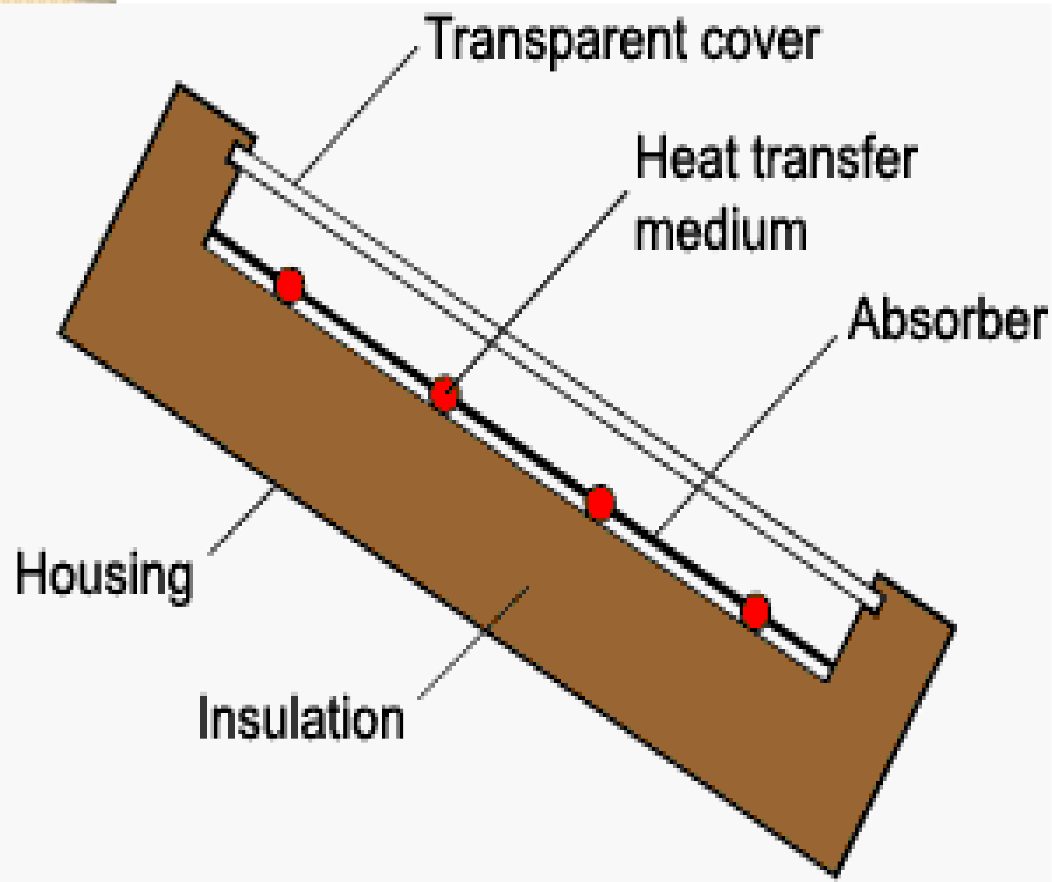
Flat – Plate Collector

- To reach higher temparatures evacuated-tube collectors and focusing collectors are used.

- In **evacuated-tube collectors** they use vacum to reduce heat lost and to protect the absorber coating from deterioration. By this way they can reach temperatures up to 140 °C and they can collect both direct and diffuse solar radiation.

- In **focusing collectors**, they are not stable and they follow the sun to get direct radiation; they can not utilize diffuse radiation. And they are also capable of producing high temperatures.

Components of a flat plate collector

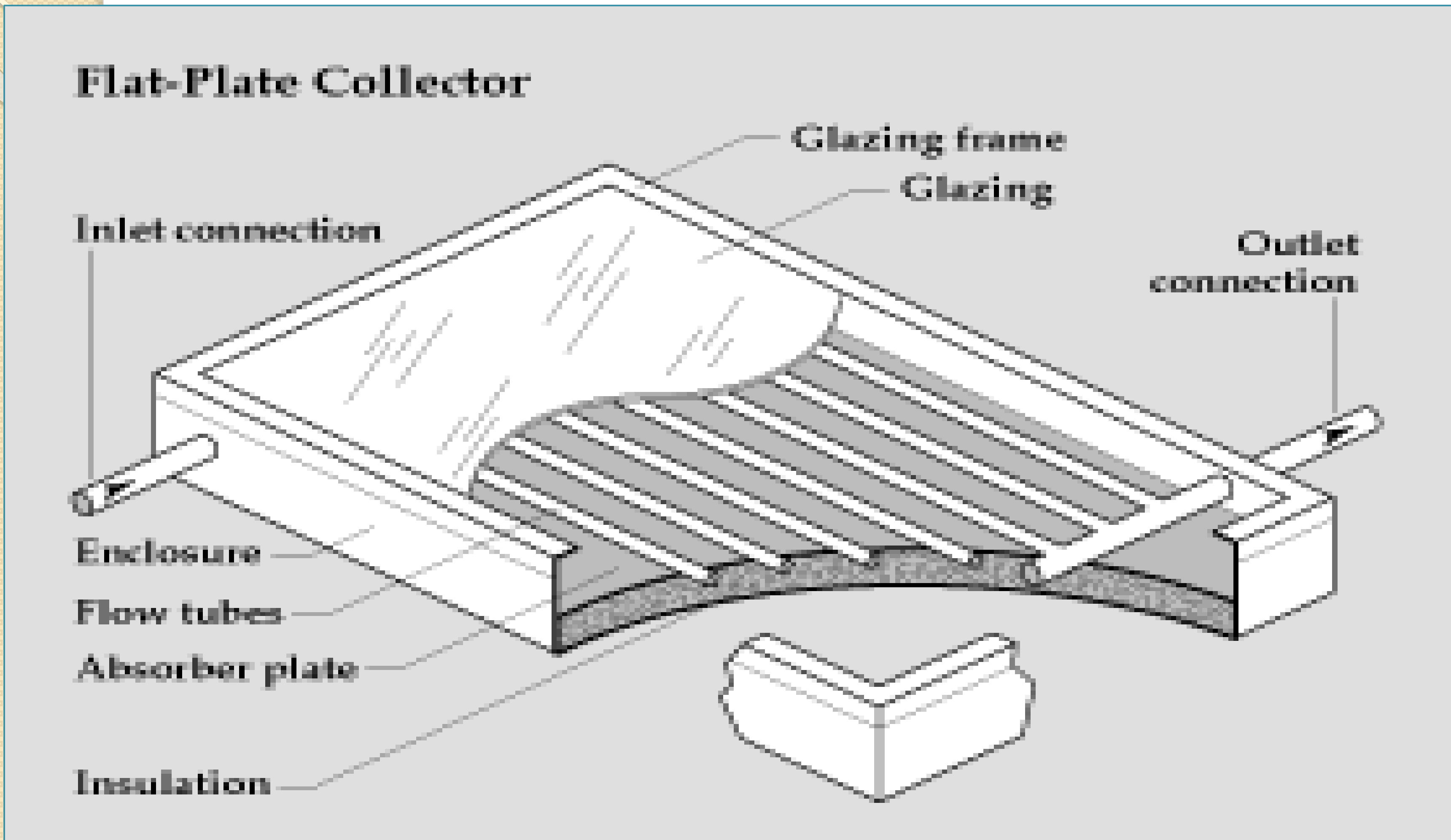


- Transparent cover
- Tubes and fins
- Absorber plate
- Insulation
- The casing

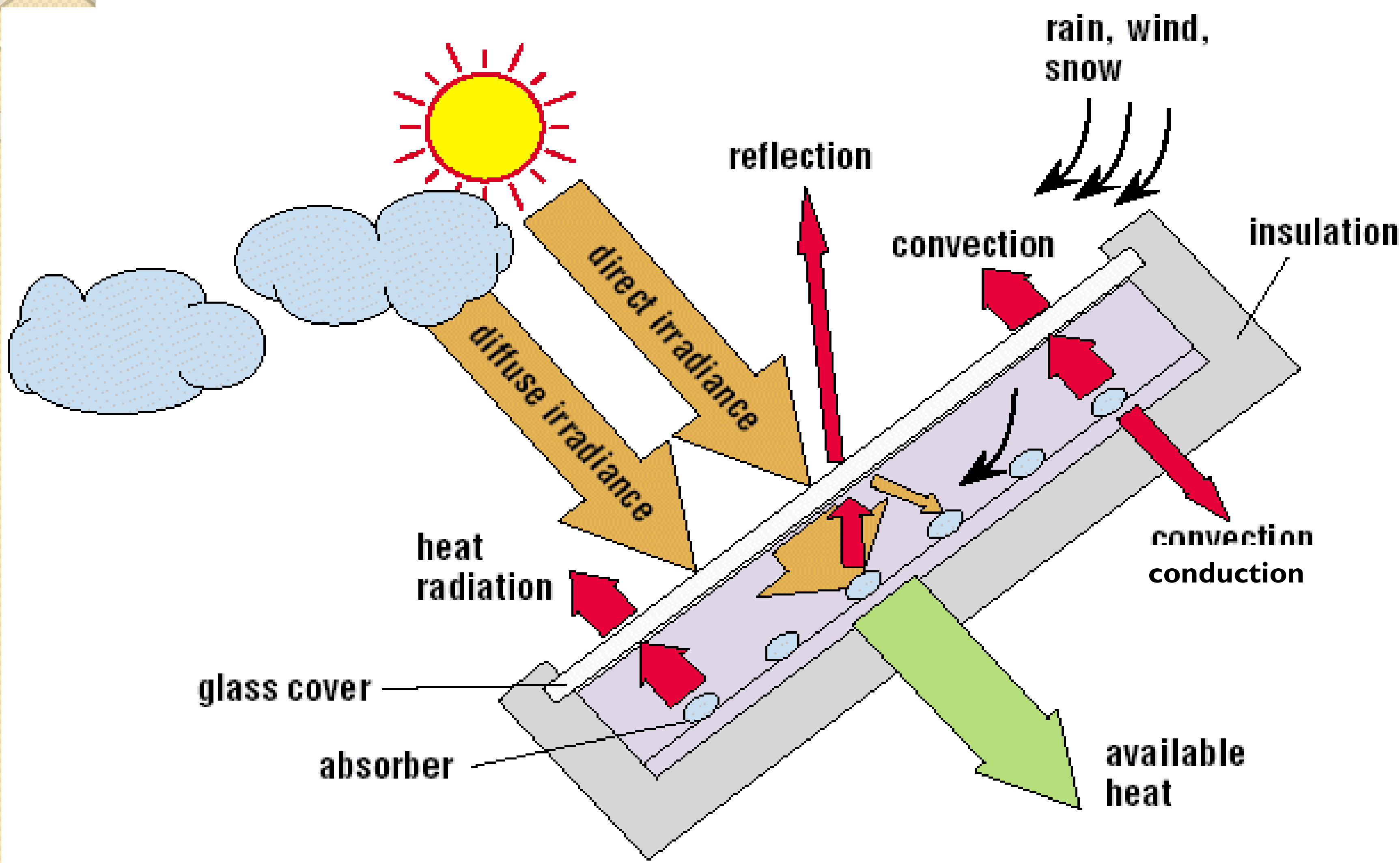
Components of a flat plate collector

1) A transparent cover – one or more sheets of glass or radiation transmitting plastic film or sheet.
2) Tubes, fins , passages or channels- integral with or connected to the absorber plate & conduct the working fluid through the collector.
3) The absorber plate- normally metallic or with a black surface
4) Insulation – provided at the back & sides to minimize heat losses
5) The casing or enclosure - encloses the other components & protects them from the weather.

Basic liquid heating flat-plate solar collector



Processes at a flat-plate collector



Selection Of Materials For Flat Plate Collectors

(i) <u>Absorber plate:</u>

- High absorbtivity
- High thermal conductivity
- Adequate tensile & compressive strength
- Good corrosion resistance
- Less specific heat
- Easily workable
- Easy to handle
- Low cost
- Eg. Copper , Aluminium, Steel.

Material specification

Material	Density kg/m^3	Specific heat Kg/KJ	Thermal conductivity $W/m\ ^oc$
Aluminum	2707	0.896	204
Iron	7897	0.452	73
Steel	7833	0.465	54
Copper	8954	0.385	386

Materials For Flat Plate Collectors

- ii) Cover plate:

- Minimize convection loss
- Minimize radiation loss
- Good strength, durability
- Non-degradability
- Efficient solar energy transmission
- Rigidity
- Resistant to thermal shock

- Eg. Tempered glass (Tempering puts the outer surfaces into compression and the inner surfaces into tension.)

Specification of transparent cover

Material	Thickness (mm)	Solar transmisivity (%)	Thermal transmission (%)
Glass	3-4	91-95	3-5
PVC	0-3	85	32

Materials For Flat Plate Collectors

iii) Insulating Material:

- Provide at the back of the absorber & on the side of the walls to reduce conduction losses and to maximize the efficiency.
- Usually made of polyurethane foam or mineral wool.
- Eg.Mineral fiber materials like glass wool, rock wool, glass fiber or fiberglass.

Properties of insulating materials

Material	Density Kg/m^3	Thermal conductivity W/m ^oc
Timber	720	0.1442
Thermocol	22	0.0314
Saw dust	188	0.0511
Glass wool	65	0.0418
Fiber glass	32	0.0372

Classification

- Based on the type of heat transfer:

1. Liquid heating collector
2. Air heating collector

Liquid flat plate collector

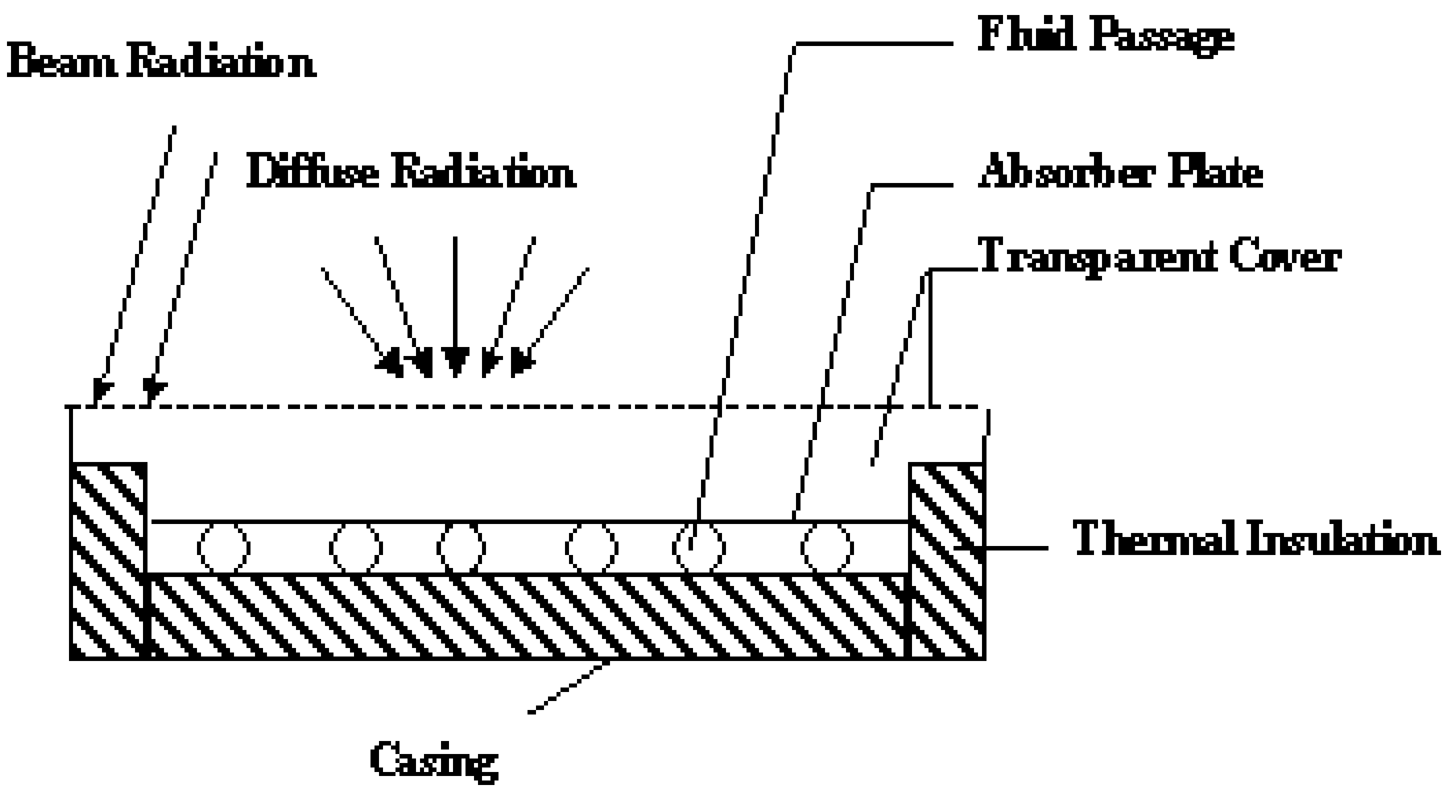


Fig.1 Liquid Flat-plate Collector

Absorber plate:

- Is basically a flat metal plate, usually made of highly conductive and corrosion resistant copper or steel or aluminum with a black surface with high absorptivity for solar radiation.

- Is made from metal sheet 1 to 2 mm in thickness.

- Generally corrugated galvanized sheet material is widely used. As copper is expensive, steel is widely used.

- The surface of the absorber plate determines how much of the incident solar radiation is absorbed and how much is emitted at a given temperature. Flat black paint which is widely used as a coating has an absorptance of about 95 percent for incident shortwave solar radiation.

Flow passages:

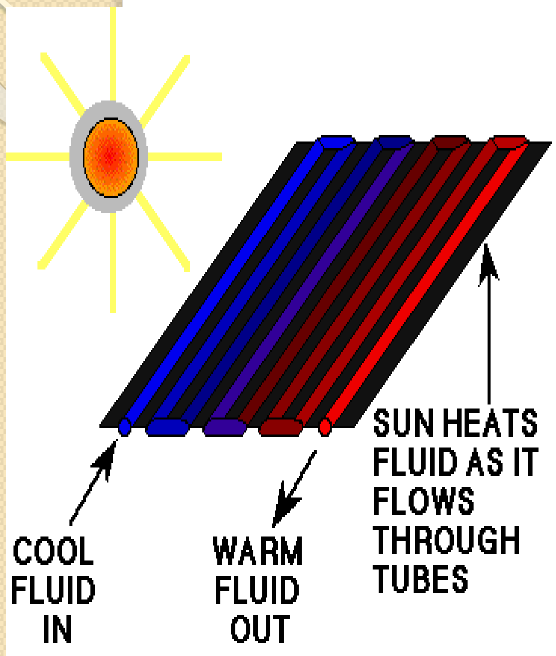


fig:Cross section of a absorber plate& flow passages of a flat plate collector

- The tubings made of copper of diameter 1 to 1.5 cm are soldered in line or integral with the absorber plate with the pitch ranging from 5 to 15 cm.

- For a copper plate 0.05 cm thick with 1.25-cm tubes spaced 15 cm apart in good thermal contact with the copper, the fin efficiency is better than 97 percent.

Transparent Cover plate:

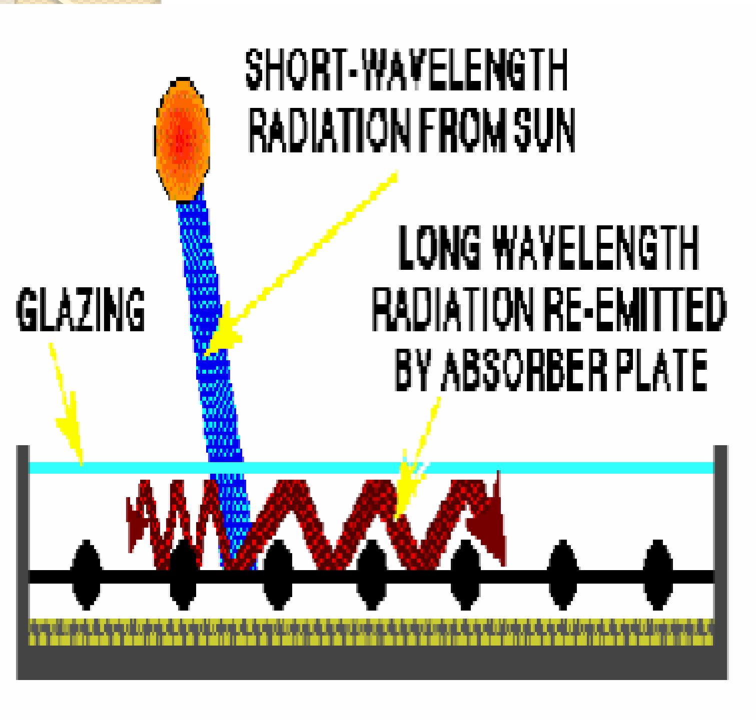


fig : Cross section of a cover part of a flat-plate collector

- One or two sheets of glass of thickness 3 to 4 mm or radiation transmitting plastic film or sheet that is transparent to incoming solar radiation and opaque to the infrared re-radiation from the absorber.
- Should have a high transmittance for solar radiation and should not deteriorate with time.
- It reduces convective and radiative heat losses from the absorber.

Insulation & Enclosure:

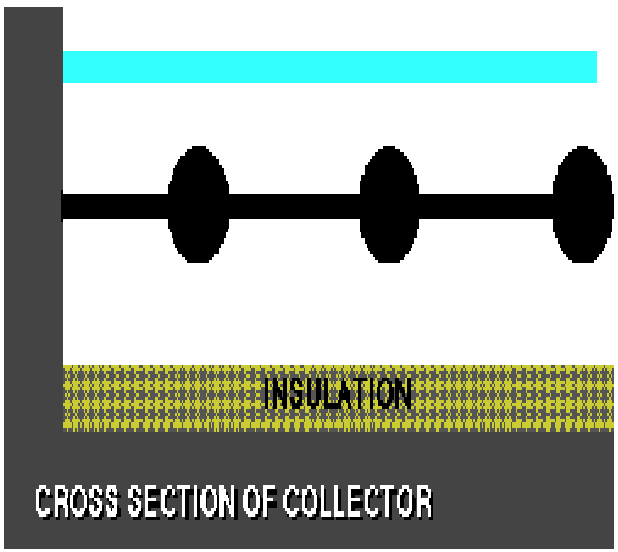


fig: Cross Section of an Insulation Part of a Flat-Plate Collector

- Thermal insulation of 5 to 10 cm thickness.
- Material is generally mineral wool or glass wool or a heat resistant fiber glass.
- Placed behind absorber plate to prevent heat losses from the rear surface.
- The collector enclosure is usually made from galvanized steel or aliminium.
- Slagwood, polyurethane foam, hay in polythene bags are other suitable insulation materials.

Flat –Plate Air Heating Collectors (Solar Air Heaters)

- A conventional air heater is typically a flat passage between two parallel plates.
- One of the plates is blackened to absorb incident solar radiation.
- One or more transparent covers are located above the absorbing surface.
- The air is made to pass through the passage so that it gets heated. Insulation around the sides and base of the unit is necessary to keep heat losses to a minimum.

Flat plate solar collector

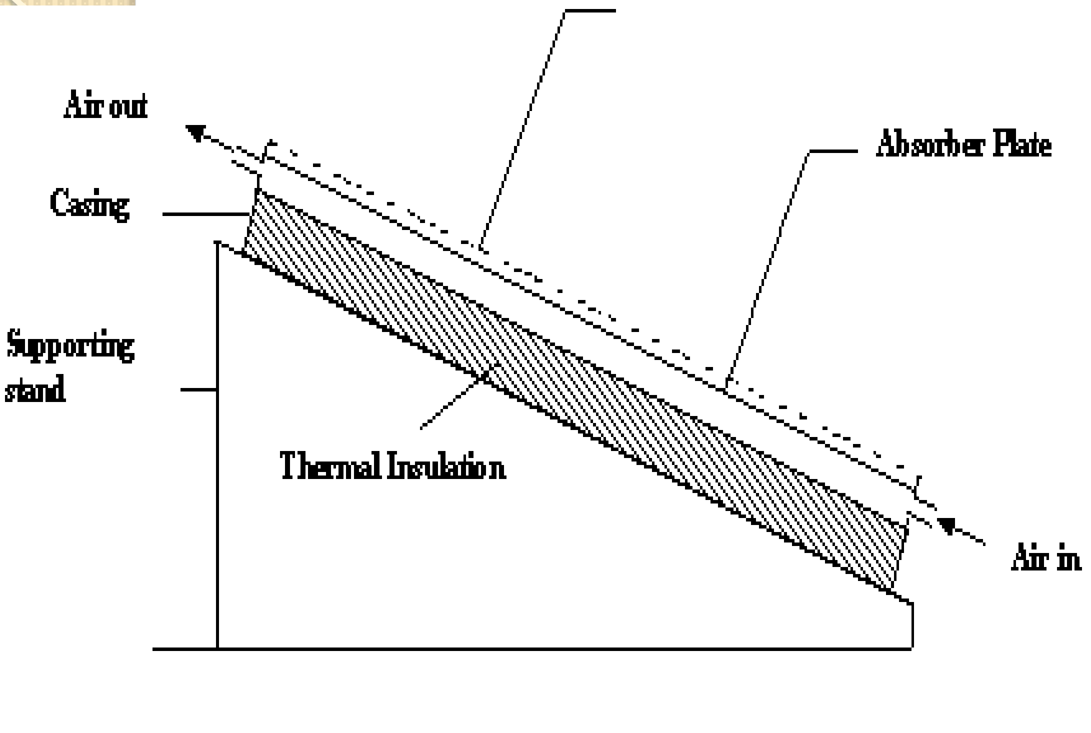
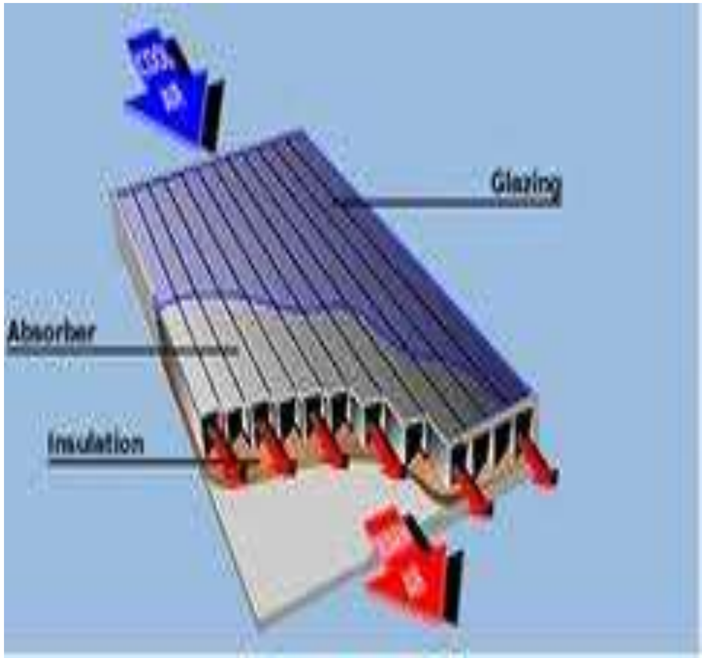


Fig 3 Solar Air Heater

fig: Cross section of a basic air-heating flat-plate solar collector



Proper Orientation And Angle Of Solar Collector

Flat plate collectorts are divided in three main groups according to how they are oriented:

- Flat-plate collectors facing south at fixed tilt
- One-axis tracking flat-plate collectors with axis oriented north-south
- Two-axis tracking flat-plate collectors

Most favourable orientation of a collector for heating only-collector facing due south at an inclination angle to the horizontal equal to the latitude plus 15^0 ($s = ø + 15^0$).

Applications

A) Domestic applications

- Domestic hot water
- Air conditioning
- Cooking

B) Commercial applications

- Laundromats
- Car washes
- Military laundry facilities
- Space heating
- Power generation
- Water pumping

fig: Flat plate collectors used for heating buildings

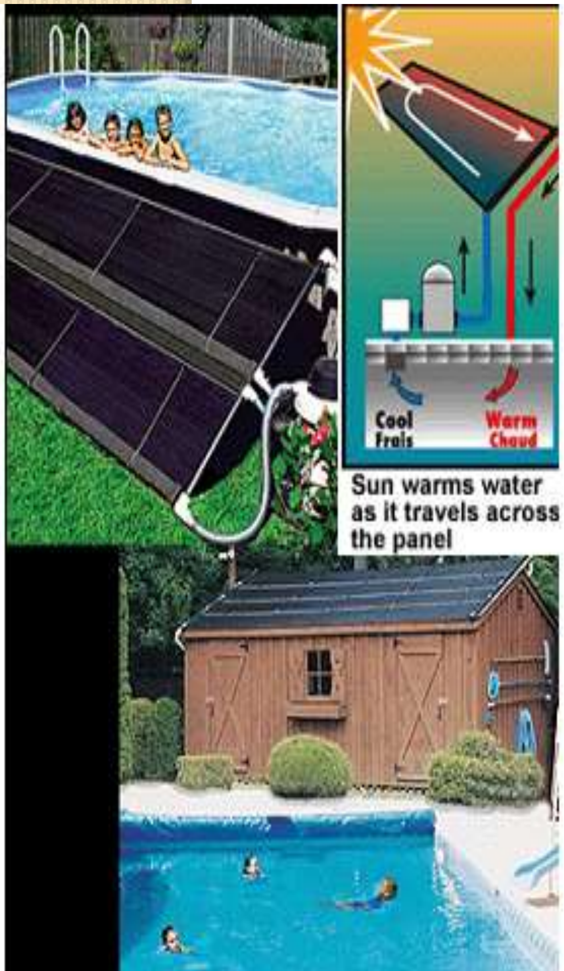


fig: Flat-plate collectors used for heating swimming pools

Comparison Of Liquid And Air Heating Flat Plate Collectors

S.NO.	PARAMETRS	LIQUID HEATING TYPE	AIR HEATING TYPE
1.	Volume of storage required	1/3rd of vol. of rocks necessary to store equal quantities of heat for air systems	Roughly 3 times as much vol. as for water heat-storage (due to low density of air as working fluid)
2.	Noise level	Less noisy	Higher noise level
3.	Energy requirements for pumping working fluid	Much less	Much more(require blowers)
4.	Energy supply to absorption air-conditioners	Easily adapted	Has difficulty
5.	Fluid circulation costs	Low	high

Advantages of FPC

- Can be use both direct and diffused radiation
- Do not require orientation towards sun
- Require little maintenance
- Mechanically simpler

Conclusion

Flat-plate collectors which are used for water heating, are long lasting, and also in long term they are cheaper than other water heating systems.However,they requires large areas if high energy output is a requirement.

Solar energy is free if we do not include the initial cost for installation and the maintenance.

Finally; besides these we should remember by using solar energy we can protect nature.