PARVATHAREDDY BABUL REDDY

VISVODAYA INSTITUTE OF TECHNOLOGY & SCIENCE

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INTRODUCTION

TO

RENEWABLE ENERGY SYSTEMS

UNIT-I

CLASS-IV-I SEM

Subject: RENEWABLE ENERGY SYSTEMS

COURSE OBJECTIVES

- Understand various sources of Energy and the need of Renewable Energy Systems.
- Understand the concepts of Solar Radiation, Wind energy and its applications.
- Analyze solar thermal and solar PV systems
- Understand the concept of geothermal energy and its applications, biomass energy, the concept of Ocean energy and fuel cells.

SYLLABUS

UNIT-I----------> SOLAR ENERGY

Solar radiation - beam and diffuse radiation, solar constant, earth sun angles, attenuation and measurement of solar radiation, local solar time, derived solar angles, sunrise, sunset and day length. flat plate collectors, concentrating collectors, storage of solar energy-thermal storage.

SYLLABUS

UNIT-II----------> PV ENERGY SYSTEMS

- Introduction, The PV effect in crystalline silicon basic principles, the film PV, Other PV technologies, Electrical characteristics of silicon PV cells and modules, PV systems for remote power, Grid connected PV systems.

SYLLABUS

UNIT III------> WIND ENERGY

- Principle of wind energy conversion; Basic components of wind energy conversion systems; windmill components, various types and their constructional features; design considerations of horizontal and vertical axis wind machines: analysis of aerodynamic forces acting on wind mill blades and estimation of power output; wind data and site selection considerations.

SYLLABUS

UNIT IV-------> GEOTHERMAL ENERGY

Estimation and nature of geothermal energy, geothermal sources and resources like hydrothermal, geo-pressured hot dry rock, magma. Advantages, disadvantages and application of geothermal energy, prospects of geothermal energy in India.

SYLLABUS

UNIT V---> MISCELLANEOUS ENERGY TECHNOLOGIES

Ocean Energy:

Tidal Energy-Principle of working, performance and limitations.

Wave Energy-Principle of working, performance and limitations.

Bio mass Energy: Biomass conversion technologies, Biogas generation plants, Classification, advantages and disadvantages, constructional details, site selection, digester design consideration

Fuel cell: Principle of working of various types of fuel cells and their working, performance and limitations.

TEXTBOOKS

1. Stephen Peake, “Renewable Energy Power for a Sustainable Future”, Oxford International Edition, 2018.
2. G. D. Rai, “Non-Conventional Energy Sources”, 4th Edition, Khanna Publishers, 2000.

REFERENCE BOOKS

1. S. P. Sukhatme, “Solar Energy”,3rd Edition, Tata Mc Graw Hill Education Pvt. Ltd, 2008.
2. B H Khan , “ Non-Conventional Energy Resources”, 2nd Edition, Tata Mc Graw Hill Education Pvt Ltd, 2011.
3. S. Hasan Saeed and D.K.Sharma,“Non-Conventional Energy Resources”,3rd Edition, S.K.Kataria& Sons, 2012.
4. G. N. Tiwari and M.K.Ghosal, “Renewable Energy Resource: Basic Principles and Applications”, Narosa Publishing House, 2004.

ONLINE LEARNING RESOURCES

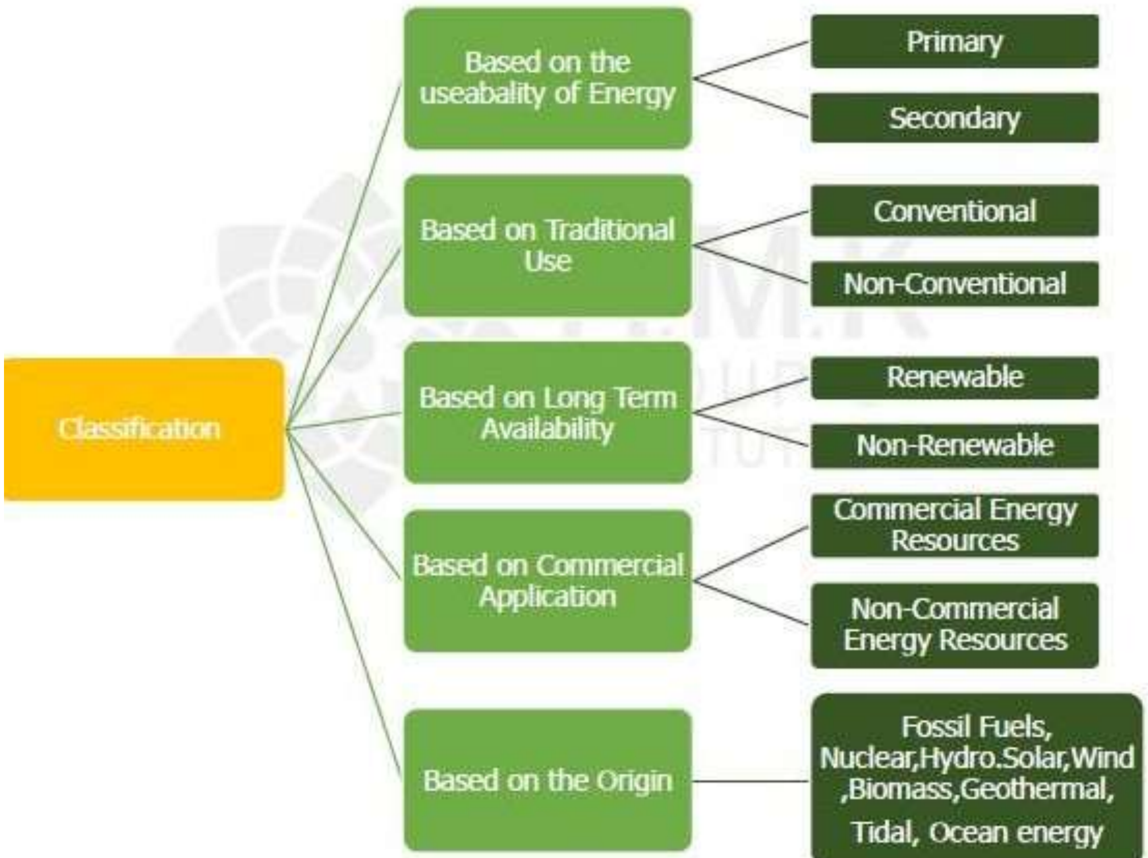
1. https://nptel.ac.in/courses/103103206
2. https://nptel.ac.in/courses/108108078

INTRODUCTION

RENEWABLE ENERGY SYSTEMS

- **What Is Energy?**
- Any physical activity in this world, whether carried out by human beings or by nature, is cause due to flow of energy in one form or the other. The work output depends on the energy input.
- Energy is one of the major inputs for the economic development of any country. In the case of the developing countries, the energy sector assumes a critical importance in view of the everincreasing energy needs requiring huge investments to meet them.

CLASSIFICATIONS OF ENERGY

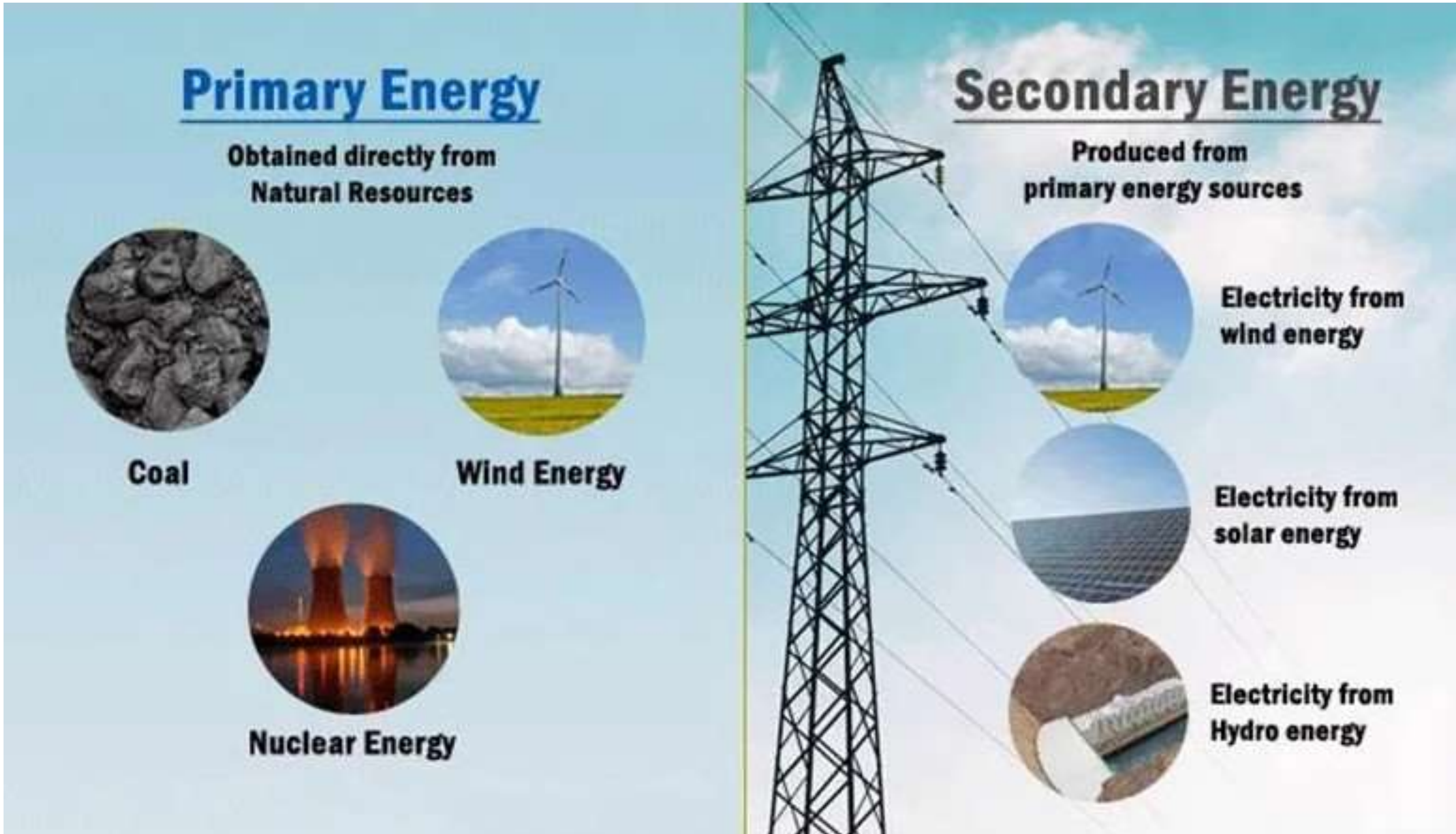


INTRODUCTION

Energy can be classified into several types based on the following criteria

- Primary and Secondary energy
- Commercial and Non commercial energy
- Renewable and Non-Renewable energy
- Conventional and Non-conventional energy

PRIMARY AND SECONDARY ENERGY



PRIMARY AND SECONDARY ENERGY

- According to different basic forms, energy can be divided into primary energy and secondary energy.
- Primary energy refers to energy resources that exist in nature in a natural form and has not been processed or converted;
- secondary energy refers to energy products converted from primary energy processing.
- Primary energy can be either renewable energy (such as hydropower, wind energy and biomass energy) or non-renewable energy (such as coal, oil, natural gas, oil shale, etc.).
- Among them, coal, oil, natural gas and water are the core of primary energy, and they constitute the foundation of global energy in contemporary society.
- In addition, renewable energy sources such as solar energy, wind energy, geothermal energy, ocean energy, biomass energy and nuclear energy are also included in the scope of primary energy.
- Secondary energy is the direct or indirect conversion of primary energy into other types and forms of energy resources, such as electricity, gas, gasoline, diesel, coke, clean coal, laser and biogas.

COMMERCIAL ENERGY AND NON COMMERCIAL ENERGY

COMMERCIAL ENERGY:

- The energy sources that are available in the market for a definite price are known as commercial energy.
- By far the most important forms of commercial energy are electricity, coal and refined petroleum products.
- Commercial energy forms the basis of industrial, agricultural, transport and commercial development in the modern world. In the industrialized countries, commercialized fuels are predominant source not only for economic production, but also for many household tasks of general population.
- Examples: Electricity, lignite, coal, oil, natural gas etc.

COMMERCIAL ENERGY AND NON COMMERCIAL ENERGY

NON COMMERCIAL ENERGY

- Non-Commercial Energy The energy sources that are not available in the commercial market for a price are classified as non-commercial energy.
- Non-commercial energy sources include fuels such as firewood, cattle dung and agricultural wastes, which are traditionally gathered, and not bought at a price used especially in rural households. These are also called traditional fuels.
- Non-commercial energy is often ignored in energy accounting.
- Example: Firewood, agro waste in rural areas;
- solar energy for water heating, electricity generation, for drying grain, fish and fruits;
- Animal power for transport, threshing, lifting water for irrigation, crushing sugarcane;
- Wind energy for lifting water and electricity generation.

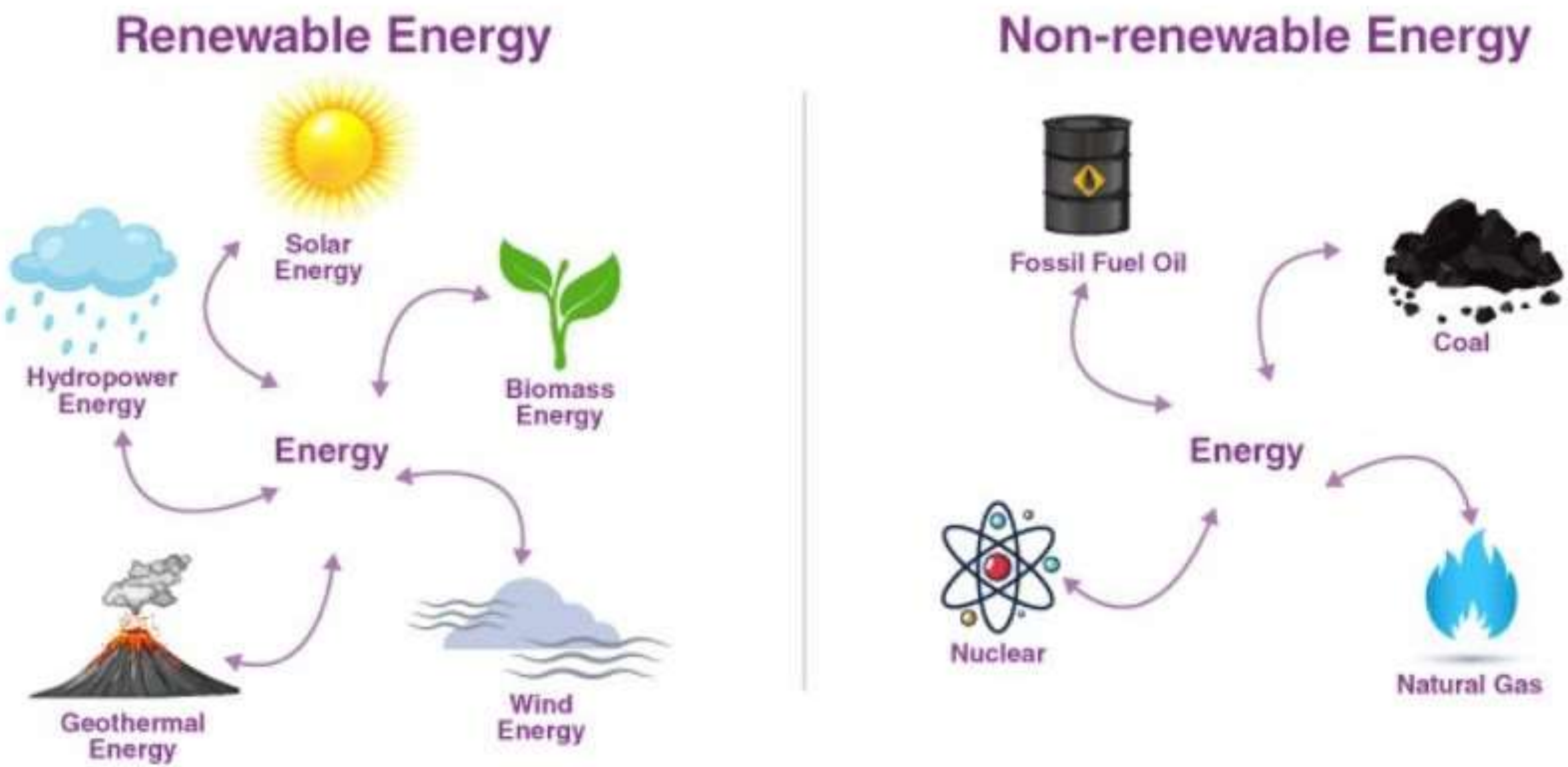
RENEWABLE AND NON-RENEWABLE ENERGY

- Renewable sources of energy are available plentiful in nature and are sustainable. These resources of energy can be naturally available.
- **Examples**
  - Solar energy, geothermal energy, wind energy, biomass, hydropower and tidal energy.

RENEWABLE AND NON-RENEWABLE ENERGY

- **Non-renewable resource**
  - A non-renewable resource is a natural resource that is found underneath the earth.
  - These type of energy resources do not replenish at the same speed at which it is used.
  - They take millions of years to replenish.
  - The main examples of non-renewable resources are coal, oil and natural gas.

RENEWABLE AND NON-RENEWABLE ENERGY



CONVENTIONAL AND NON-CONVENTIONAL ENERGY

- Conventional energy resources which are being traditionally used for many decades and were in common use around oil crisis of 1973 are called conventional energy resources,

  E.g., fossil fuel, nuclear and hydro resources.

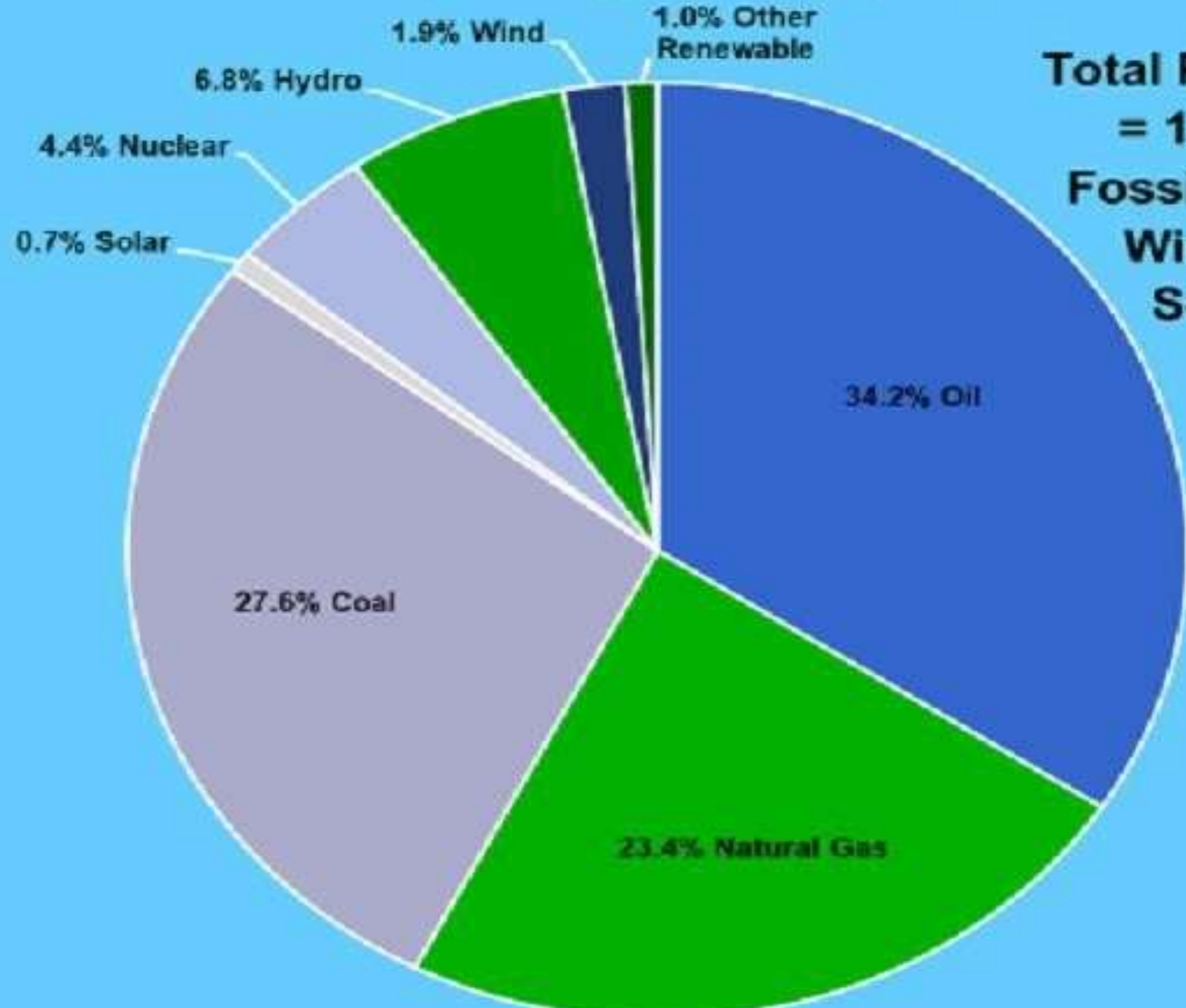
- Non-conventional energy resources which are considered for large– scale use after oil crisis of 1973.

  E.g., solar, wind, biomass, etc

NEED OF RENEWABLE ENERGY SOURCES

- World faces many of the environmental problems with the usage of fossil fuels (like coal, anthracite, brown coal, oils and gaseous fuels).
- The burning of fossil fuel produces carbon dioxide everyday.
- This increased content of Carbon Dioxide is playing main role for increasing the global atmospheric temperature called as “Global Warming Effect”.

World Primary Energy Consumption in 2017



Total Primary Energy = 13,511 MTOE
Fossil Fuel = 85.2%
Wind = 1.9% &
Solar = 0.7%

Source: https://www.bp.com/content/dam/bp/en/corporate/pdf/energy-economics/statistical-review/bp-stats-review-2018-full-report.pdf

COAL

FOSSIL FUELS are used for 85% of the world's commercial energy

OIL

NATURAL GAS

THE PROBLEMS FACED IN THE USAGE OF FOSSIL FUELS ARE

- Environmental hazards
- Rising prices of fuels
- Oil spills
- Acid rain etc
- Effect on Human Health
- Non-Renewable
- Coal Mining
- Need Huge Amount of Reserves

1. Environmental Hazards

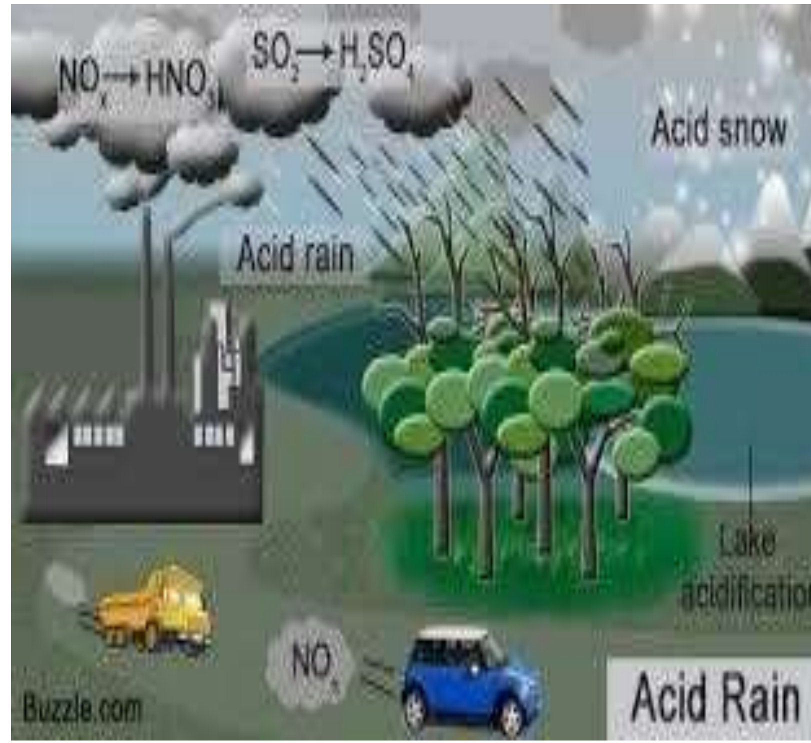
- Environmental pollution is one of the major disadvantages of fossil fuels.
- It is a known fact that carbon dioxide gas released when fossil fuels are burnt, and it is one of the primary gas responsible for global warming.

2. Rising Prices

- Only few countries have huge reserves of oil and natural gas.
- Due to heavy usage of fossil fuels , the fuel rates are increased.

3. ACID RAIN

- The gases that are emitted by cars, vehicles, and factories are released into the atmosphere.
- They dissolve in rainwater, causing acid rains and acid snow.
- Acid rains affect human life to a great extent



4. Impact on Aquatic Life by Oil Spill:

- An oil spill is the release of a liquid petroleum hydrocarbon into the environment, especially marine areas, due to human activity or natural disasters, and is a form of pollution. .
- Often we hear of some leaks in oil tankers or ship getting drowned deep under the sea that were carrying crude oil to get refined.
- The impact of this is that crude oil contains some toxic substances which when mixed up with water poses serious impact on aquatic life.

5. Effect on Human Health

- Pollution from vehicles and coal powered power plants can cause serious
environmental hazards and can significantly affect quality of human life.
- Air pollution can result in asthma, chronic obstructive pulmonary disorder and lung cancer.
- Long-term exposure may increase respiratory infections in general population.

6.Non-Renewable

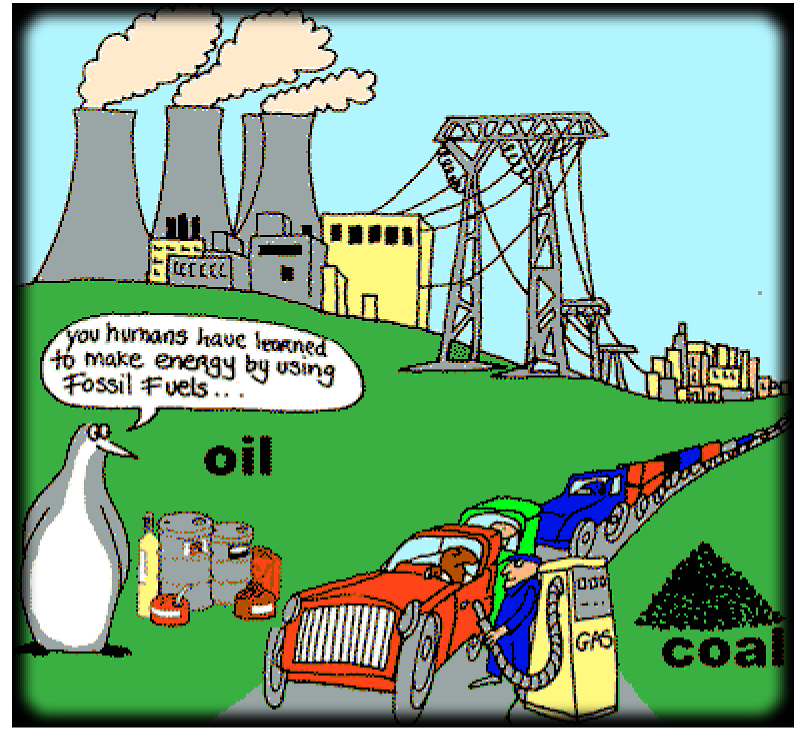
- Fossil fuels are being extracted to meet the gap between demand and supply and it is estimated that they will be finished in next 30-40 years.
- They are non-renewable. This means once these non-renewable sources are completely used up, there is nothing more left.

7. Coal Mining

- Extraction of coal from areas that have huge reserves is not only a difficult and dangerous task but also poses a serious health hazard to the lives of several workers who work there.
- The coal mining destroys wide areas of land and results in ecological imbalance.

8. Need Huge Amount of Reserves

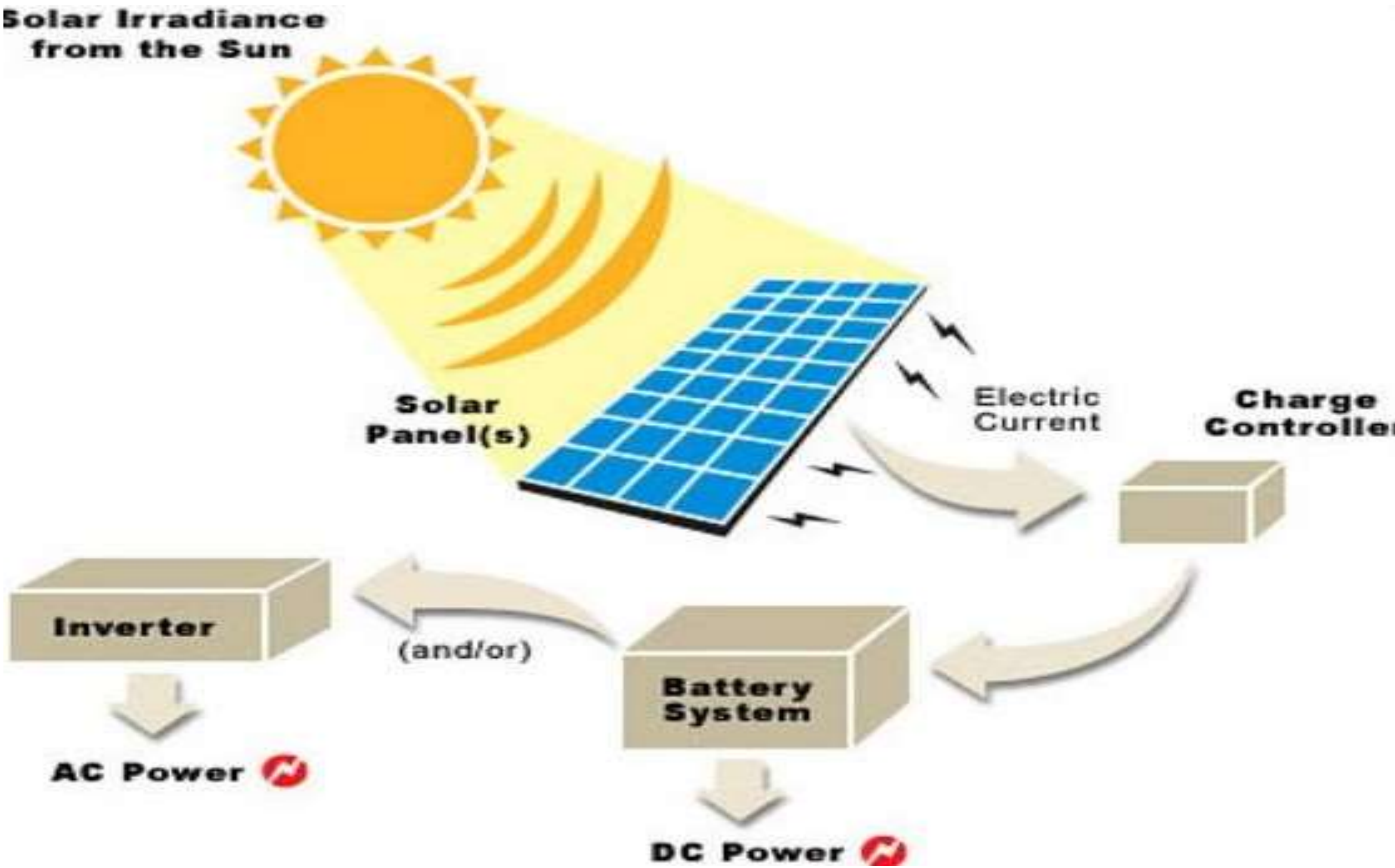
- The coal power plants requires huge and regular supply of coal to produce large amount of energy on a constant basis.
- This means that these plants need train-loads of fuel near power stations to carry out the process of generating power.
- This is needed as many countries are still dependent on coal as a major source for producing power.



SOLAR ENERGY

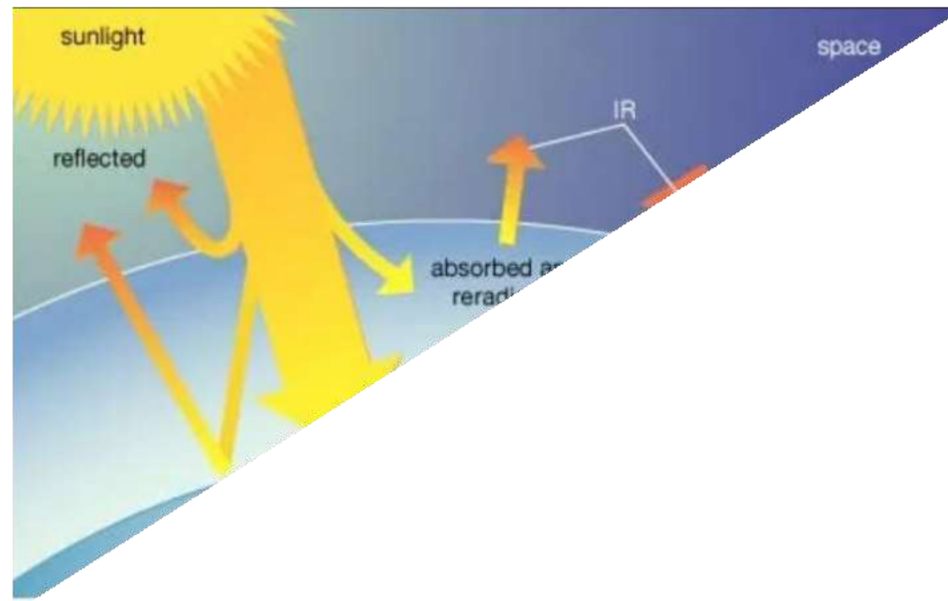
- Solar radiation from the sun that is capable of producing heat, causing a chemical reaction, and producing electricity is called Solar Energy.
- It is the most powerful and vast source of Energy.
- The total Solar Energy incident on the earth's surface is enormously greater than the world's current and future Energy requirements.
- Solar Energy is expected to be the most attractive renewable Energy source.
- Solar Energy has an inexhaustible supply and it is non-polluting as in the non-renewable sources like coal, natural gas, and petroleum.

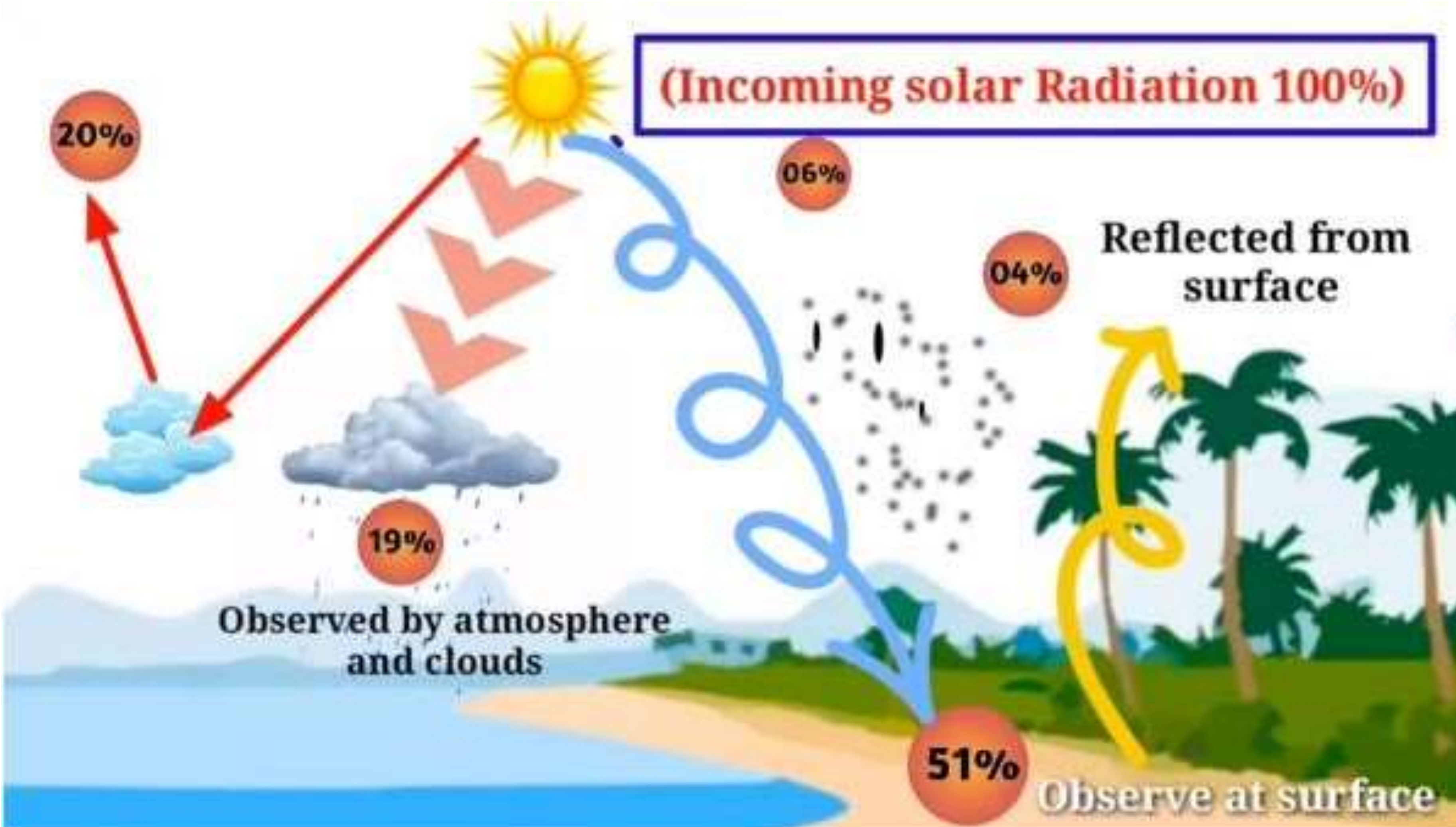
SOLAR POWER ENERGY CONVERSION PROCESS



SOLAR RADIATION

- **Solar radiation** refers to energy produced by the Sun.
- *Solar radiation*, often called the solar resource or just sunlight, is a general term for the electromagnetic radiation emitted by the sun.
- Solar radiation can be captured and turned into useful forms of energy, such as heat and electricity, using a variety of technologies.





(Incoming solar Radiation 100%)
20%
06%
04%
Reflected from surface
19%
Observed by atmosphere and clouds
51%
Observe at surface

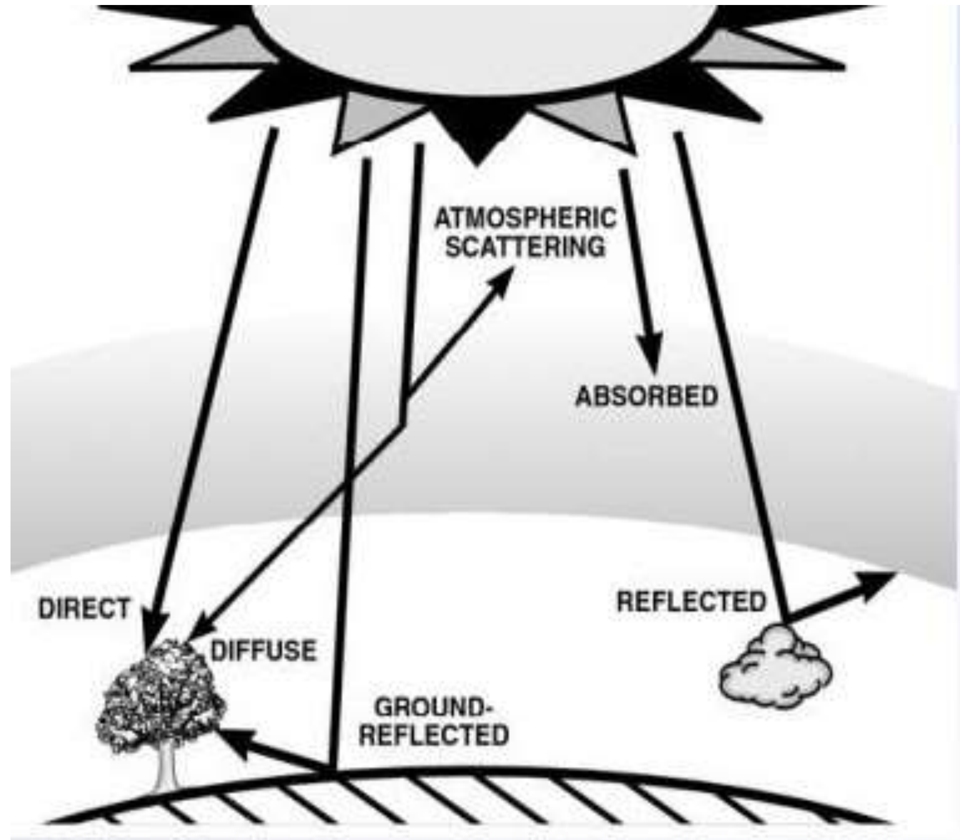
ALBEDO

- The total reflectivity of the earth is 31% which is technically known as **Albedo.**

BEAM AND DIFFUSE RADIATION

Atmospheric Effects:

- Solar radiation is absorbed, scattered and reflected by components of and reflected by components of the atmosphere .

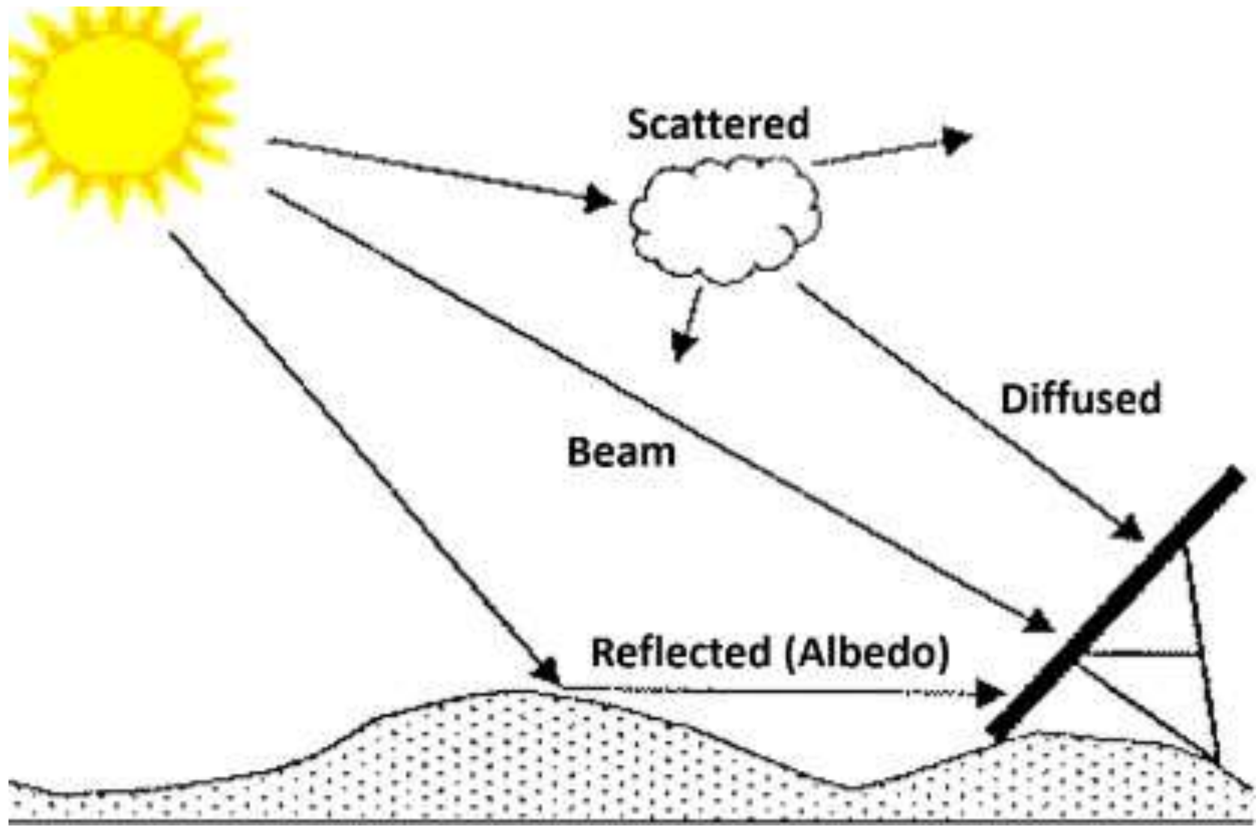


BEAM AND DIFFUSE RADIATION

- The amount of radiation reaching The amount of radiation reaching the earth is less than what entered the top of the atmosphere We classify it in atmosphere. We classify it in two categories:

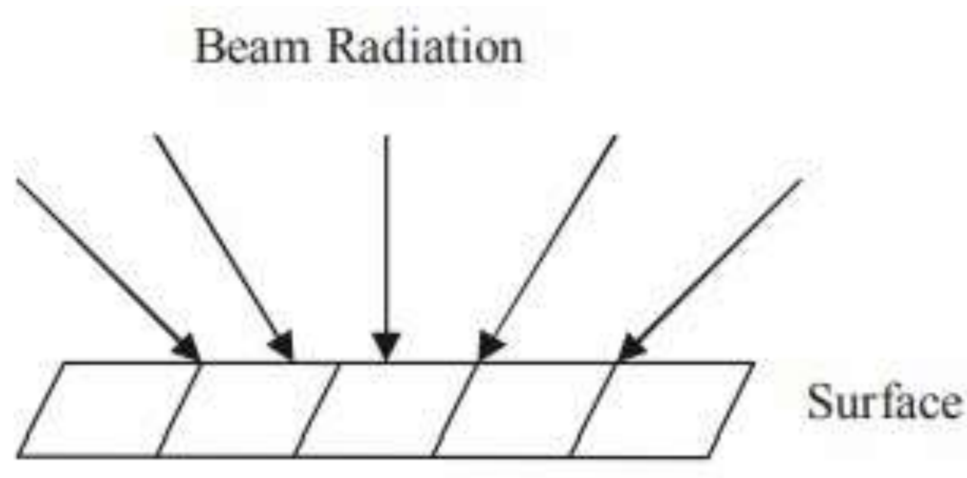
1. Direct Radiation or beam radiation
2. Diffuse Radiation

BEAM AND DIFFUSE RADIATION



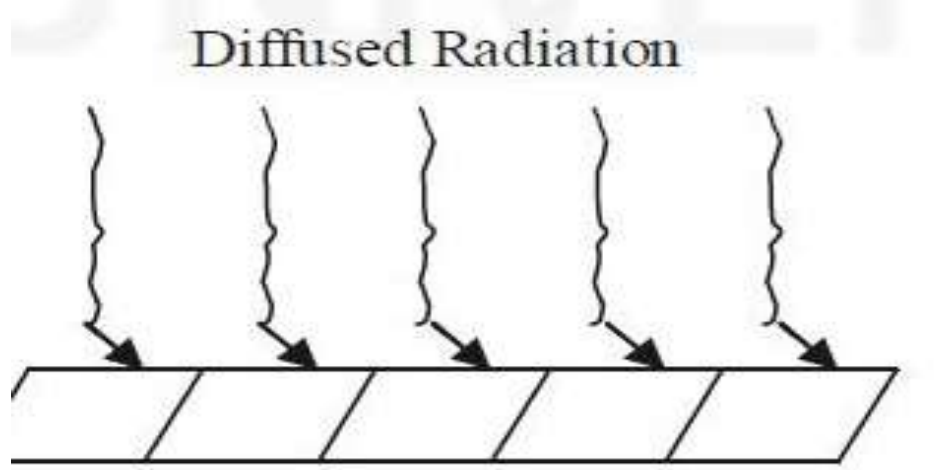
BEAM RADIATION OR DIRECT RADIATION

- The radiation received by the Earth without any change in the direction is referred to as beam radiation or direct radiation as shown in Figure



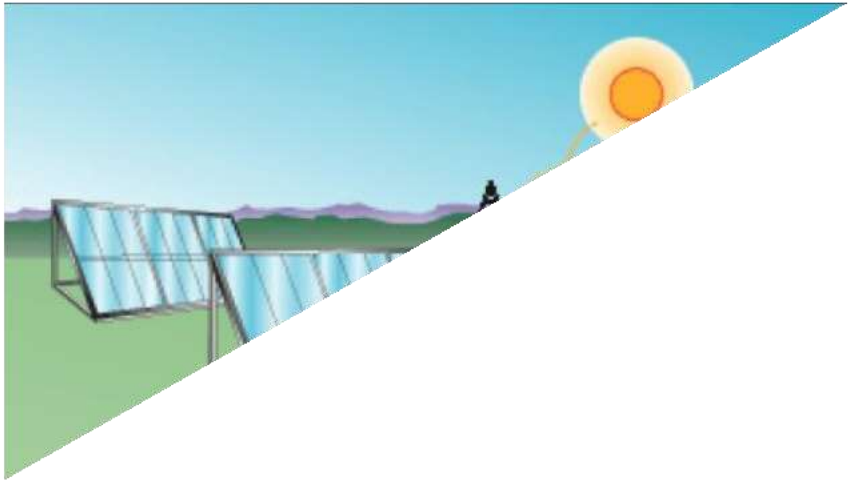
DIFFUSED RADIATION

- The diffused radiation is received by the Earth from all directions.
- The radiations may change their direction due to scattering from dust particles, clouds etc. while passing through atmosphere.
- Diffused radiations do not have a unique direction.
- The diffused radiation is shown in Figure .



GLOBAL RADIATION

- The total radiation is the sum of direct radiation and diffused radiation and is called ***global radiation or simply insolation.***
- Diffused component of solar radiation (B) is that portion which is reflected from clouds, the ground, and nearby objects, and direct component of solar radiation (A) is that portion which falls onto flat-plate solar panels



Insolation

- **Total amount of solar radiation per unit area per day reaching a part of the Earth is called the ‘insolation’, a short form of “incident solar radiation”.**

Irradiance

- The rate at which radiations fall on a surface per unit area is called irradiance (W/m2).

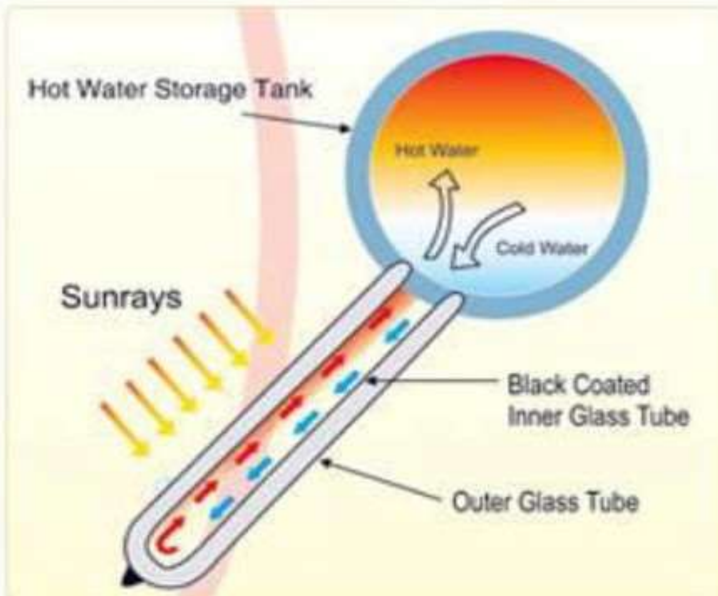
APPLICATIONS

The solar energy can be used for following applications

1. Water heating
2. Refrigeration, heating and ventilation
3. Cooking
4. Process heating
5. Water treatment
6. Electricity generation
7. Agriculture
8. Transport

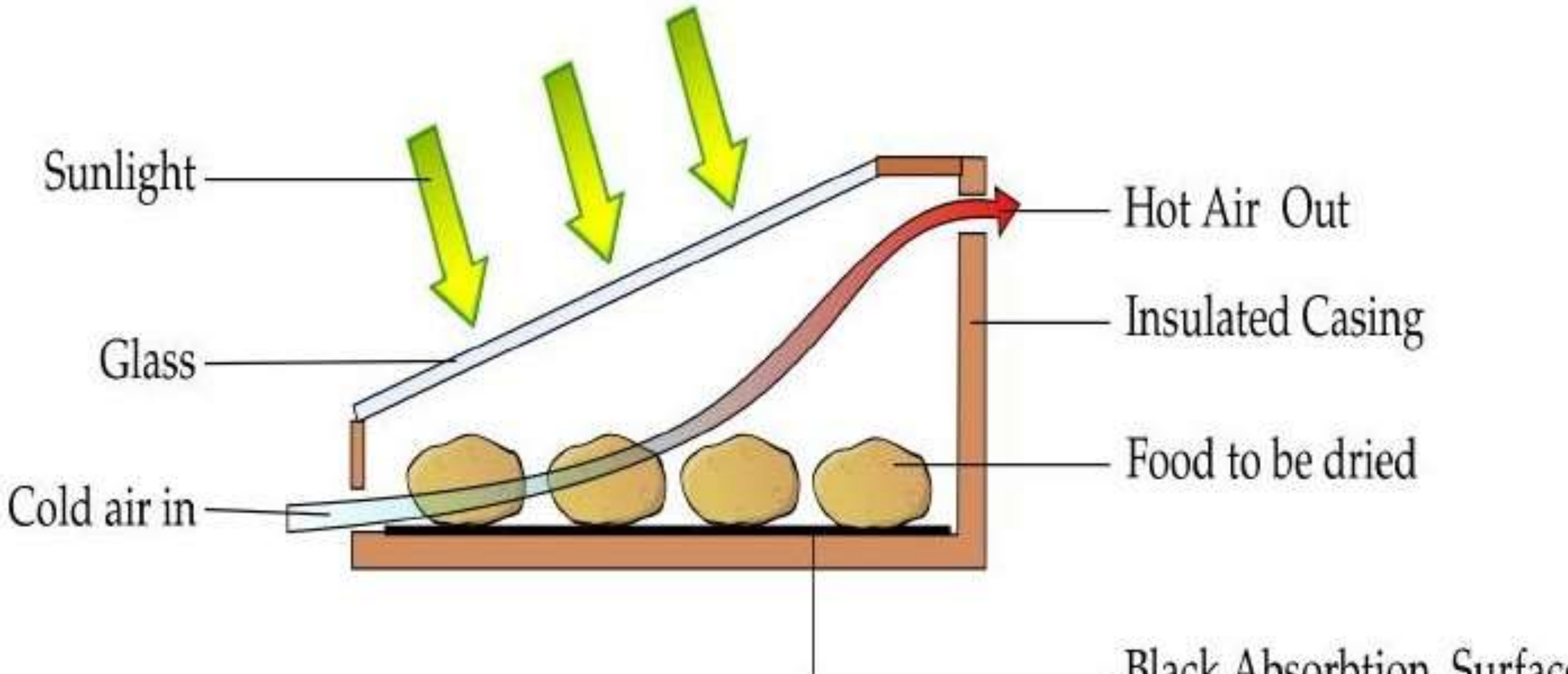
WATER HEATING

Evacuated tube water heater:

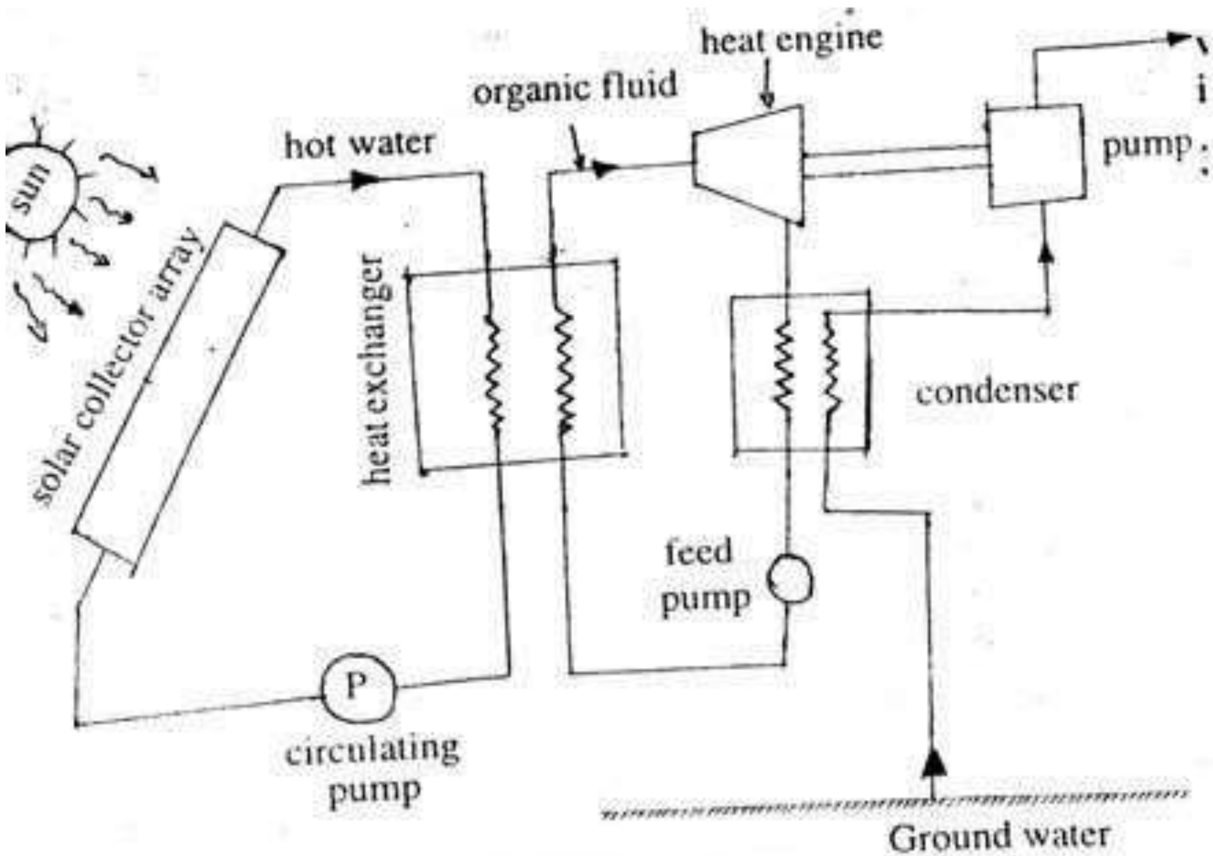


SOLAR COOKER

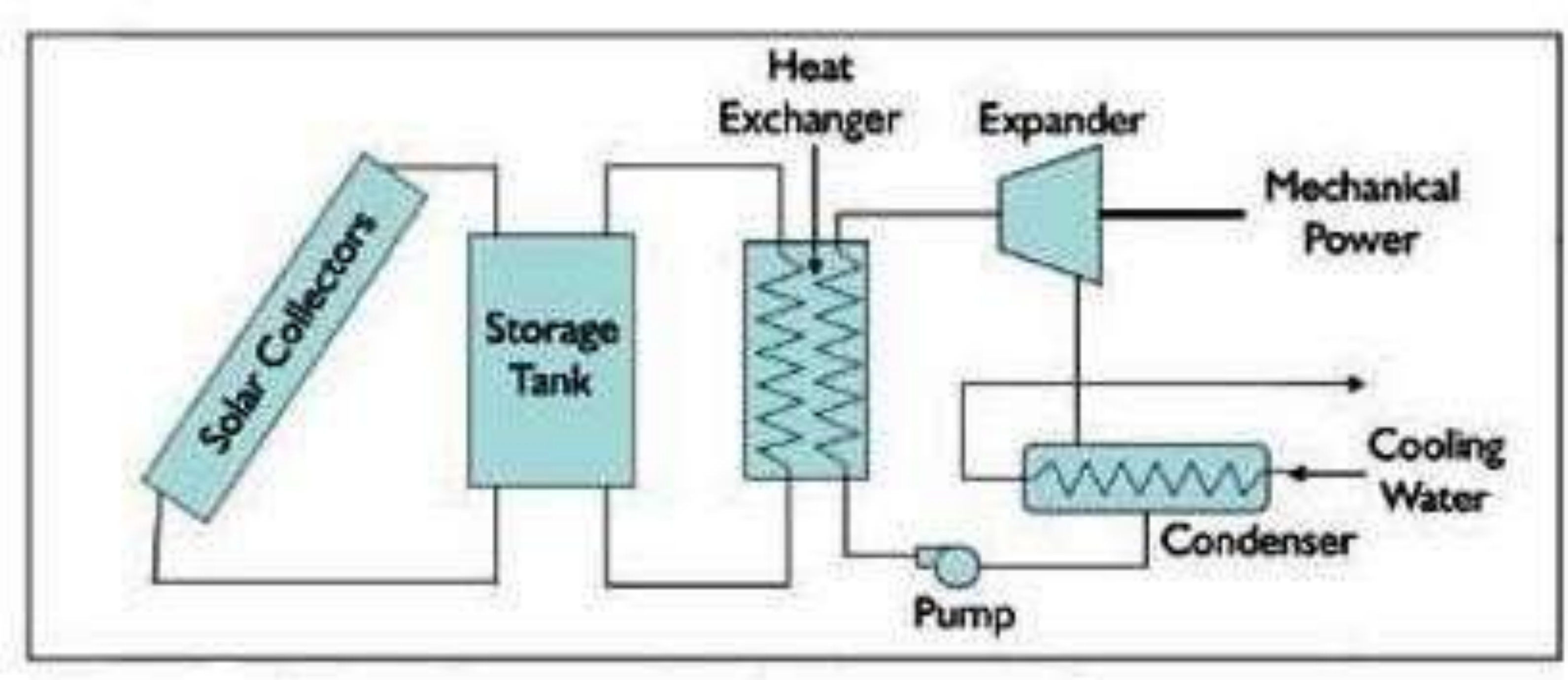
SOLAR DRIER


Sunlight
Glass
Cold air in
Hot Air Out
Insulated Casing
Food to be dried
Black Absorbtion Surface

SOLAR WATER PUMPING

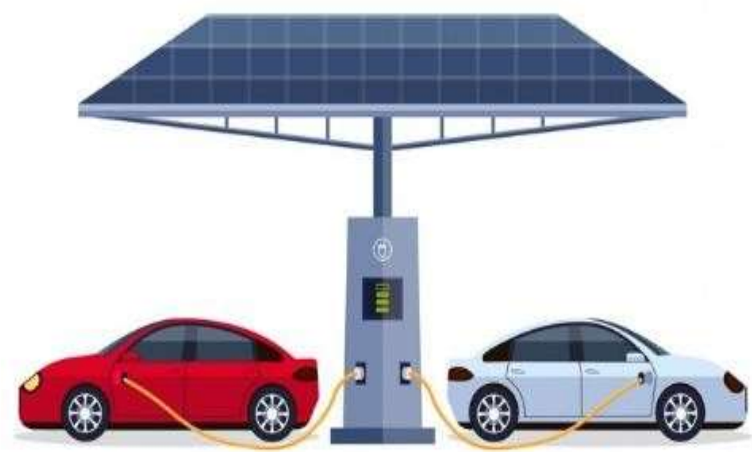


SOLAR THERMAL POWER GENERATIONS



SOLAR REFRIGERATION

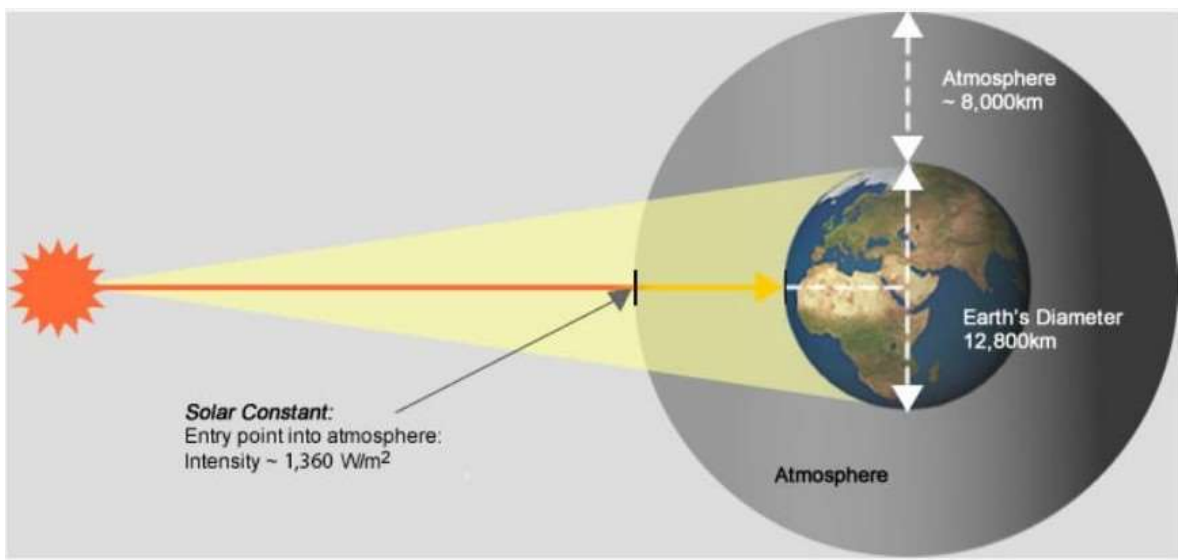
TRANSPORTATION USING SOLAR



SOLAR CONSTANT

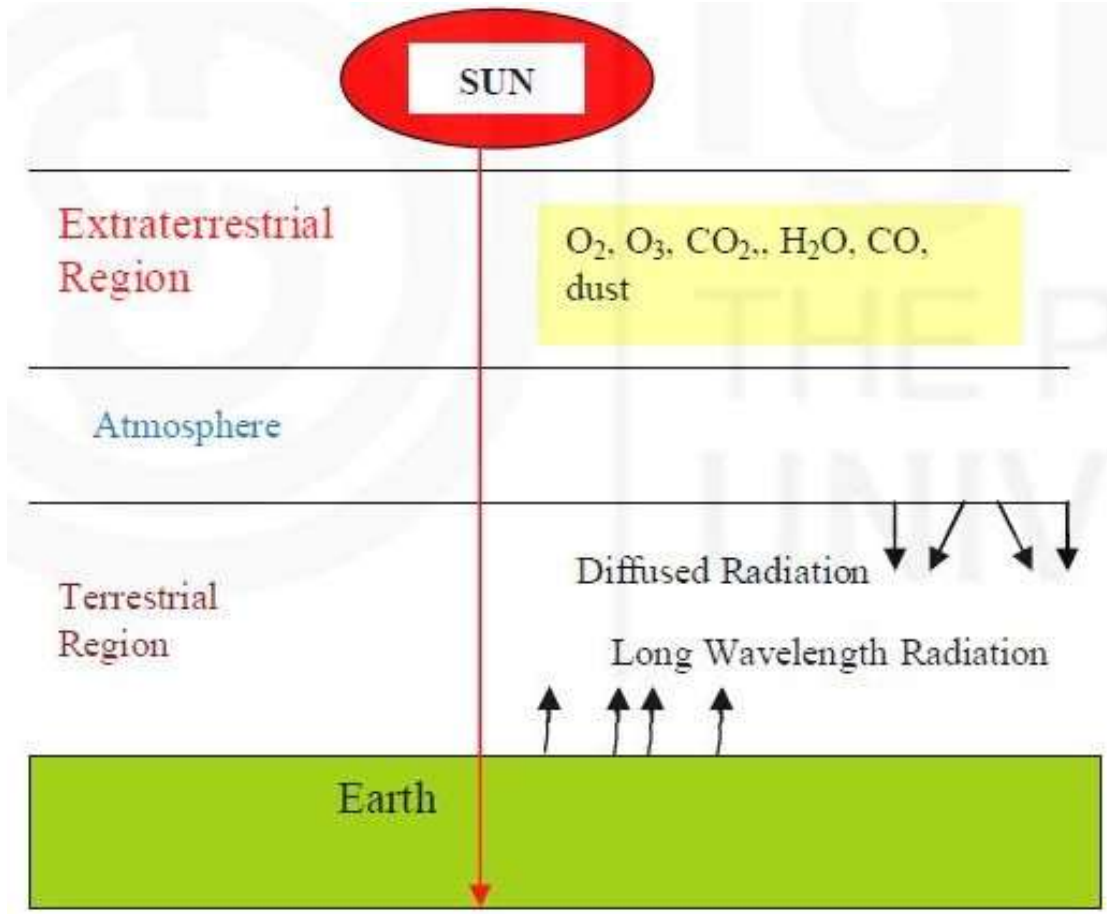
- The solar energy reaching unit area at outer edge of the Earth's atmosphere exposed perpendicularly to the rays of the Sun at the average distance between the Sun and Earth is known as the solar constant.

Solar Constant = 1.353kW/m^2.



EXTRATERRESTRIAL SOLAR RADIATION AND TERRESTRIAL SOLAR RADIATION

- In order to understand these terms, let us consider terrestrial and extraterrestrial regions as shown in Figure



EXTRATERRESTRIAL RADIATION

The intensity of extraterrestrial radiation measured at a plane normal to the radiation is given by (Duffie and Beckman 1991).

$$I_{ext} = I_{sc}[1 + 0.033\cos(360n/365)] \qquad \ldots (1.7)$$

where I_{ext} = extraterrestrial radiation,

I_{sc} = solar constant, and

n = day of the year (n = 1 for January 1, n = 365 for December 31).

PROBLEM

- Evaluate the extraterrestrial solar radiation on January 1, June 22 and December 1.

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where I_{ext} = extraterrestrial radiation,

I_{sc} = solar constant, and

n = day of the year (n = 1 for January 1, n = 365 for December 31).

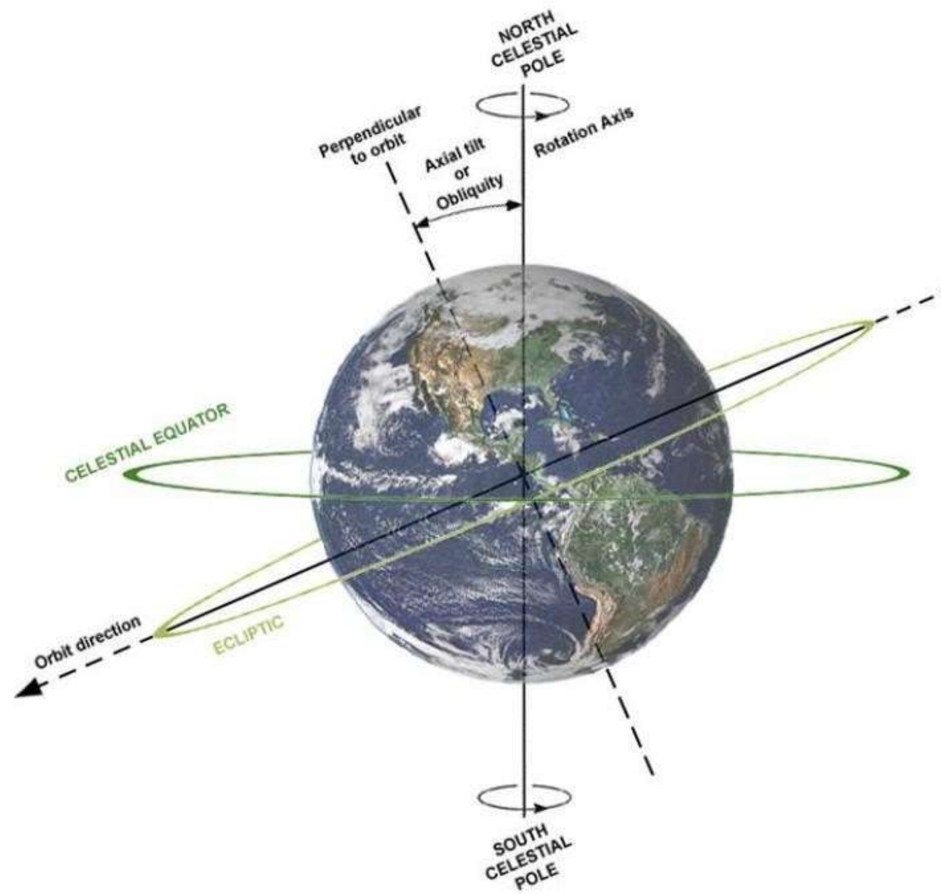
For January 1, n = 1
For June 22, n = 174
For December 21, n = 355

PROBLEM

- For January 1 :
- I_{ext} = 1353 [1 + 0.033 cos (360 X 1/365)] = 1398 W/m^2
- For June 22 :(31+28+31+30+31+22)
- I_{ext} = 1353 [1 + 0.033 cos (360 X 173/365)] = 1309 W/m2
- For December 21 :(31+28+31+30+31+30+31+31+30+31+30+21)
- I_{ext} = 1353 [1 + 0.033 cos (360 X355/365)] = 1397 W/m2

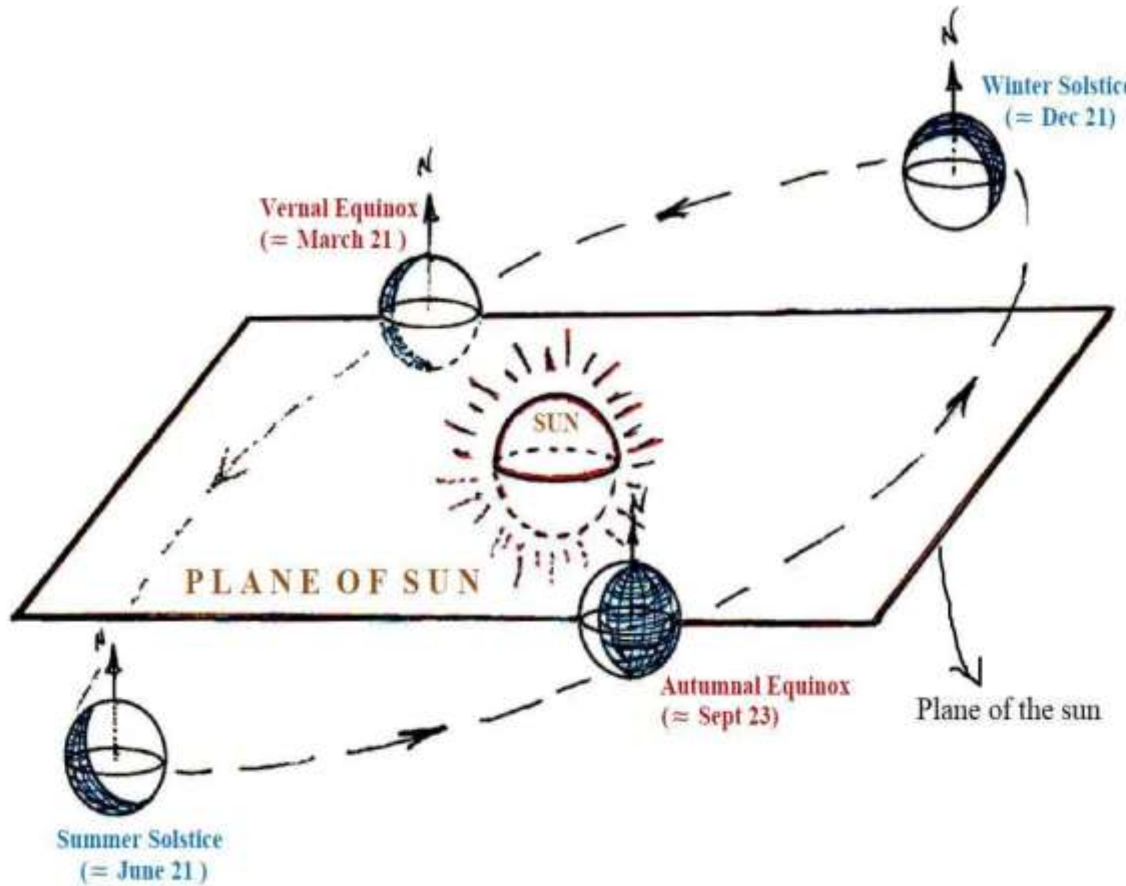
SUN AND EARTH ANGLES

- The Earth's daily rotation about the axis through its two celestial poles (North and South) is perpendicular to the equator, but it is not perpendicular to the plane of the Earth's orbit.
- In fact, the measure of tilt or obliquity of the Earth's axis to a line perpendicular to the plane of its orbit is currently about 23.5°.



SUN AND EARTH ANGLES

- We call the plane parallel to the Earth's celestial equator and through the center of the sun the **plane of the Sun.**
- The Earth passes alternately above and below this plane making one complete elliptic cycle every year



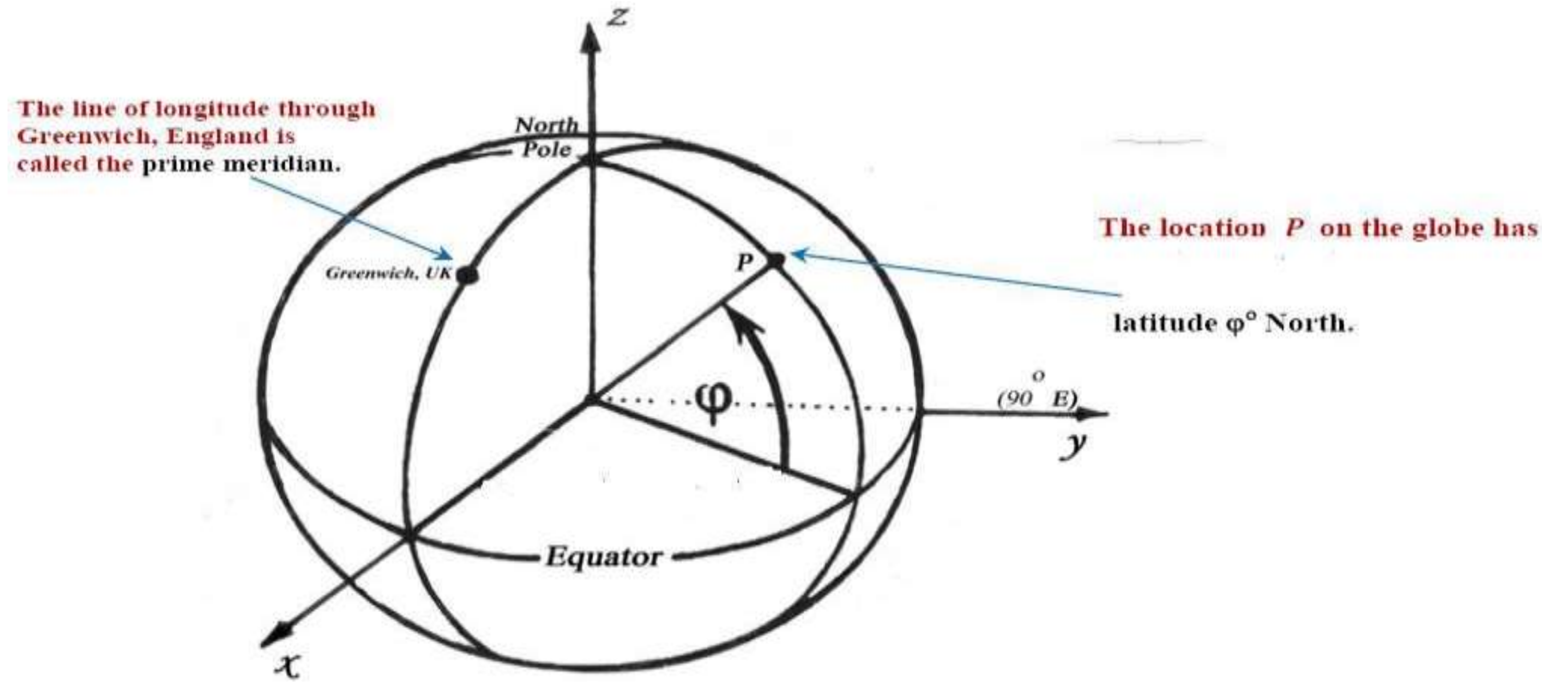
SUN AND EARTH ANGLES

In solar radiation, the following parameters are important.

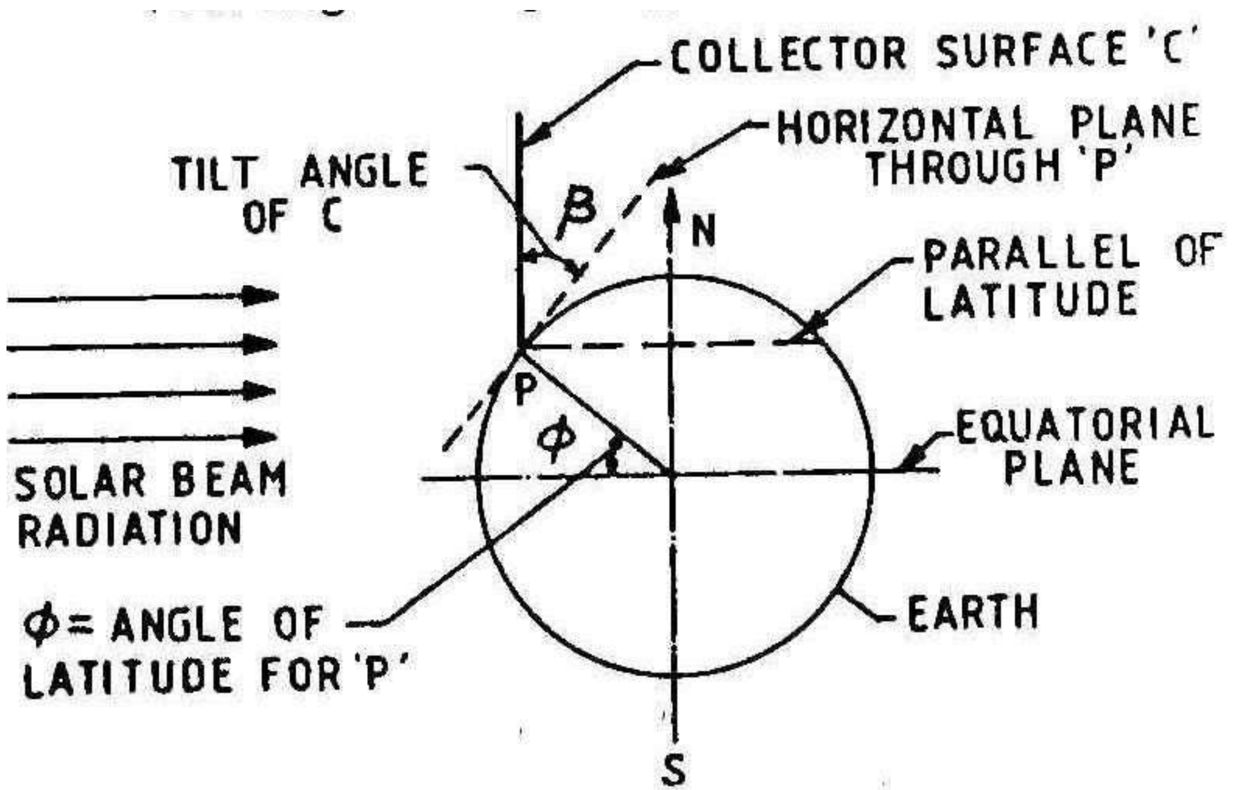
- Latitude of location (ø)
- Declination angle (**δ)**
- Altitude angle (α)
- Hour angle (ω)
- Solar azimuth angle (γ)
- Zenith angle (θz)
- Tilt angle or slope angle (β)

LATITUDE OF LOCATION OR ANGLE OF LATTITUDE (ø)

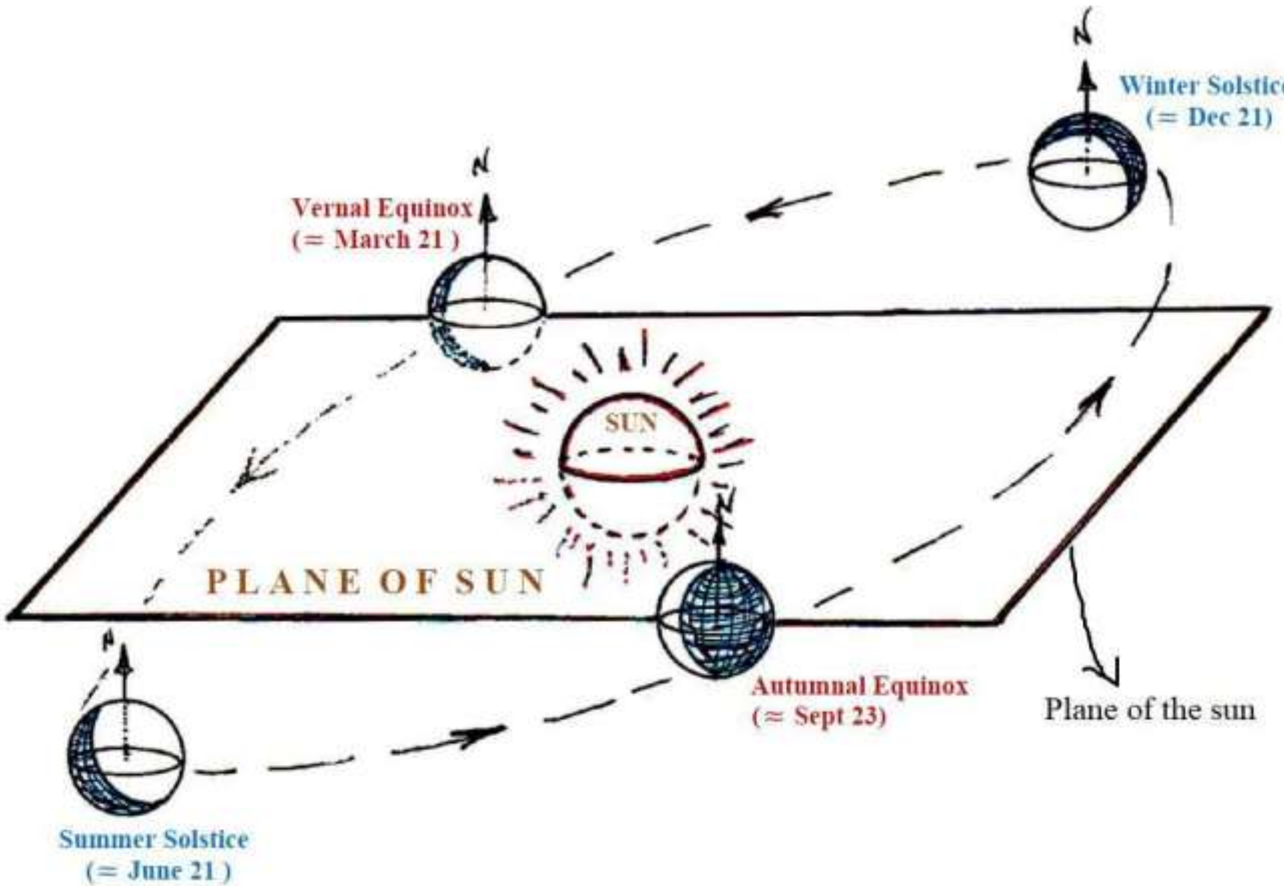
- The latitude of a location or a point on the Earth is the angle between the line joining that location to the centre of the earth and the equatorial plane.



ANGLE OF LATITUDE (ø)

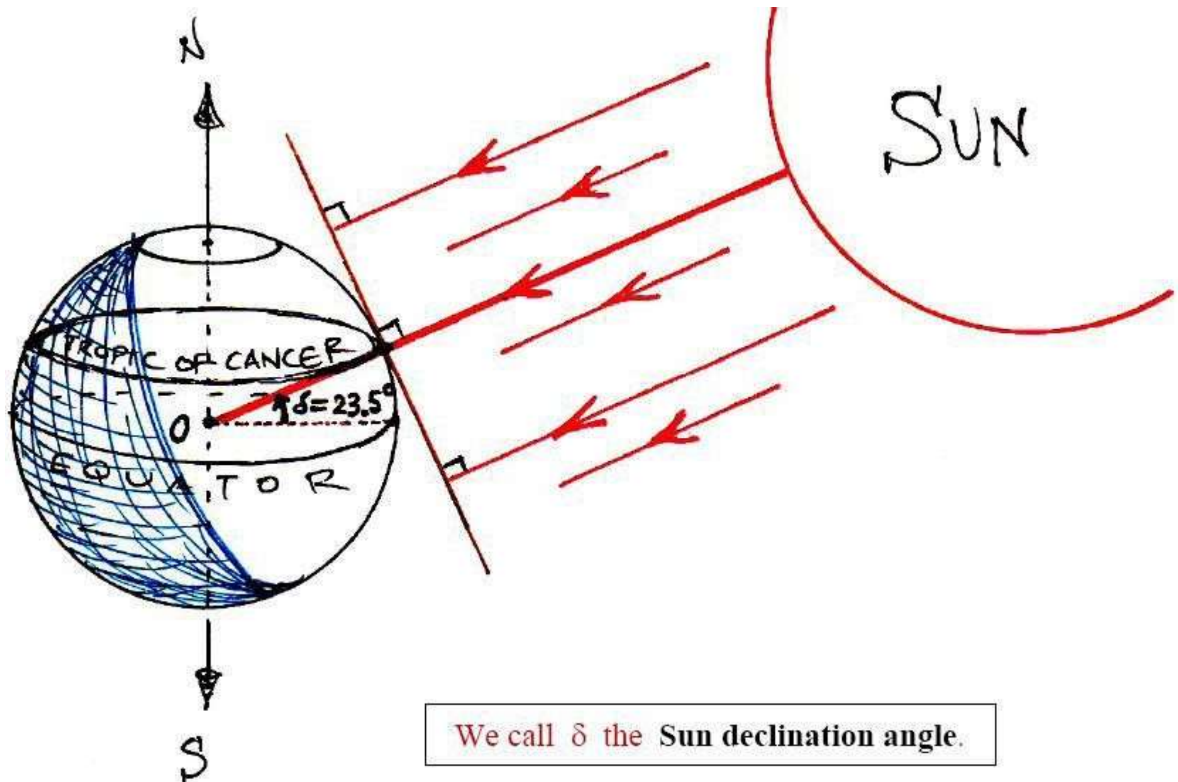


DECLINATION ANGLE (δ)

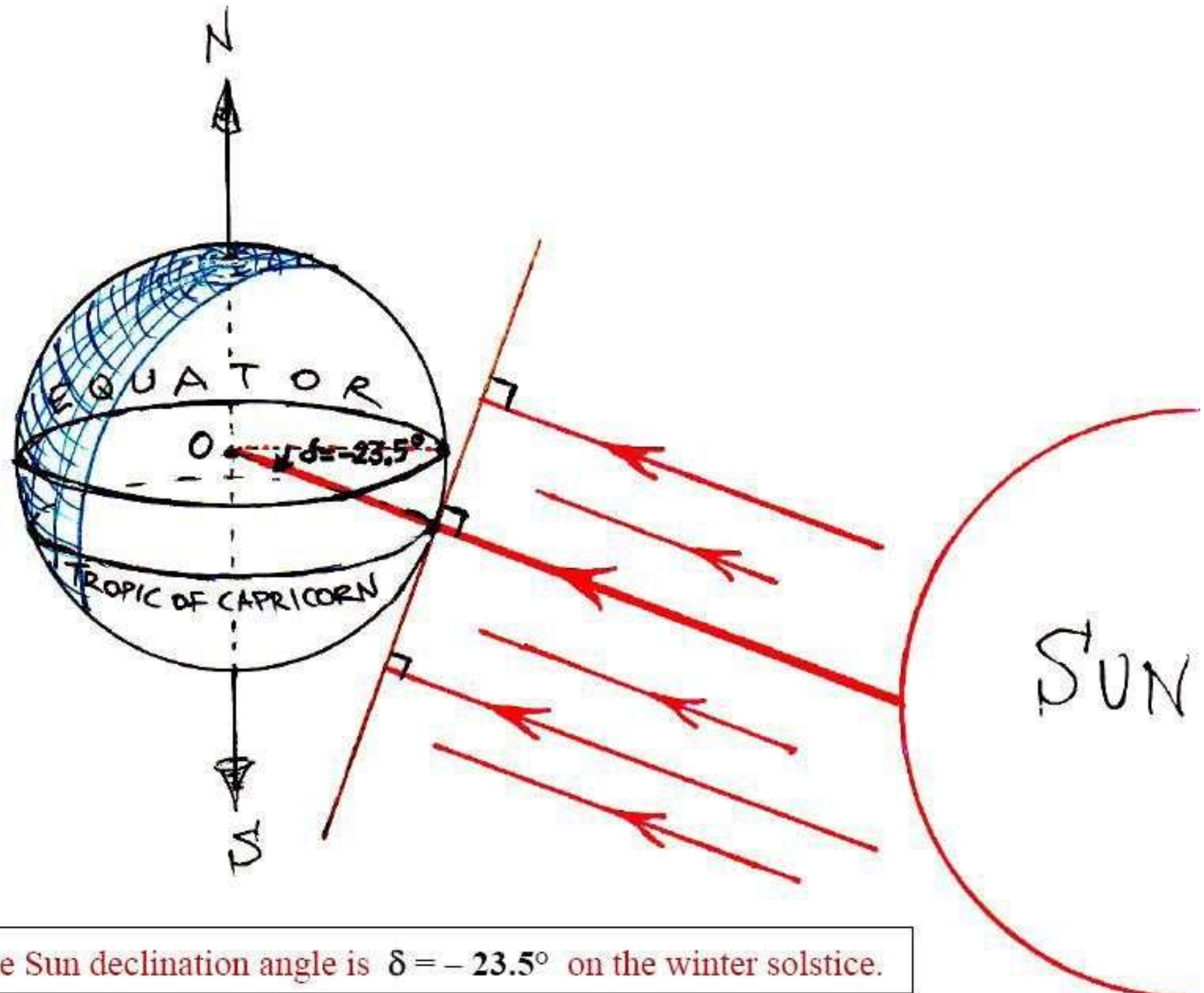


DECLINATION (δ)

In general, the Sun declination angle, δ, is defined to be that angle made between a ray of the Sun, when extended to the centre of the earth, O, and the equatorial plane.



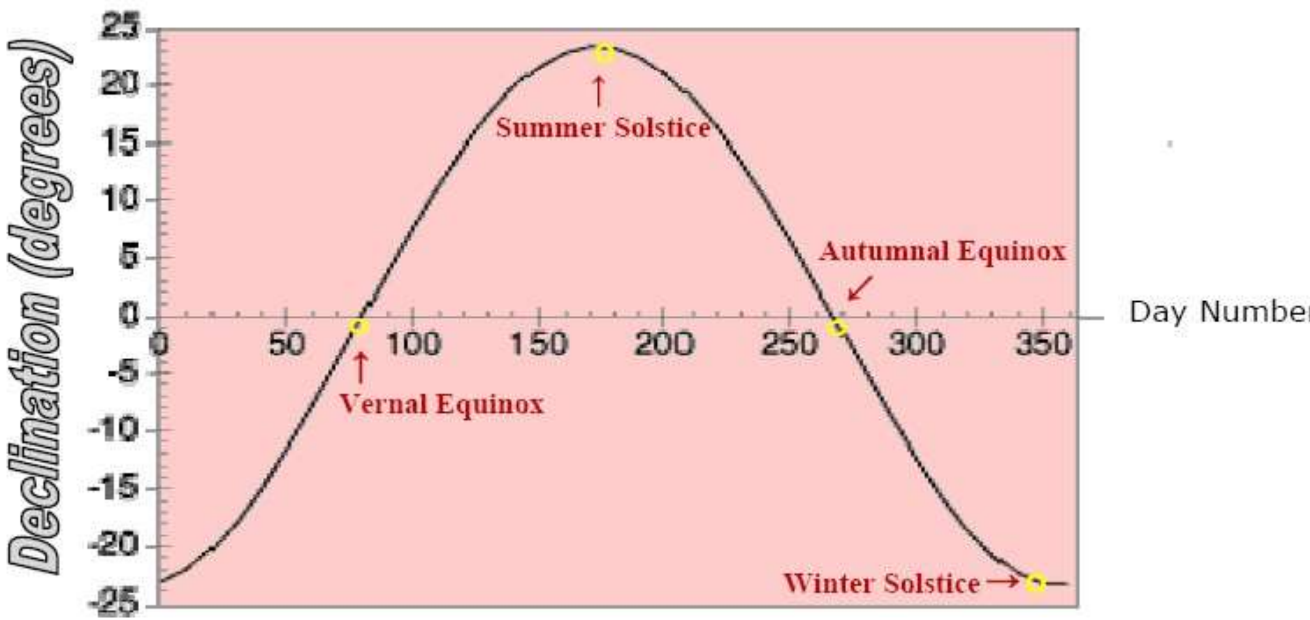
We call δ the **Sun declination angle**.



The Sun declination angle is $\delta = -\mathbf{23.5°}$ on the winter solstice.

The Sun declination angle, δ, has the range: $-23.5° \leq \delta \leq +23.5°$ during its yearly cycle.

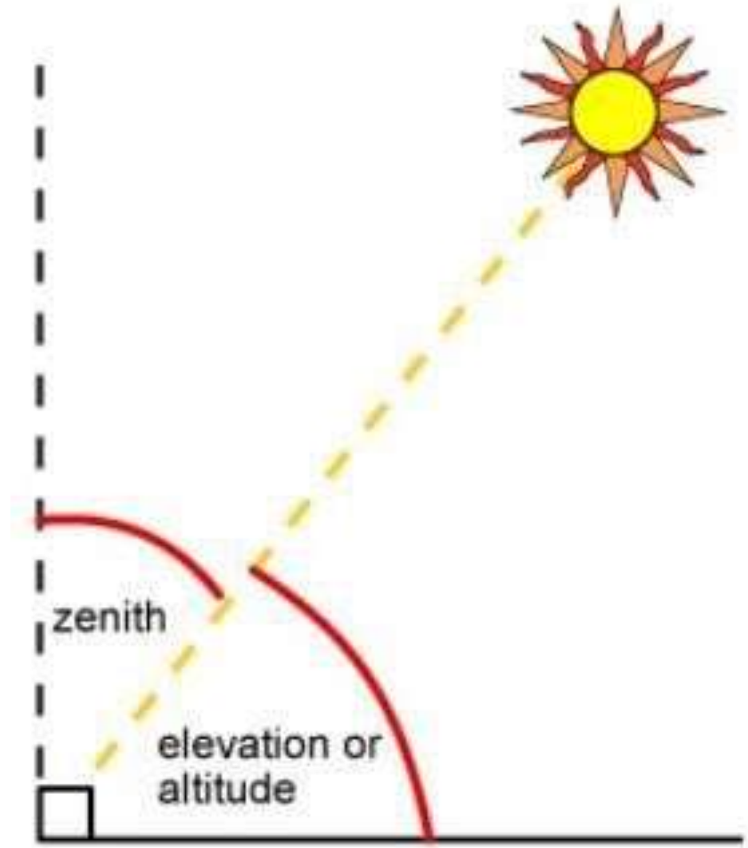
Yearly Variation in Declination

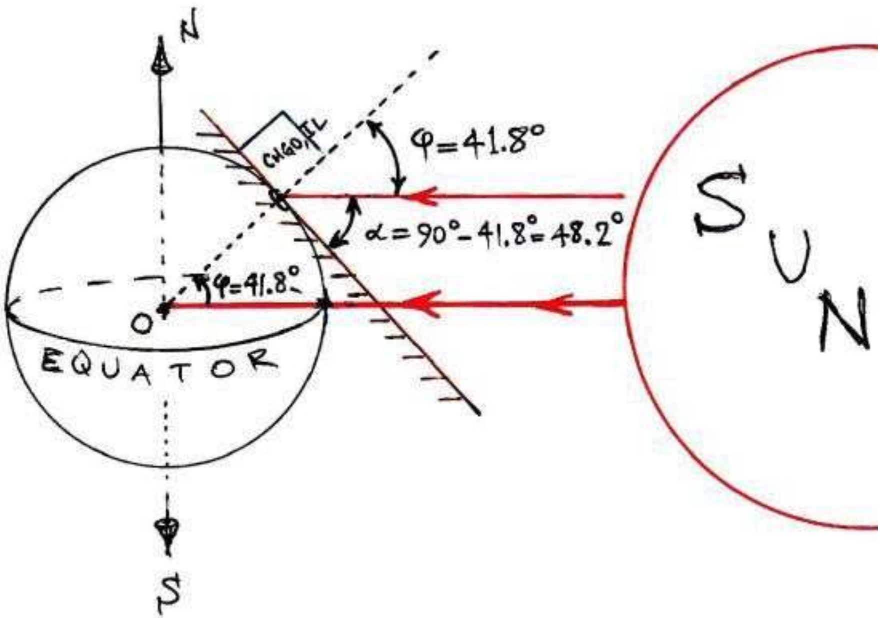


The Sun declination angle has measure: $\delta = 0°$ on the days of the vernal and the autumnal equinox.

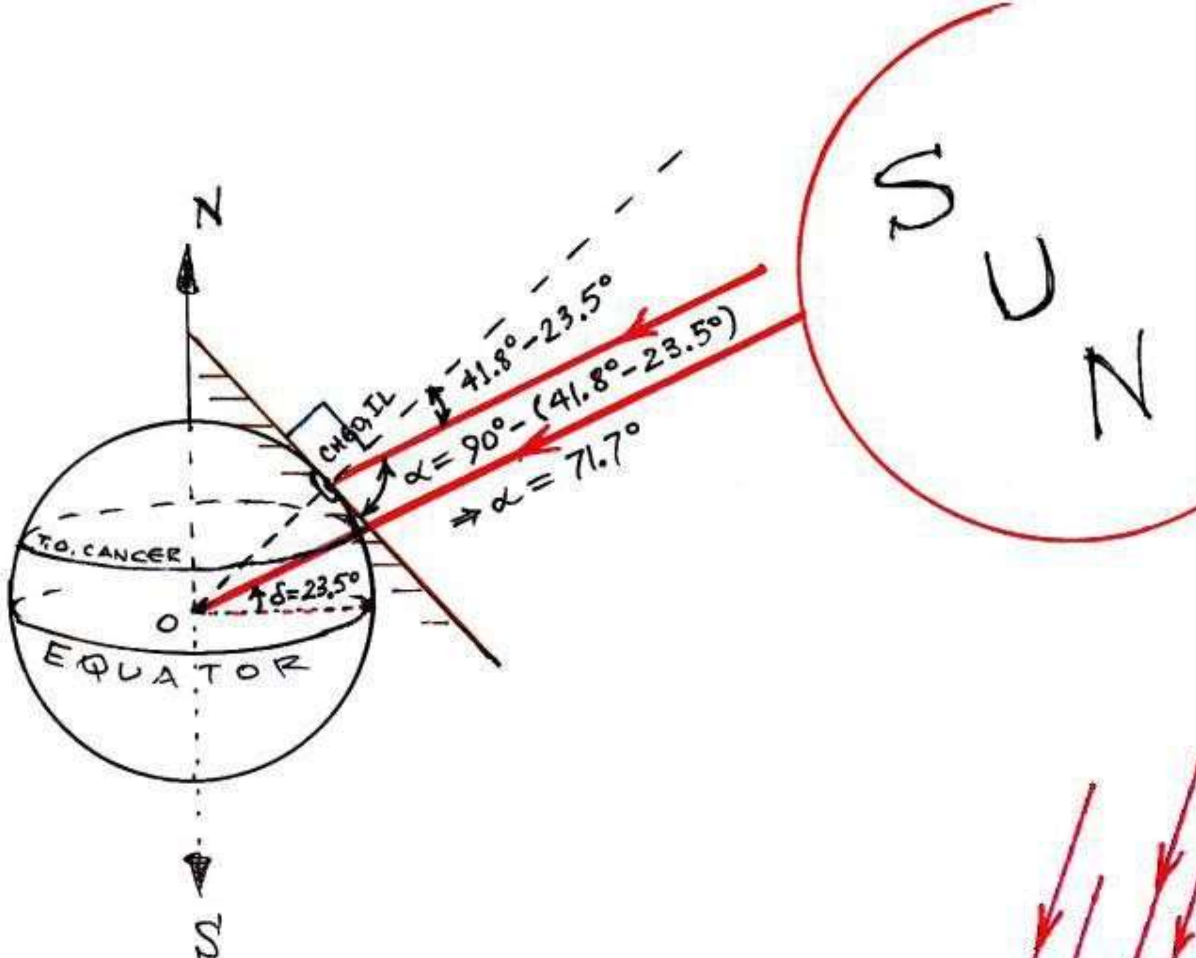
ALTITUDE ANGLE OR SOLAR ALTITUDE (α)

- It is a vertical angle between the projection of the sun’s rays on the horizontal plane and the direction of sun’s rays (passing through the point).



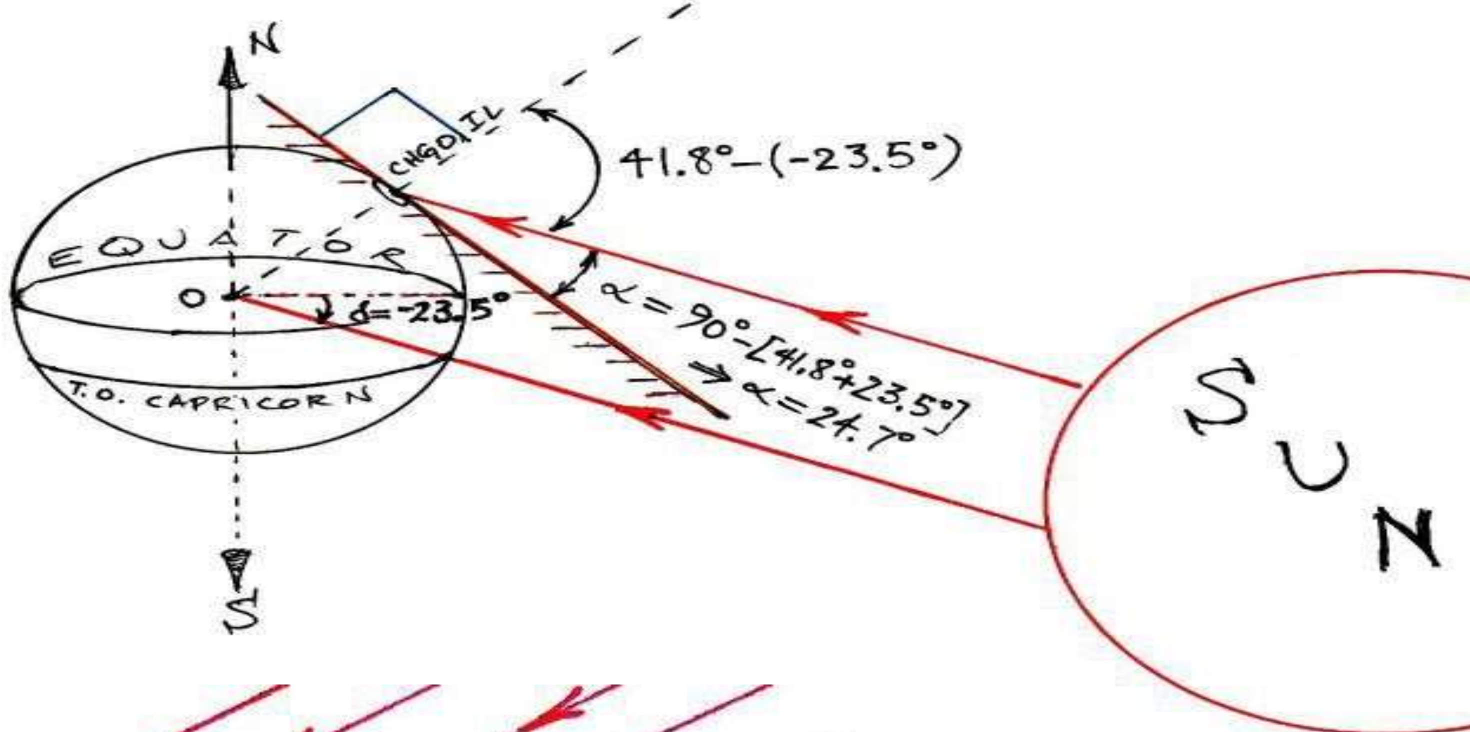

N
CHGO, IL
φ=41.8°
α=90°-41.8°=48.2°
φ=41.8°
O
EQUATOR
S
SUN


N
α=48.2°
S
SHADOW
LENGTH

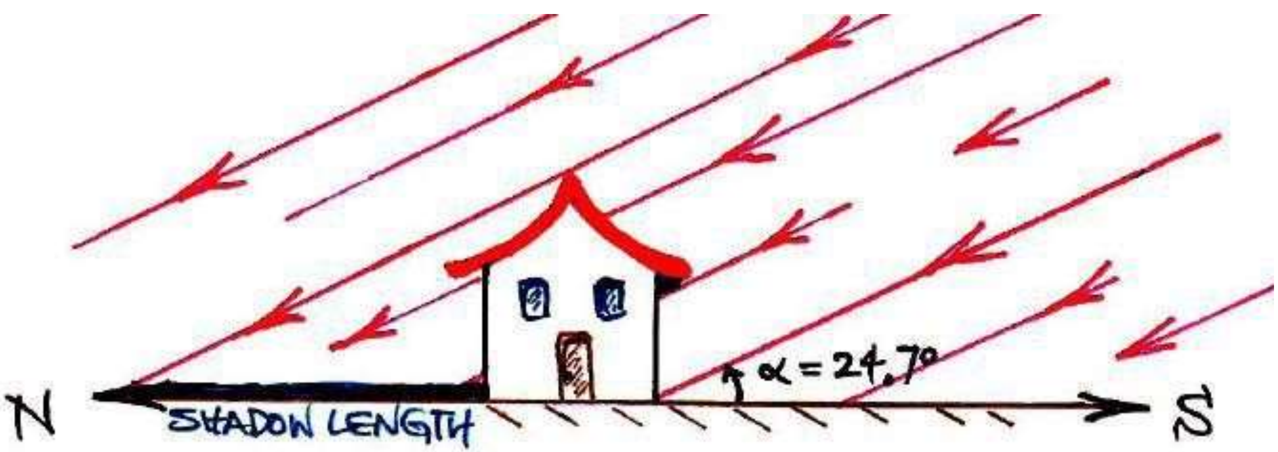


N
S
SUN
41.8°-23.5°
α = 90° - (41.8°-23.5°)
⇒ α = 71.7°
T.O. CANCER
δ=23.5°
O
EQUATOR

N
S
α=71.7°
SHADOW LENGTH



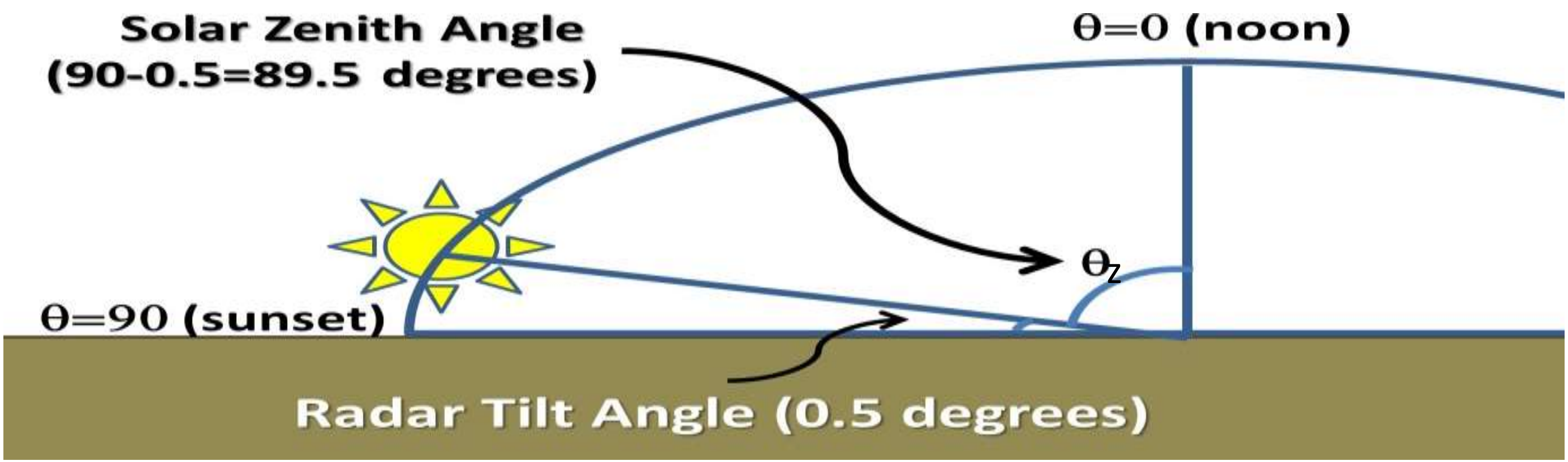
N
CHGO, IL
41.8°-(-23.5°)
EQUATOR
O
δ=-23.5°
α=90°-[41.8°+23.5°]
⇒ α=24.7°
T.O. CAPRICORN
S
SUN



α=24.7°
N
SHADOW LENGTH
S

ZENITH ANGLE (θz)

- **It is a vertical angle between the sun's rays and a line** perpendicular to the horizontal plane through a point.
- Therefore zenith and altitude angles are complementary angles



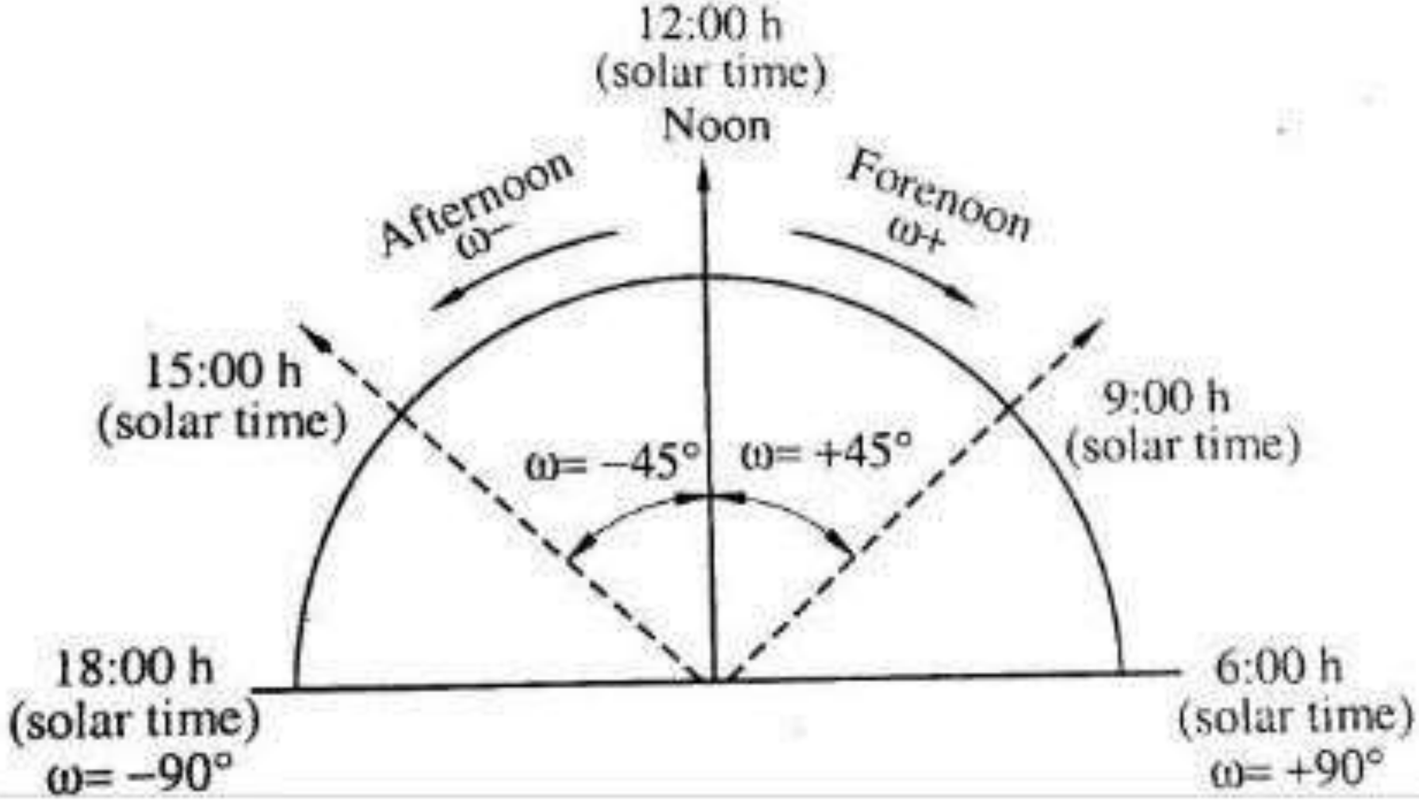
HOUR ANGLE (ω)

- The hour angle, ω, is the angle between two planes: one containing the Earth's axis and the zenith (the meridian plane), and the other containing the Earth's axis and the given point (the hour circle passing through the point).
- It can also say that angle traced by sun in 1 hour with reference to 12 noon (Local Solar Time) and is equivalent to 15°per hour.
- The hour angle can de measured as

  ω= 15×(12-ST),where ST is local solar time
- Example:

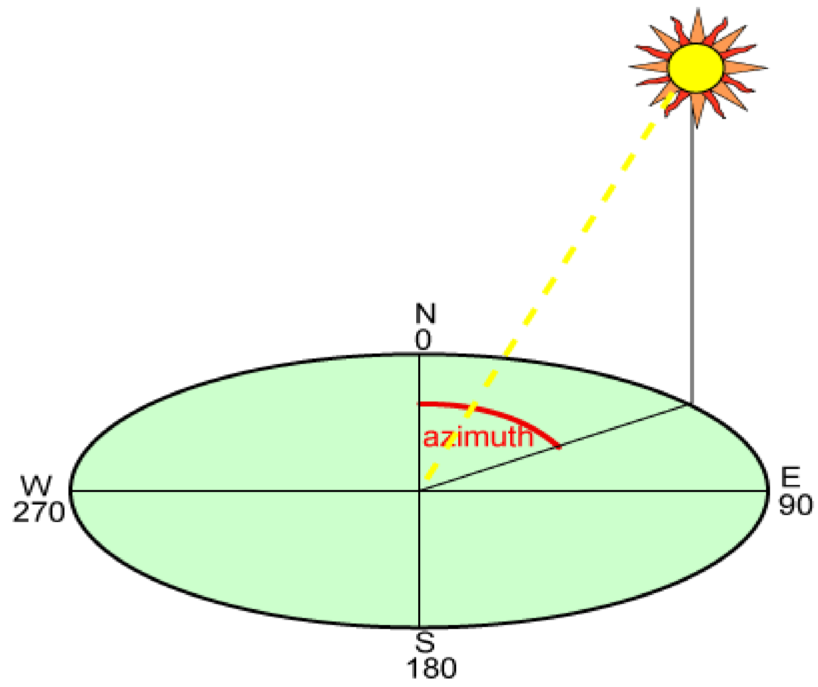
  At 9 am, ω= 15×(12-9) = 45°

  At 6 pm, ω= 15×(12-18) =- 90°


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°

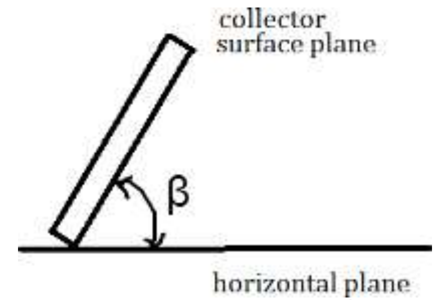
AZIMUTH ANGLE (γ)

- **It is a horizontal angle between the north and** the horizontal projection of the sun’s rays.



TILT ANGLE OR SLOPE ANGLE (β)

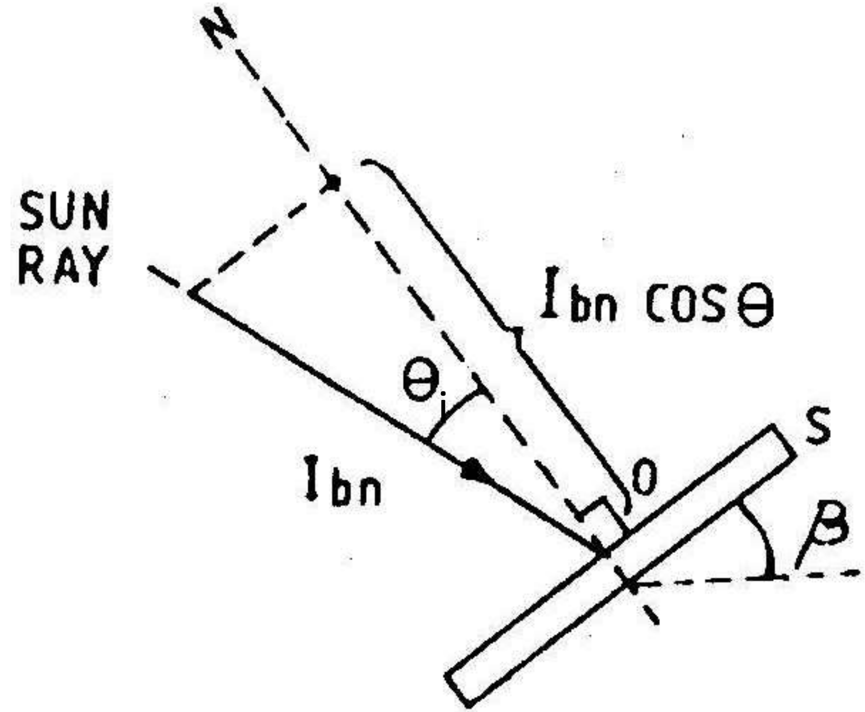
- The angle between the collector surface plane and the horizontal plane is called the tilt angle or the slope angle and is designated by β.



- ➢ For vertical surface $\beta = 90^0$
- ➢ For horizontal surface $\beta = 0^0$
- ➢ βis always positive.
- For sun tracking collectors/reflectors, the angle β is changed automatically to track the sun.
- For fixed type collectors/reflectors, angle β is constant.

INCIDENCE ANGLE

- The angle between the incident beam(I bn) and normal (ON) to surface (S).
- If surface S is fixed, angle of incidence (θ_i) has hourly variation due to changing position of the sun.



Attenuation

- The variation in solar radiation reaching the earth than received at the outside of the atmosphere is due to absorption and scattering in atmosphere.

MEASUREMENT OF SOLAR RADIATION

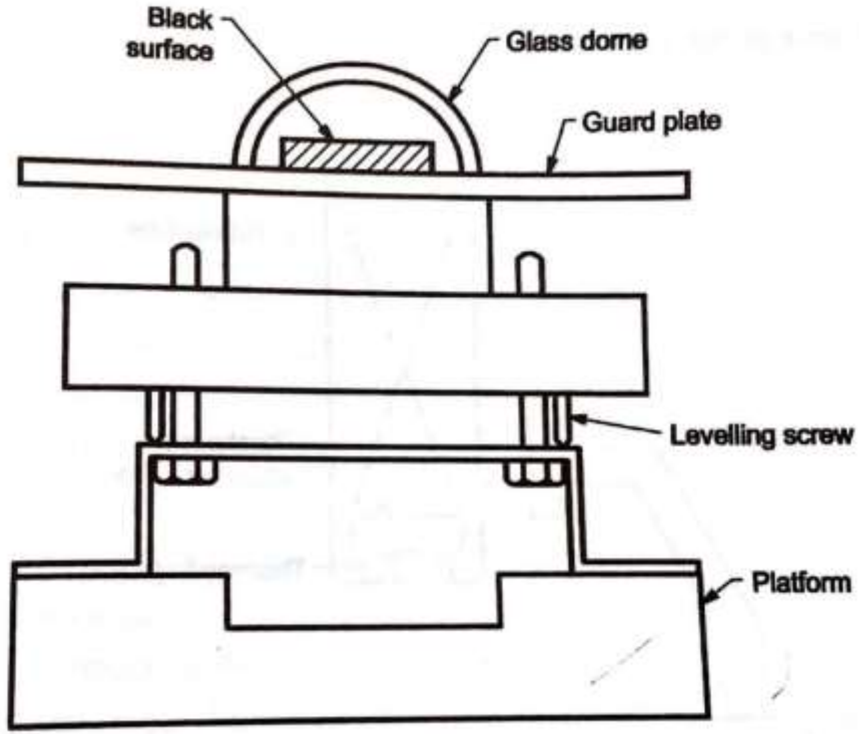
- Measurement of solar radiation is the most important aspect which can give the accurate quantum of energy that can be derived from a particular location
- Three types of instrument are generally used which can measure three different aspect for solar radiation these are.

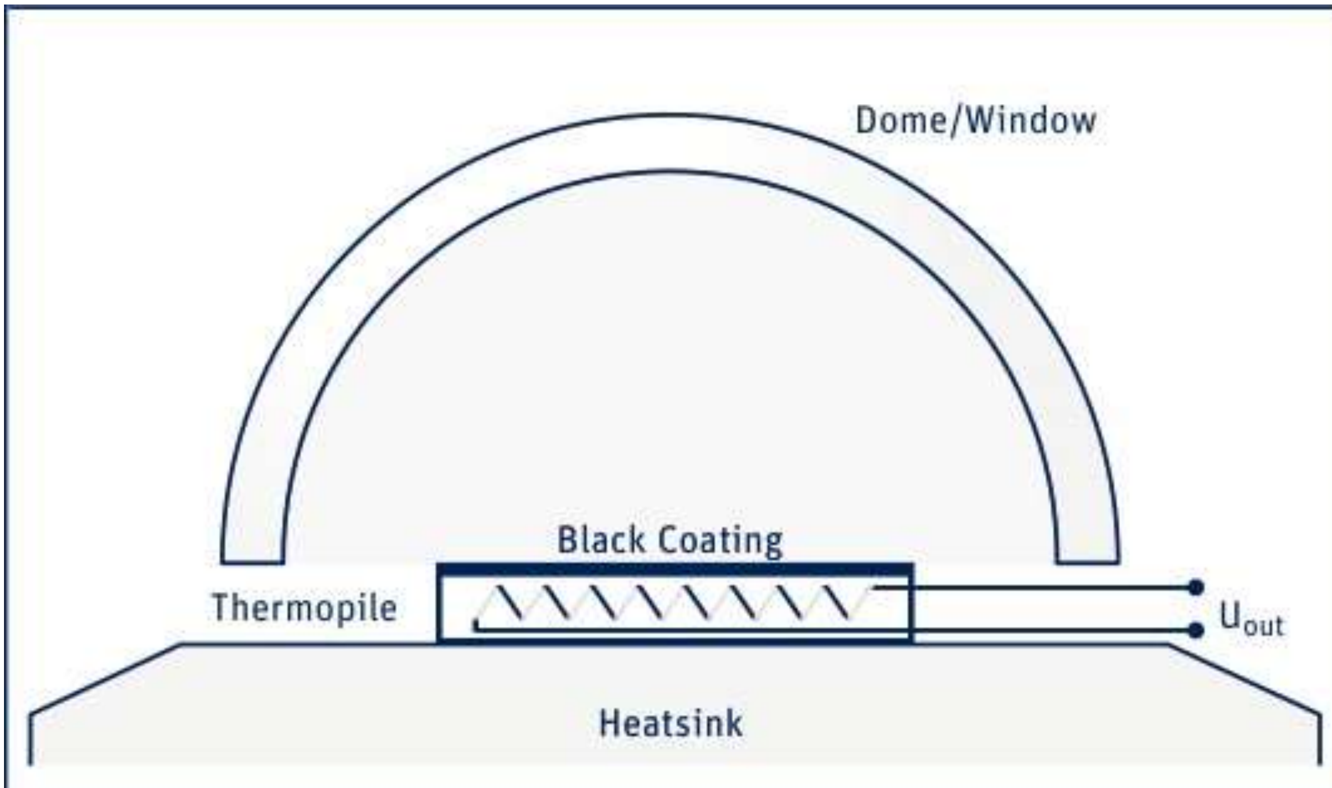
1. **Pyranometer:** It is used to measure the Both beam and diffuse radiation.
2. **Pyrheliometer**: The beam radiation or direct radiation could be measured by using pyrheliometer
3. ***Sun shine recorders :*** *These instrument are used to measure* the hours of sunshine over a day

PYRANOMETER

- This instrument measures the total radiation arriving from all directions, including both ***direct and diffuse components i.e. it measures all of the*** radiation that is of potential use to a Solar Energy collecting system.
- It is a sensor that is designed to measure the solar radiation flux density (in watts per meter square).
- 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.

PYRANOMETER




Dome/Window
Black Coating
Thermopile
U_{out}
Heatsink

CONSTRUCTION

- This instrument also known as *solarimeter is generally mounted in a horizontal* position away from tall objects so that the 2π field of view of the instrument covers the entire sky.
- It responds equally to the energy in all wavelengths.
- The most important part of a pyranometer is the detector that responds to incoming radiation.
- The most accurate detectors use a stack of thermocouples, called a thermopile, to measure how much hotter a black surface becomes when exposed to sunlight relative to a White surface .
- They incorporate a sensor surface that consists of alternating black and white segments as shown in the figure below.

DETAILED VIEW OF A SENSOR

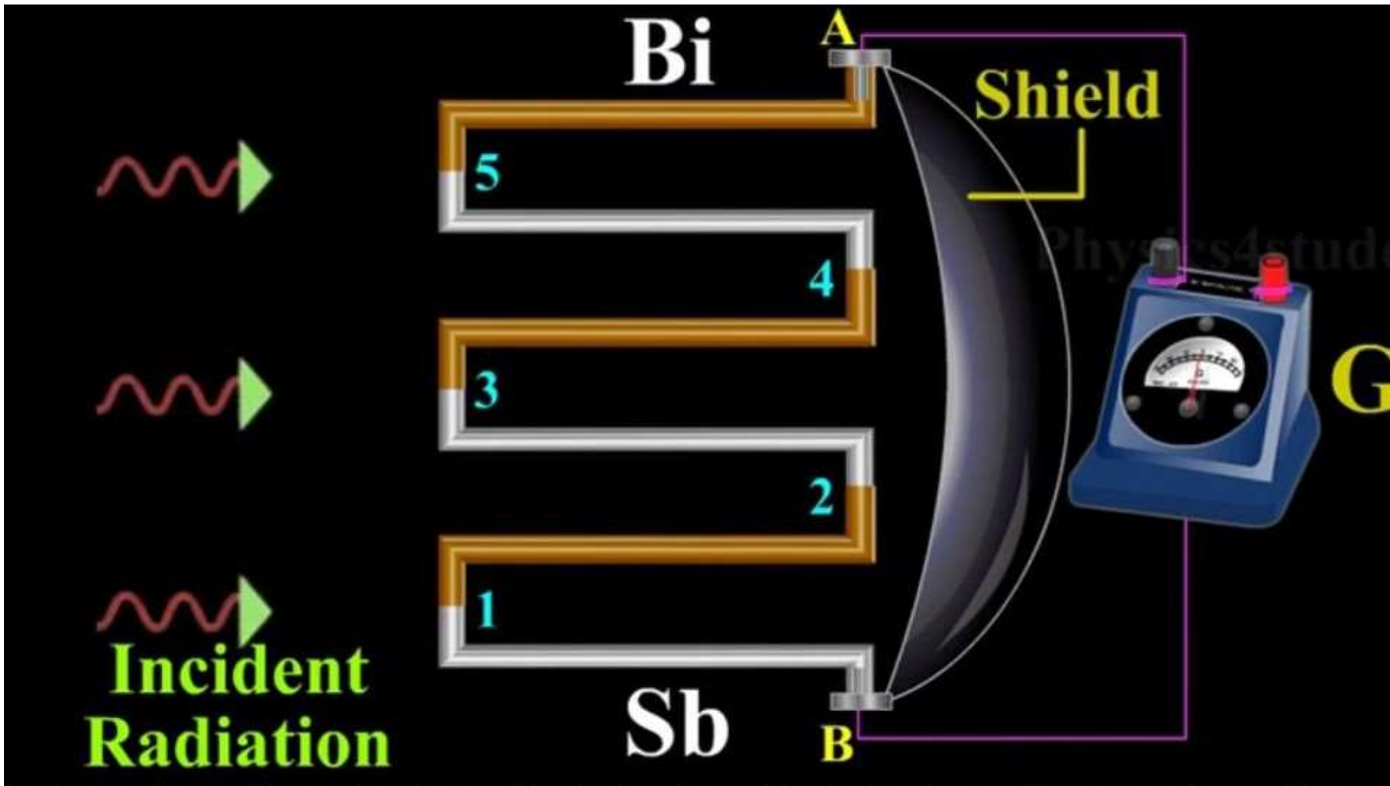
CONSTRUCTION

- Pyranometer consists of a black surface which is exposed to solar radiation and heated by solar radiation.
- The hot junctions of a thermopile are attached to the black surface and cold junctions are placed under a guard plate.
- Hot junctions are in the form of horizontal circular disc of 25mm diameter and these junctions are coated with special black lacquer which is having high absorptivity.
- Two glass domes which are having 30mm and 50mm diameter and having excellent transmission characteristics.
- These glass domes are used to protect disc (hot junction) from weather.
- The accuracy of this instrument is +or – 2%

WORKING OF PYRANOMETER

- The pyranometer is kept exposed to the sun & it start receiving the radiation.
- Due to the absorption of the radiation, the surface temp starts increasing
- If only the diffuse radiation is to be measured the direct radiation is blocked by a shield.
- So only the diffuse radiation will be incident on the surface
- Hence the thermo emf will be proportional to be diffuse radiation

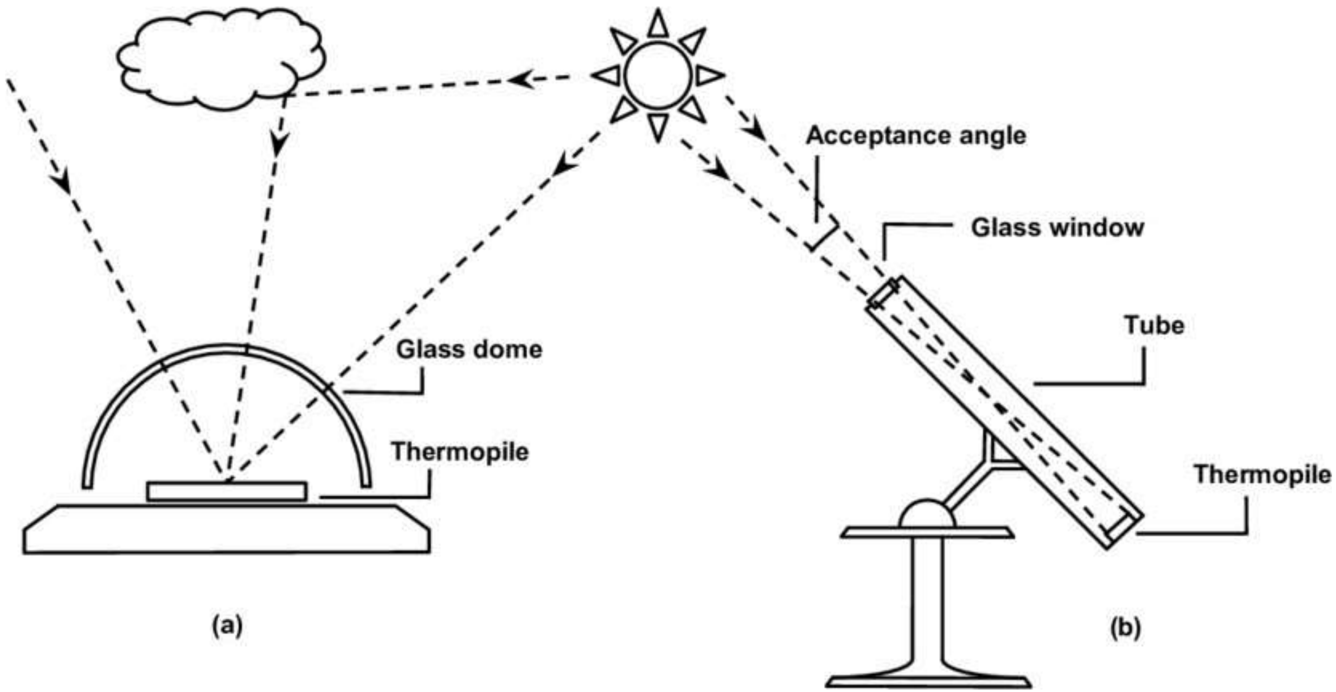
WORKING PRINCIPLE



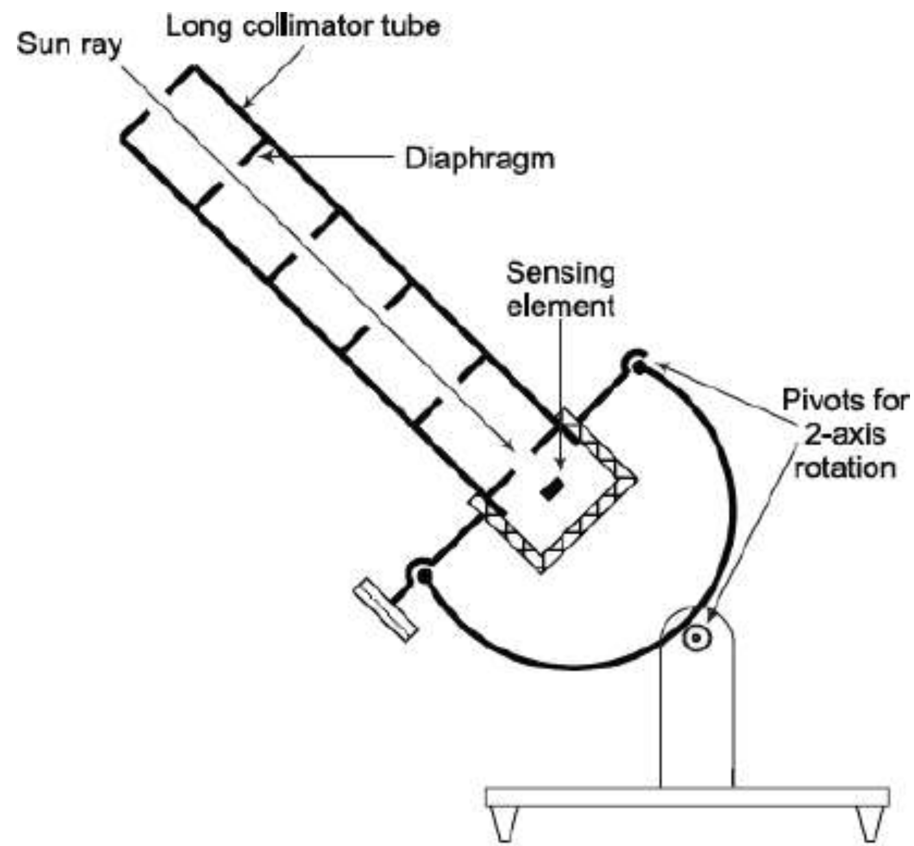
WORKING PRINCIPLE

- The hot junctions of thermopile are attached to the black surface, while the cold junctions are located under a guard plate so that they do not receive the radiation directly.
- As a result an emf is generated. This emf which is usually in the range of 0 t0 10mv can be read, recorded or integrated over a period of time and is a measure of global radiation.

PYRHELIOMETER



PYRHELIOMETER

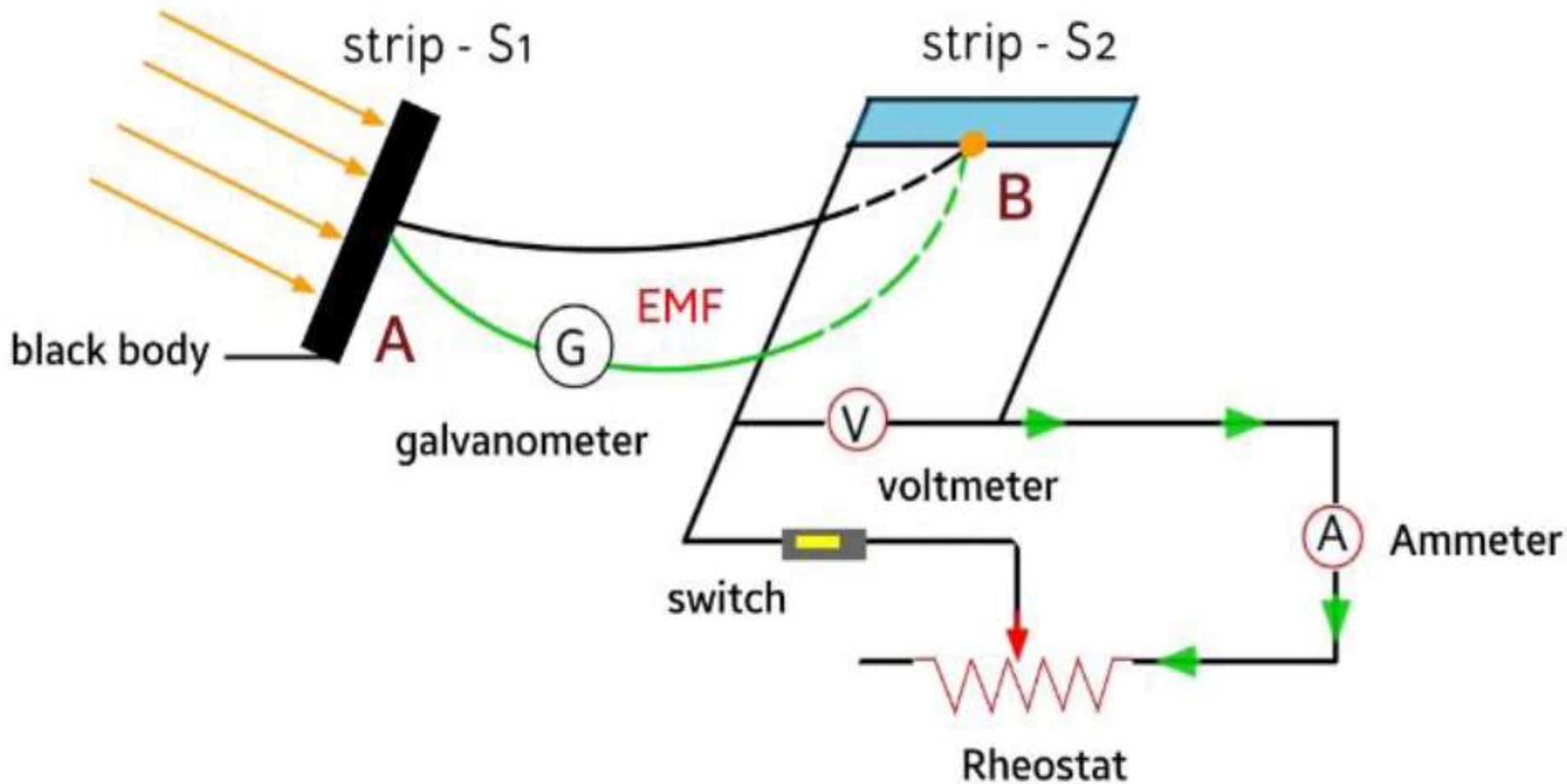


Pyrheliometer

CONSTRUCTION

- This is an instrument which measures beam radiation falling on a surface normal to the sun's rays.
- In contrast to a pyranometer, the black absorber plate (with hot junctions of a thermopile attached to it) is located at the base of a collimating tube.
- The tube is aligned with the direction of the sun's rays with the help of a two-axis tracking mechanism and alignment indicator.
- Thus the black plate receives only beam radiation and a small amount of diffuse radiation falling within the acceptance angle of the instrument.

INTERNAL CIRCUIT

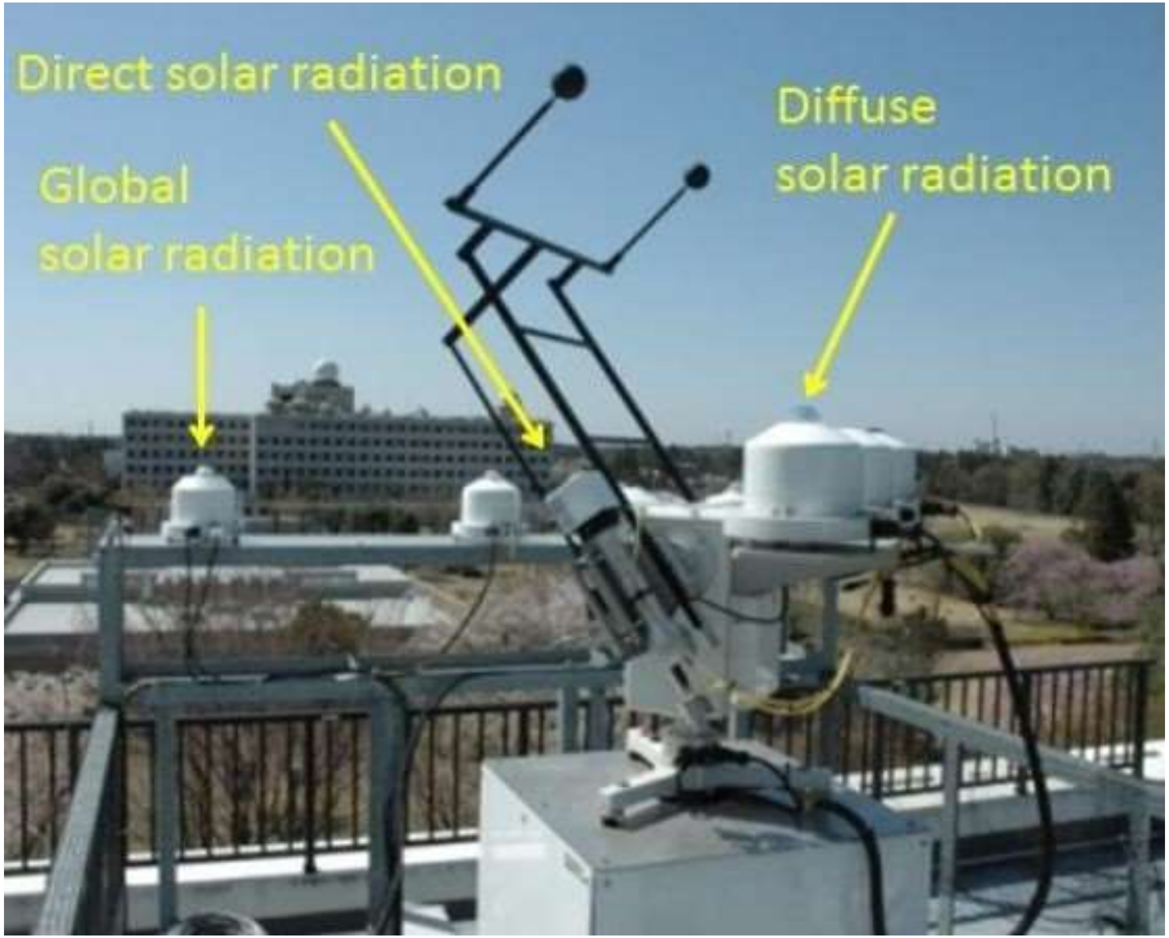


WORKING

- In the circuit, it can be seen that the black body absorbs the radiation falling from the lens and a perfect black body completely absorbs any radiation falling on it, so the radiation falling into the tube gets absorbed by the black object entirely .
- Once the radiation gets absorbed the atoms in the body gets excited because of the increasing temperature of the entire body.
- This temperature increase will also be experienced by the thermocouple junction ‘A‘.
- Now with junction ‘A‘ of the thermocouple at high temperature and junction ‘B‘ at low temperature, a current flow takes place in its loop.

- This current in the loop will also flow through the galvanometer which is in series and thereby causing a deviation in it.
- This deviation is proportional to current, which in turn is proportional to temperature difference at junctions.
- Now by adjusting the rheostat until the galvanometer deviation becomes completely void.
- Once this happens we can obtain voltage and current readings from the meters and do a simple calculation to determine the heat absorbed by the black body.
- This calculated value can be used to determine the radiation, as heat generated by the black body is directly proportional to the radiation.

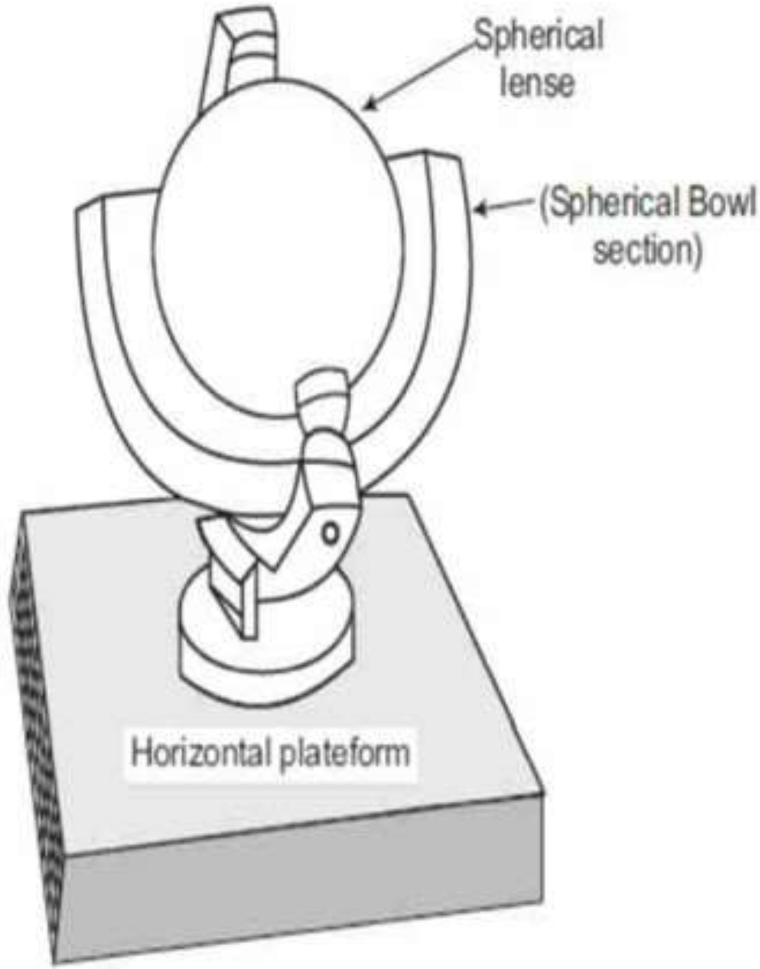
OBSERVATION METHODS



SUNSHINE RECORDER

- This instrument measures the duration in hours,of bright sunshine during the course of the day.
- It essentially consists of glass sphere (about 10 cm in diameter) mounted on its axis parallel to that of earth, within a spherical section (bowl).
- The bowl and glass sphere is arranged in such a way that sun‟s rays are focused sharply at a spot on a card held in a groove in the bowl.
- The card is prepared from special paper bearinga time scale.

SUNSHINE RECORDER



SUNSHINE RECORDER

- As the sun moves, the focused bright sunshine burns a path along this paper.
- The length of the trace thus obtained on the paper is the measure of the duration of the bright sunshine.

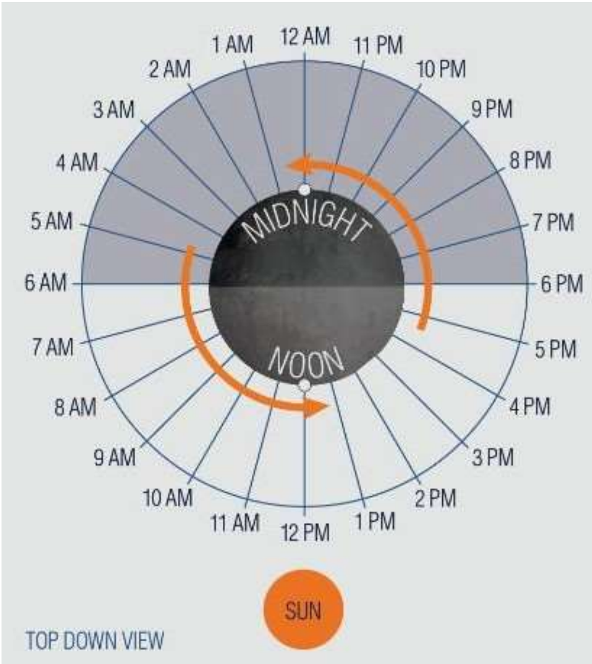
- Three overlapping pairs of grooves are provided in the spherical segment to take care of the different seasons of the year.

Fig. Sunshine record cards

Fig. Sunshine record cards

LOCAL SOLAR TIME

- "Local solar time" (or simply "solar time") is the time according to the position of the sun in the sky relative to one specific location on the ground.

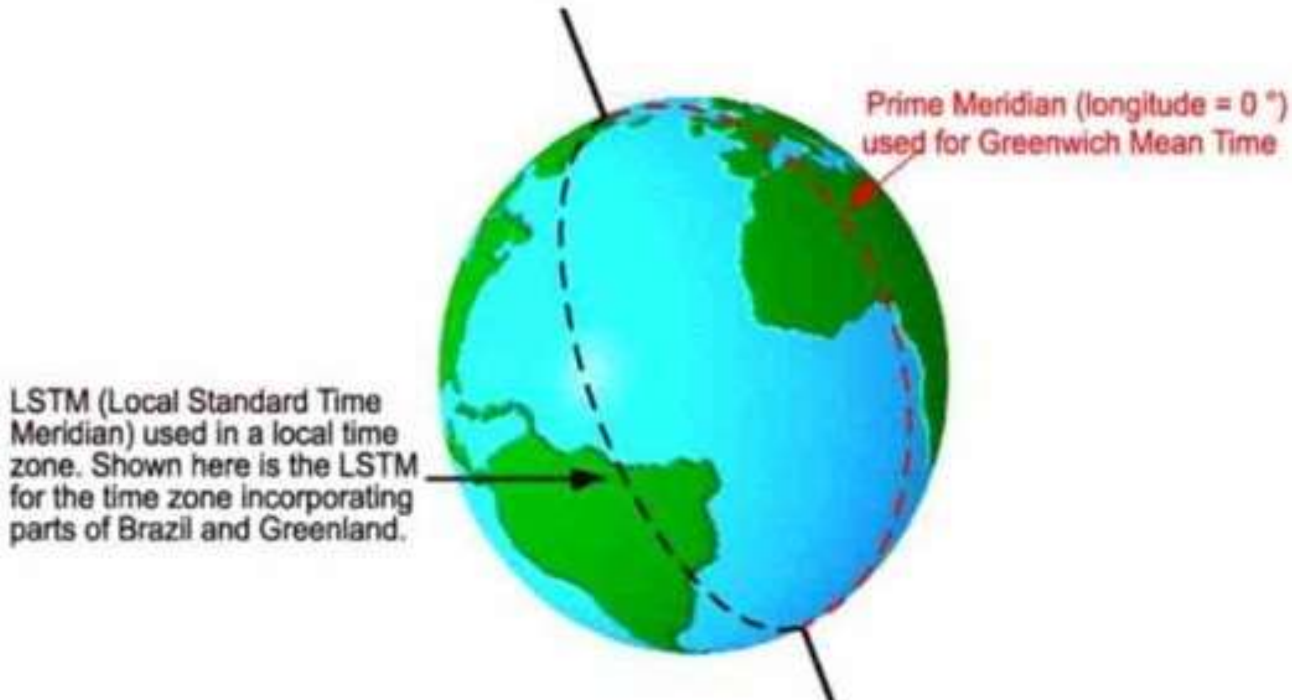


CALCULATION LOCAL SOLAR TIME

- Local Solar Time can be calculated from standard time by applying two corrections.
- The first correction arises due to the difference in longitude of the location and meridian on which standard time is based.
- The correction has a magnitude of 4minutes for every degree difference in longitude.
- Second correction called the equation of time correction is due to the fact that earth‘s orbit and the rate of rotation are subject to small perturbations.

Local Standard Time Meridian (LSTM)

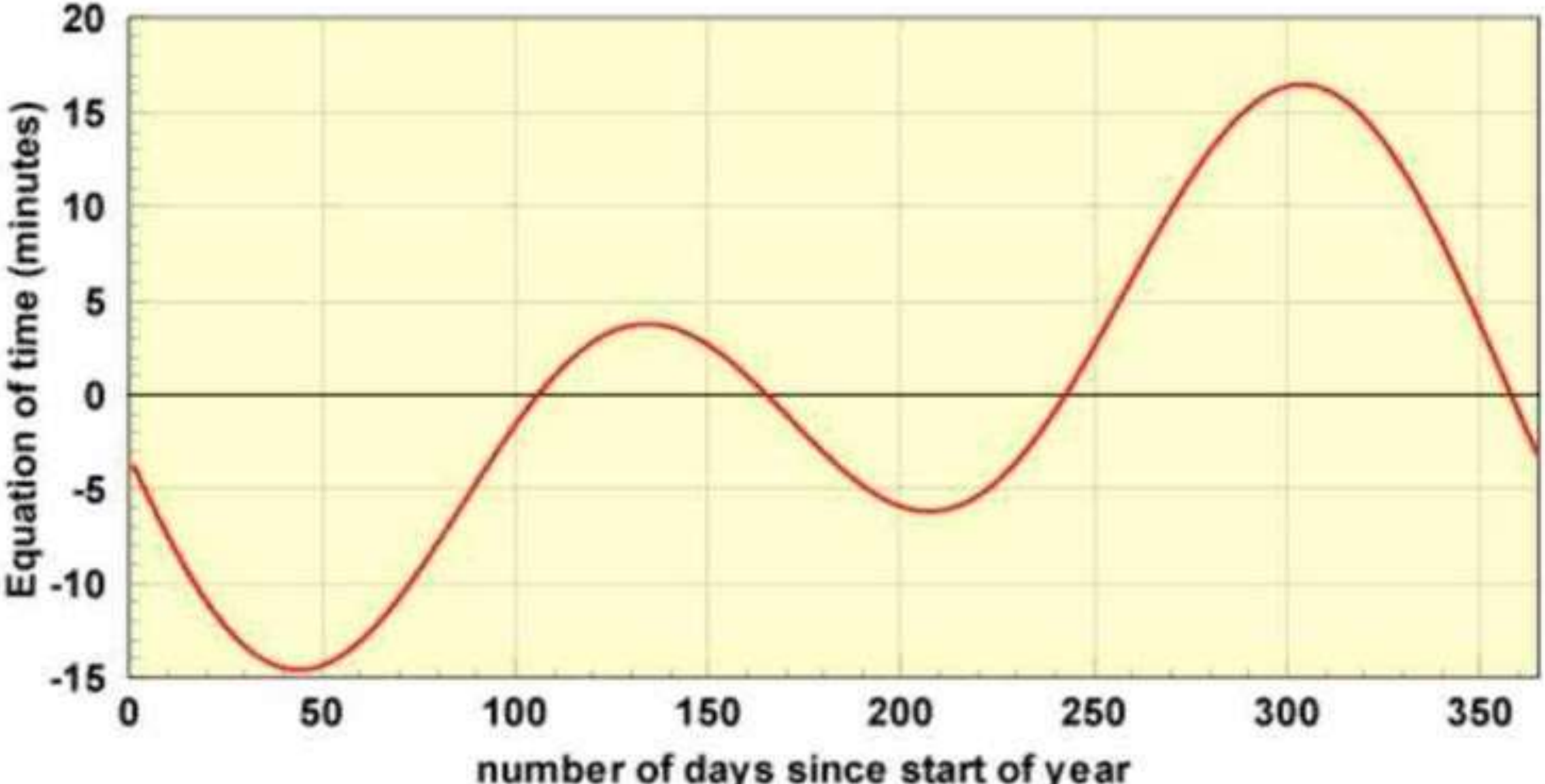
The Local Standard Time Meridian (LSTM) is a reference meridian used for a particular time zone and is similar to the Prime Meridian, which is used for Greenwich Mean Time. The LSTM is illustrated below.



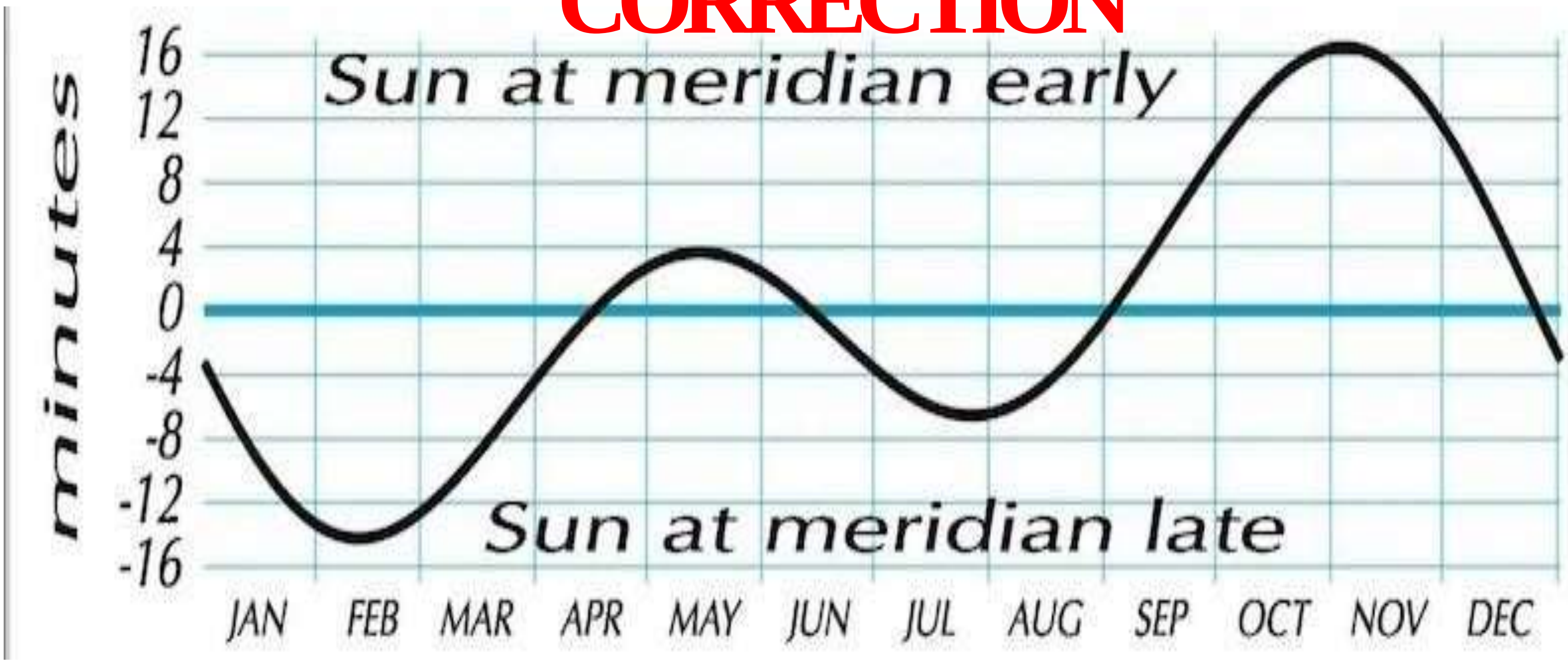
Equation of time

- The difference between apparent solar time (the actual time between noons) and mean solar time (the average time between noons) is called the *equation of time*.

Equation of time correction



EQUATION OF TIME CORRECTION



LOCAL SOLAR TIME

- **Local Solar Time = Standard time $\pm$ 4(Standard time Longitude-Longitude of the location)+(Equation of time correction)**

PROBLEM

- Determine the local solar time and declination at a location latitude $23^0 15'$N, longitude $77^0 30'$E at 12.30 IST on june 19. Equation of Time correction is = -(1'01"‖).

The Local solar time=IST$\pm$(standard time longitude-longitude of location)+Equation of time correction.

$$=12^h 30' - 4(82^0 30' - 77^0 30') - 1'01‖$$

$$=12^h 8' 59''$$

PROBLEM (CONTD..)

Declination δ can be calculated Cooper's Equation i.e,

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

$$= 23.45 \sin\{\frac{360}{365}(284 + 170)\} = 23.45\ \sin 86^0 = 23.43^0$$

DAY LENGTH

- The period during sunrise and sunset decides the length of the day.
- This is essential requirement to know about the period during which sun's energy availability.
- The hour angle corresponding to sunrise or sunset on a horizontal surface can be found using equation and substituting

DAY LENGTH

- At the time of sunset or sunrise the zenith angle $\theta z=90^o$, we obtain sunrise hour angle as

$$\omega s = Cos^{-1}\{-\tan\phi \ tan\delta\}$$

Since 15^0 of the hour angle are equivalent to 1 hour The day length(hrs) is given by

$$td = \frac{2\omega}{15} = \frac{2}{15} Cos^{-1}\{-\tan\phi \ tan\delta\}$$

1. Calculate the sunset hour angle and day length at a local latitude of 35° North(N) on February 14

Given data

Latitude angle (ϕ) $= 35^\circ$

$n =$ Feb 14

$= 31 + 14$

$= 45^{th}$ day in the year

Declination angle δ is given by

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

$$\delta = 23.45 \sin\left[\frac{360(284+45)}{365}\right]$$

$$= 23.5 \sin(324.49)$$

$$= -13.64^\circ$$

Hour angle is given by

$$\omega = \cos^{-1}[-\tan\phi \tan\delta]$$

$$\omega = \cos^{-1}[-\tan(35) \tan(13.64)]$$

$$\omega = 80.21^\circ$$

the day length is given by

$$T_d = \frac{2\omega}{15} \text{ hr}$$

$$= \frac{2(80.21)}{15} = 10.69 \text{ hrs}$$

2. Calculate the Suns altitude angle, Azimuth angle at 4:30pm Solar time on Aug 1st for the location at 40° N latitude.

4:30 = 16:3

Solar time (ST) = 16:30

$$n = 31+28+31+30+31+30+31+1$$

$$\phi = 40^\circ$$

$$\alpha = ?$$

$$\gamma = ?$$

W.K.T

$$\cos\theta = \cos\phi \cdot \cos\omega \, \cos\delta + \sin\phi \cdot \sin\delta$$

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

$$\delta = 23.45 \sin\left[\frac{360(284+213)}{365}\right]$$

$$\boxed{\delta = 17.95}$$

$$\omega = 15(ST - 12)$$

$$= 15(16{:}30 - 12)$$

$$= 67.5^{o}$$

$$\cos\theta = \cos(40)\cos(64.5)\cos(17.95) + \sin(40)\cdot\sin(17.95)$$

$$\boxed{\theta = 59.21^\circ}$$

$\cos(59.21) = 0.5118$

$\sin^{-1}(0.5118)$

$= 30.79$

$$\cos\theta = \sin\alpha$$

$$\boxed{\alpha = 30.79}$$

$$\sin\gamma = \sec\alpha \cos\delta \sin\omega_s$$

$$= \sec(30.79)\cdot\cos(17.95)\sin(64.5)$$

$$\gamma = 88.25$$

SOLAR COLLECTOR

- A solar collector is a device that collects and/or concentrates solar radiation from the Sun.
- These devices are primarily used for active solar heating and allow for the heating of water for personal use.
- These collectors are generally mounted on the roof and must be very Strong as they are exposed to a variety of different weather conditions.

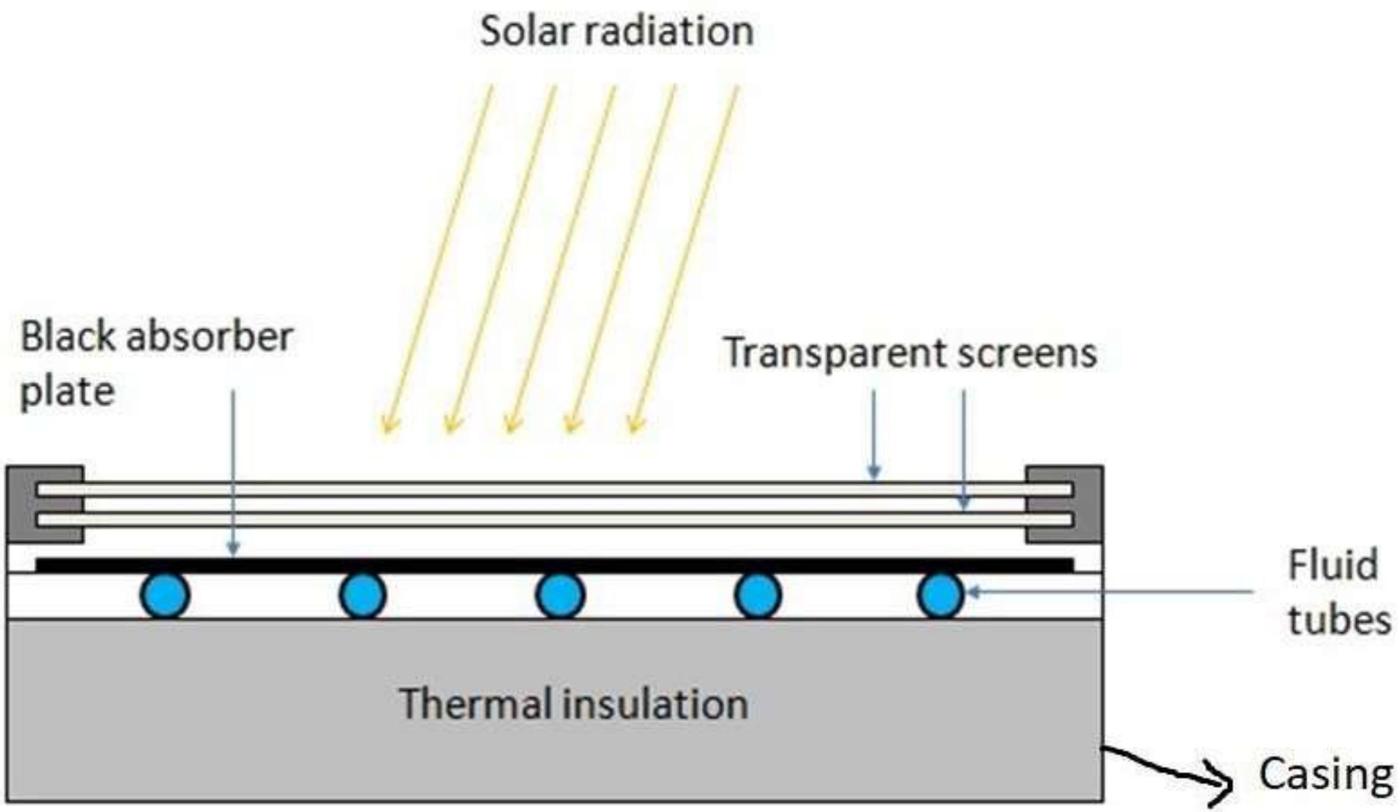
SOLAR COLLECTOR

- The use of these solar collectors provides an alternative for traditional domestic water heating using a water heater, potentially reducing energy costs over time.
- As well as in domestic settings, a large number of these collectors can be combined in an array and used to generate electricity in solar thermal power plants.

CLASSIFICATION:

- Solar collectors
  - Non-concentrating type (Flat-plate collector)
    - (a) Liquid flat-plate collector
    - (b) Flat-plate air-heating 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 conc.
        - (c) Circular Fresnel lens conc.
        - (d) Central Tower receiver
    - Non-focus type
      - (a) Modified flat-plate collector
      - (b) Compound-parabolic Concentarting (CPC) type

FLAT PLATE COLLECTOR (FPC) OR NON CONCENTRATING COLLECTOR



FLAT PLATE COLLECTOR (FPC)

- A non-concentrating or flat plate collector is one in which the absorbing surface for solar radiations is essentially flat with no means for concentrating the incoming solar radiation.
- The flat-plate solar collectors are probably the most fundamental and most studied technology for solar-powered domestic hot water systems.
- The Sun heats a dark flat surface which collect as much energy as possible, and then the energy is transferred to water, air, or other fluid for further use.

COMPONENTS

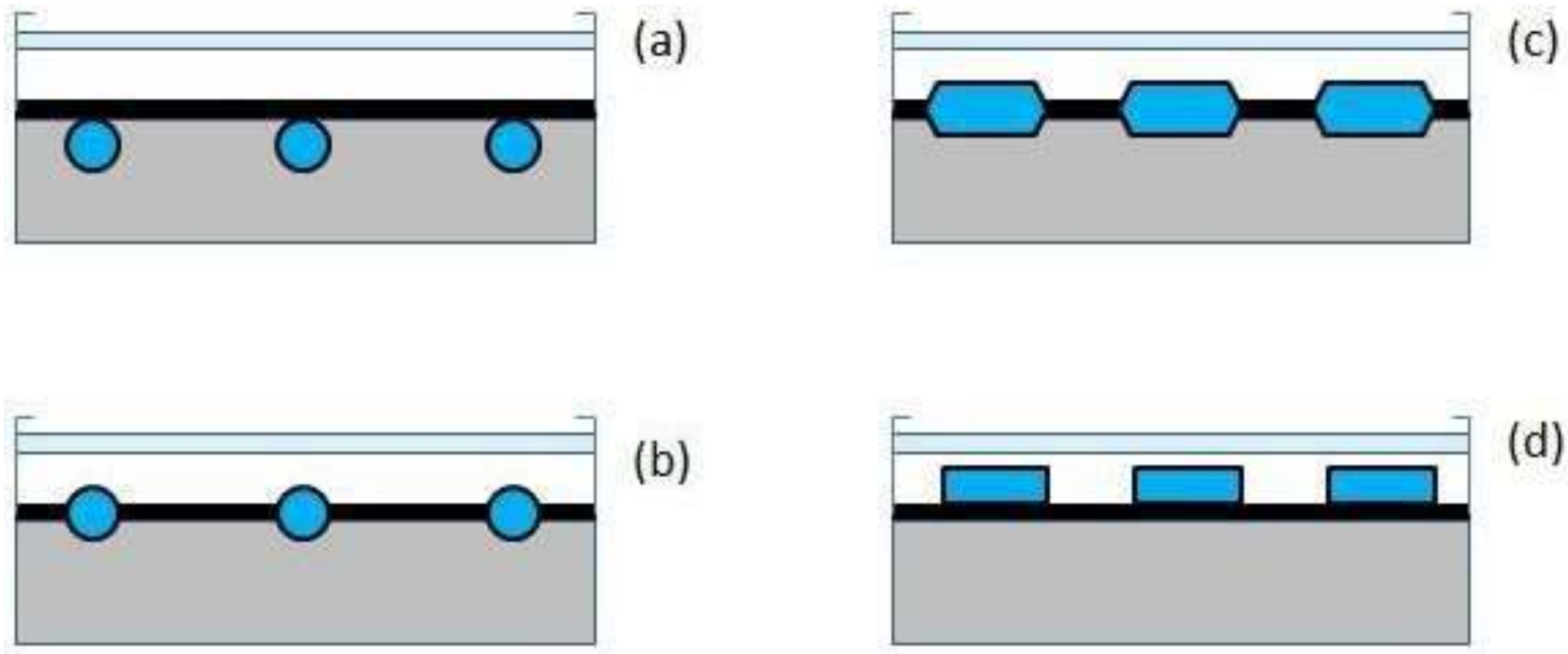
The main components of a typical flat-plate solar collector:

1) **Black surface -** Absorbent of the incident solar energy
2) **Glazing cover -** A transparent layer(made of glass) that transmits radiation to the absorber plate. It prevents radiative and convective heat loss from the surface
3) **Tubes** containing heating fluid to transfer the heat from the collector
4) **Support structure or casing** to protect the components and hold them in place
5) **Thermal Insulation** is used to reduce heat losses

FLAT PLATE COLLECTOR (FPC)

- A special coating is provided on the absorber plate to reduce radiation loss. This coating has excellent absorption characteristics & low emission characteristics. As a result, collection efficiency increases.
- The flat-plate systems normally operate and reach the maximum efficiency within the temperature range from 40 ^{o} to 100^{o}C.
- The disadvantage of flat plate collector is that it is not suitable for high temperature applications.

VARIOUS DESIGNS OF FLAT-PLATE COLLECTOR ASSEMBLY



VARIOUS DESIGNS OF FLAT-PLATE COLLECTOR ASSEMBLY

- Color codes:
  - Light blue - glass cover,
  - Dark blue - fluid channels,
  - Black - absorber material,
  - Gray - insulation.
- Some constructions (b, c) include fluid channels in the absorber plate structure to maximize thermal conductance between the components.
- Other modifications (a, d) include tubes and channels soldered or cemented to the plate

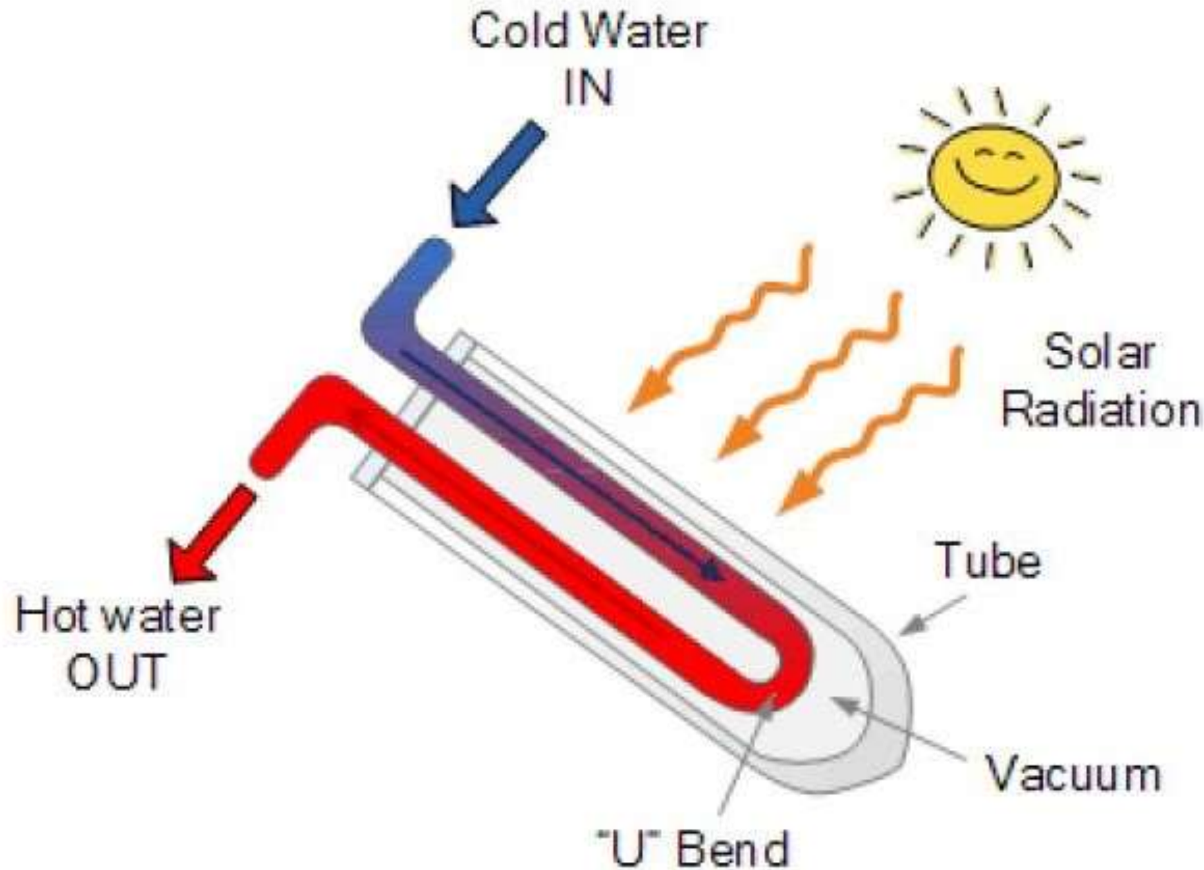
ADVANTAGES OF FLAT PLATE COLLECTOR

- Absorb energy coming from all directions above the absorber (both beam and diffuse solar irradiance).
- Do not need to track the sun
- Simpler and Less Expensive
- High output can be achieved by providing two axis tracking mechanism,etc.

Applications

- Water heating
- Space heating
- Vapour absortpion refrigeration

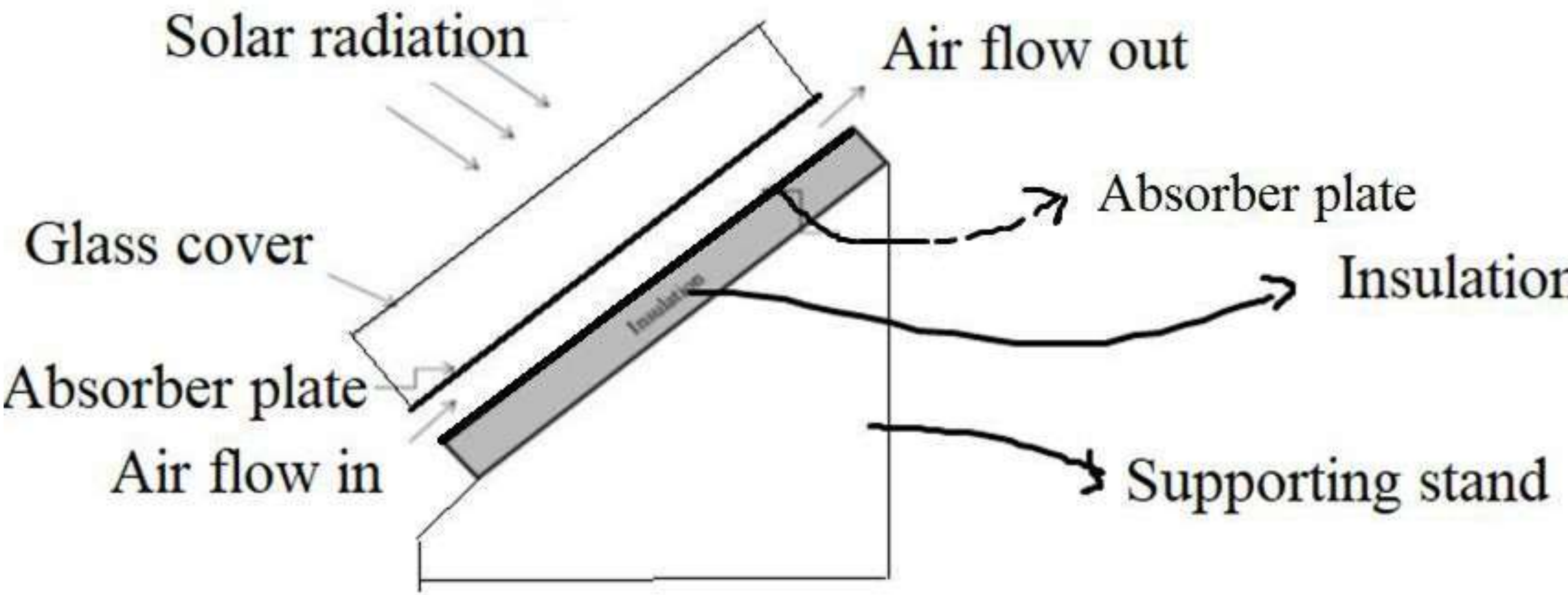
EVACUATED TUBE COLLECTOR



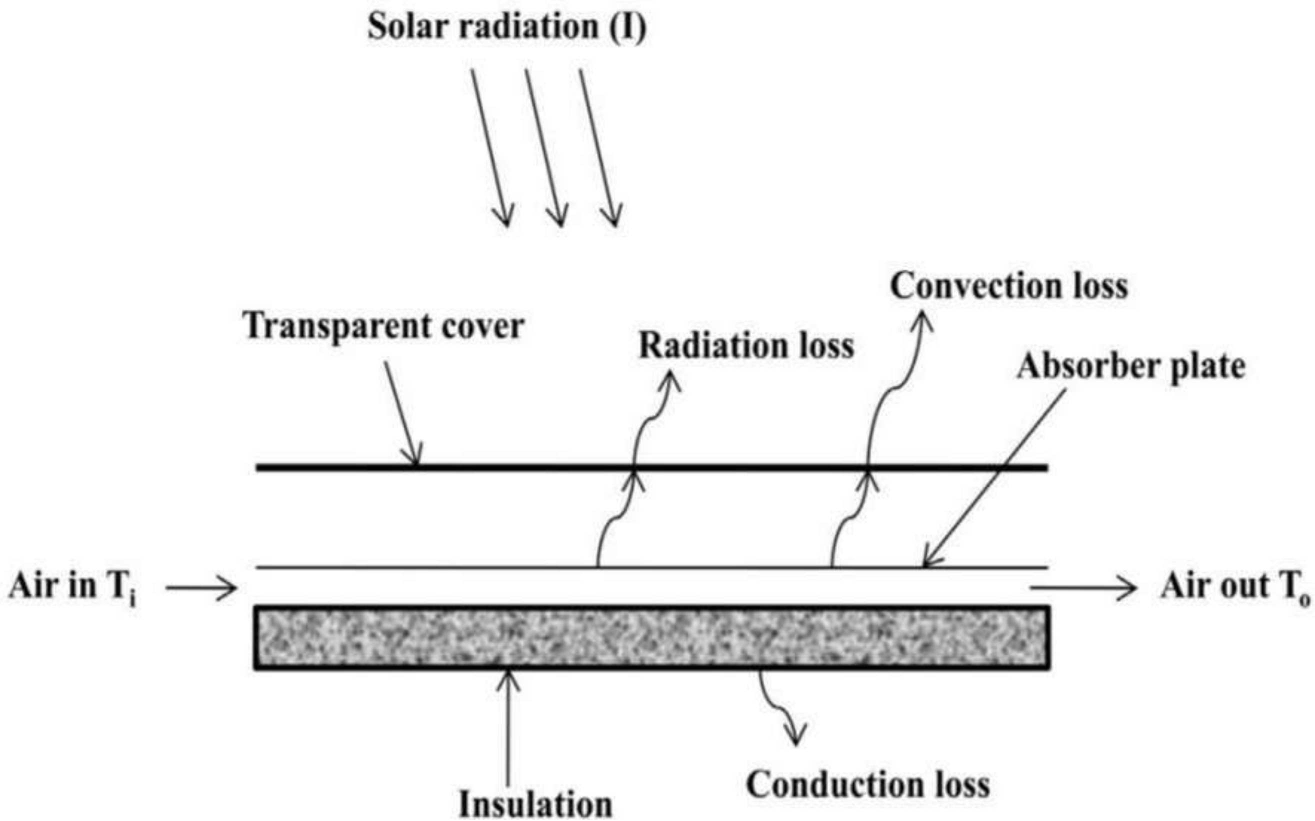
EVACUATED TUBE COLLECTOR

- It consists of two concentric glass tubes which are completely evacuated.
- The outer surface of glass tube is specially coated for having high absorptivity characteristics and low emissivity characteristics.
- When heat is transferred, the water inside the tube is heated and supplied to the proper application.
- Water circulation is based on density differences (thermosyphon circulation)
- Heat loss to surroundings by convection is reduced by providing vacuum. Collection efficiency is increased.

SOLAR AIR HEATER



SOLAR AIR HEATER



SOLAR AIR HEATER

- A conventional solar air heater is essentially a flat plate collector with an absorber plate.
- It is a transparent cover system at the top and insulation at the bottom and on the sides. The whole assembly is enclosed in a sheet metal container as shown in figure.
- Cold air is drawn by fan in to duct which is covered by solar collector.
- The heat absorbing by solar collector is transfer to the air in duct and so air become warm.
- Warm air has low density as compare to cold air so it flow to upward and thus natural convection current is being set.
- Air has low co-efficient of heat convection so for increasing velocity blower is used.

APPLICATIONS

- Heating buildings
- Drying agricultural products and lumber
- Heating green houses
- As heat source for heat engines (like Brayton or Stirling cycles)

CONCENTRATING COLLECTORS

- Concentrating, or focusing, collectors catch direct radiation over a large area and focus it onto a small absorber area.
- These collectors can provide high temperatures more efficiently than flat-plate collectors, since the absorption surface area is much smaller
- Most concentrating collectors require mechanical equipment that constantly orients the collectors toward the sun and keeps the absorber at the point of focus.

CONCENTRATING COLLECTORS

- These are devices that optically reflect and focus incident solar energy onto a small receiving area.
- As a result of this concentration, the intensity of the solar energy is magnified and the temperatures that can be achieved at the receiver can approach several hundred or even several thousand degrees Celsius.

CONCENTRATING COLLECTORS

- 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 conc.
    - (c) Circular Fresnel lens conc.
    - (d) Central Tower receiver
- Non-focus type
  - (a) Modified flat-plate collector
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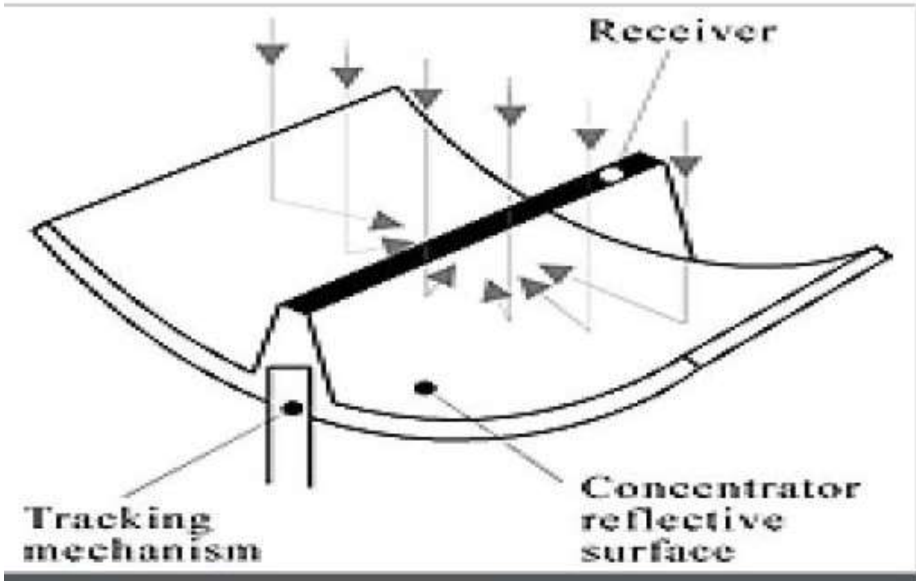
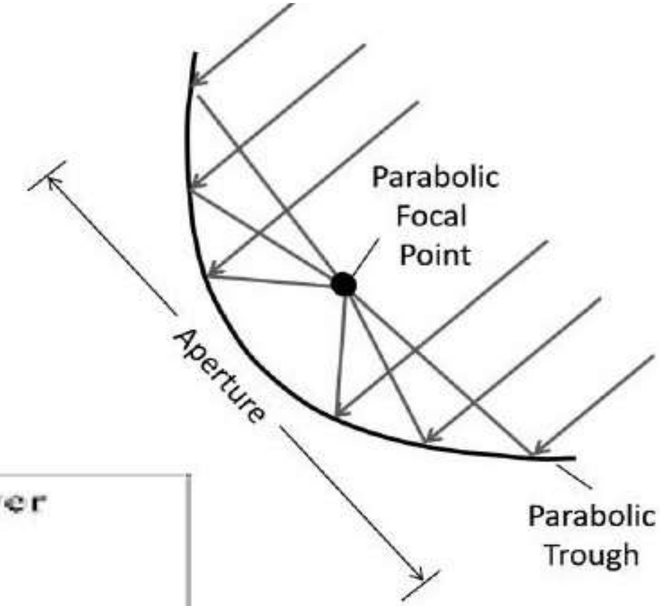
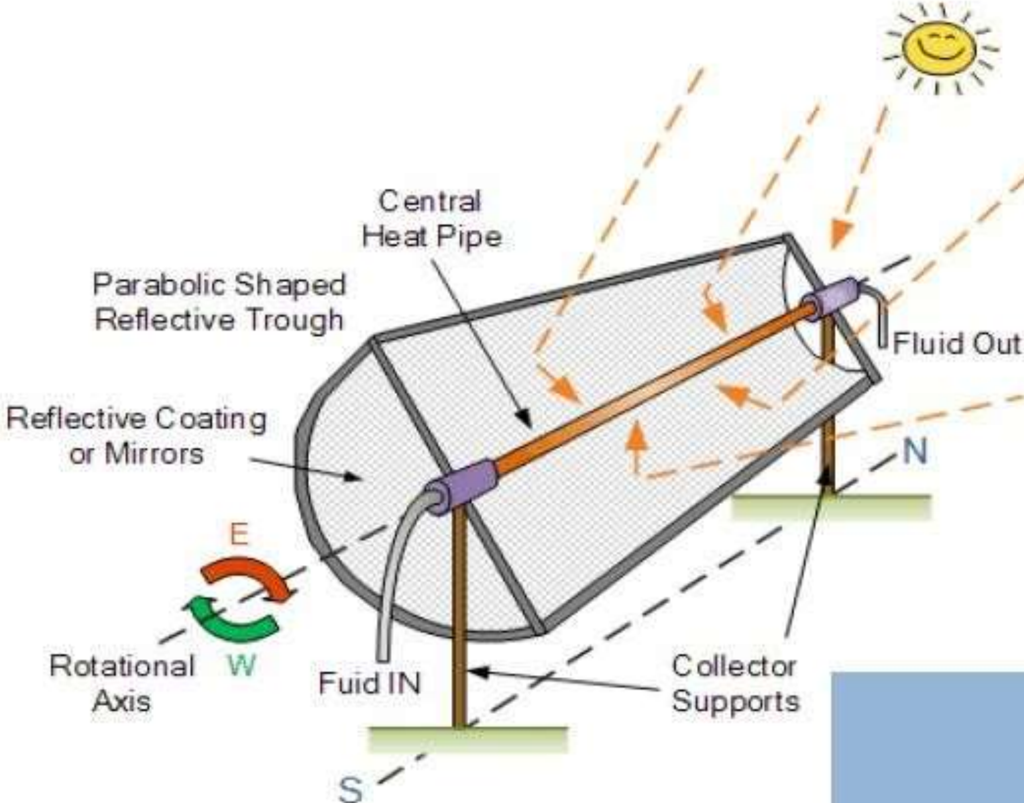
Parabolic trough system



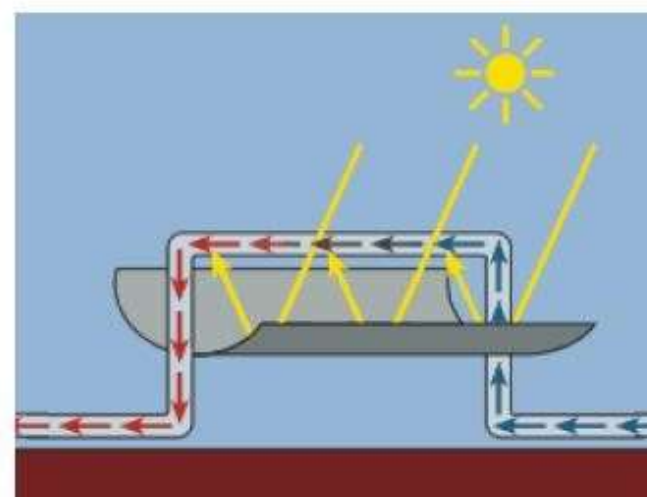


Parabolic trough system

- Parabolic troughs are devices that are shaped like the letter ‘U’.
- The troughs concentrate sunlight onto a receiver tube that is positioned along the central line of the trough.
- Sometimes a transparent glass tube surrounds the receiver tube to reduce heat loss.
- The energy from the sun sent to the tube which heats fluid flowing through the tube, and the heat energy is then used to generate electricity in a conventional steam generator.
- Many troughs placed in parallel rows are called a collector field.
- The troughs in the field are all aligned along a north - south axis so they can track the sun from east to west during the day, ensuring that the sun is continuously focused on the receiver pipes.
- Individual trough systems currently can generate about 80 MW of electricity.



Central
Heat Pipe
Parabolic Shaped
Reflective Trough
Fluid Out
Reflective Coating
or Mirrors
N
E
W
Rotational
Axis
Fuid IN
Collector
Supports
S



Parabolic trough system

The aperture width of a commercial PTC is about 5.7 m.

THE PARABOLIC TROUGH SYSTEM

The below figure shows one axis tracking parabolic trough with axis oriented E-W.

The below figure shows two axis tracking concentrator.

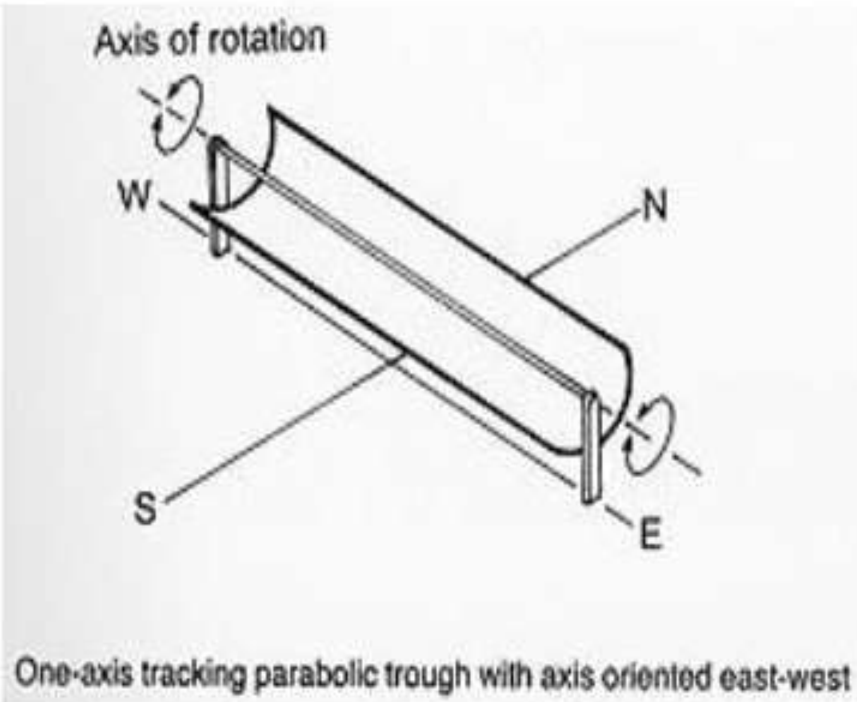


Figure :One Axis Tracking Parabolic Trough with Axis Oriented E-W .

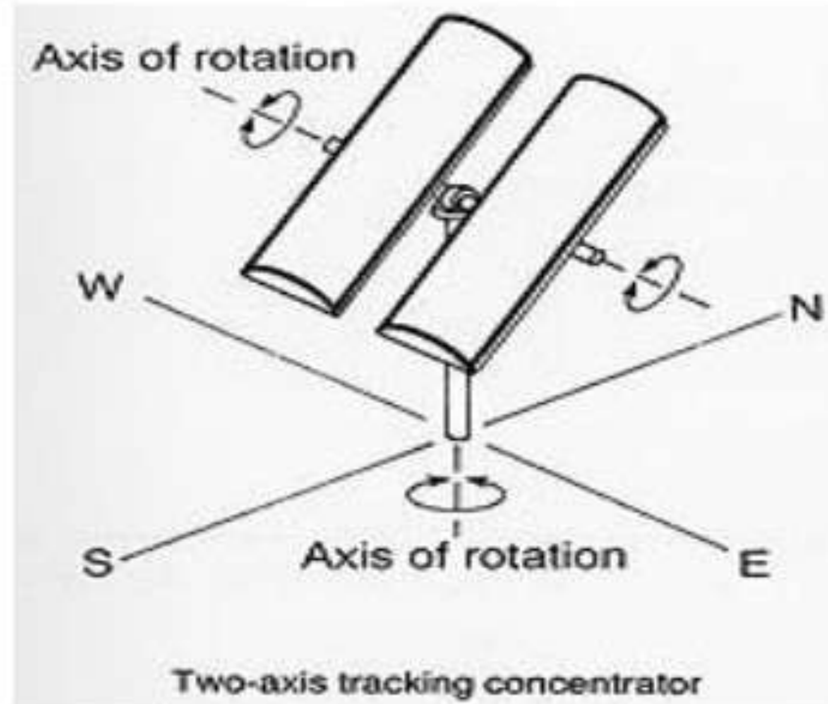
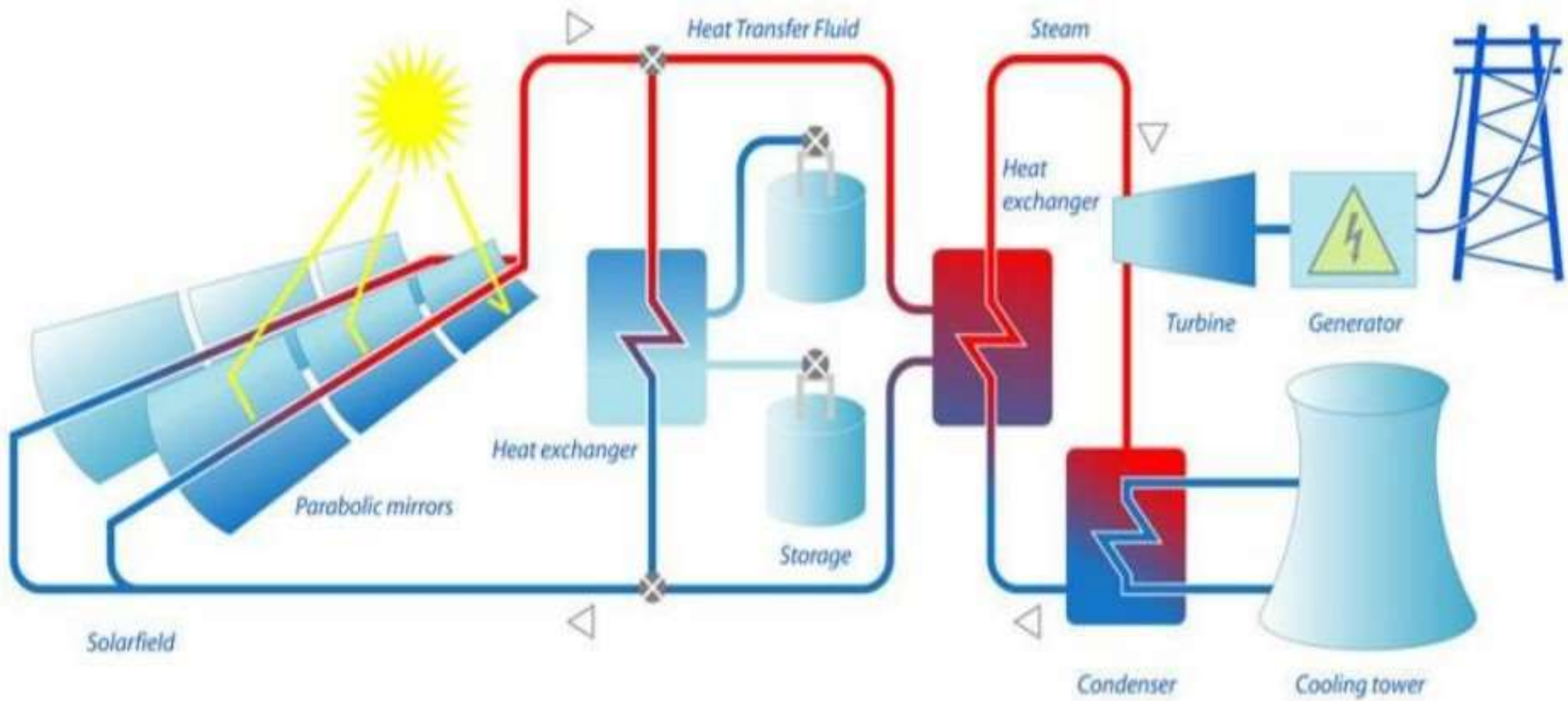


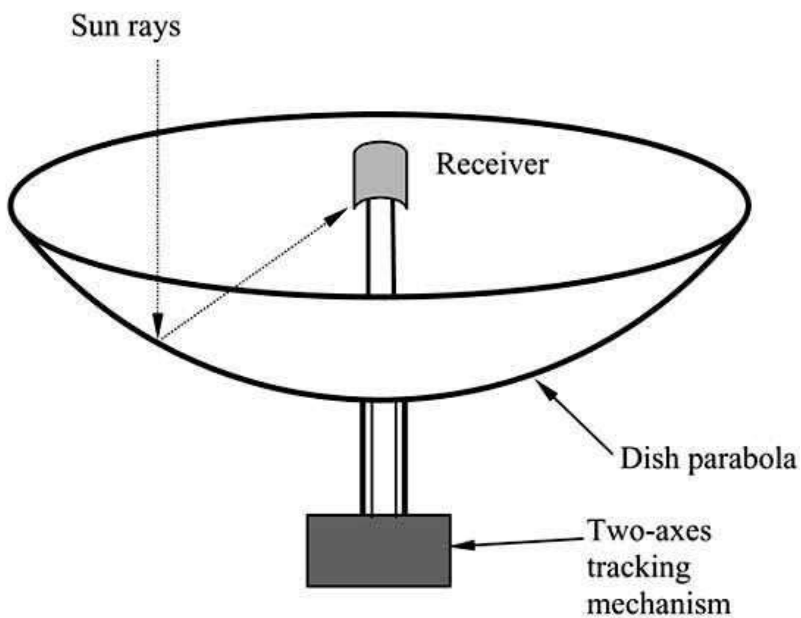
Figure :Two **Axis Tracking Concentrator** .

Power generation by parabolic trough system



PARABOLIC DISH COLLECTOR

- A parabolic dish collector is similar in appearance to a large satellite dish, but has mirror-like reflectors and an absorber at the focal point. It uses a dual axis sun tracker.



The below figure shows crossection of parabolic dish.

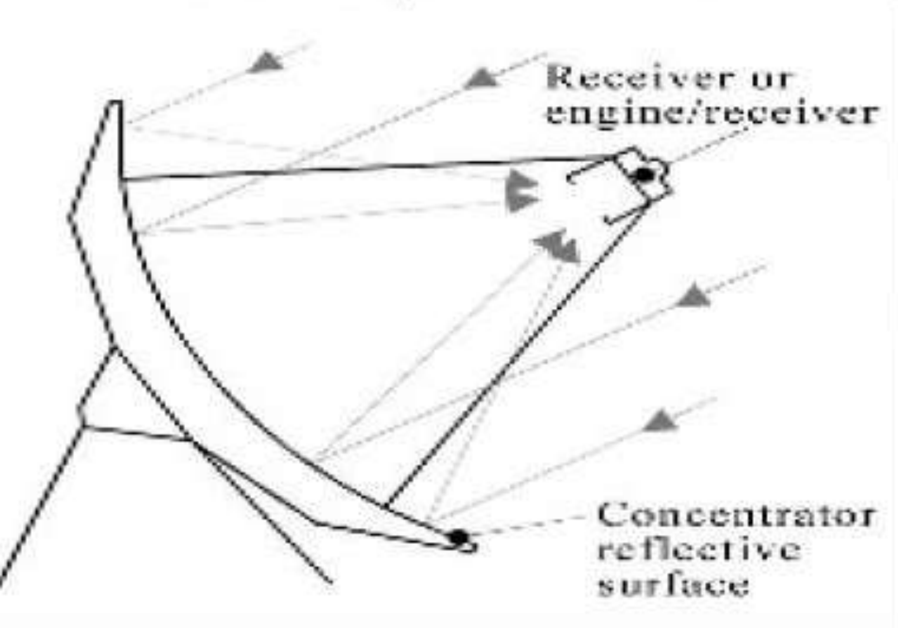


Figure :Crossection of parabolic dish

The Parabolic dish collector is shown in the below figure.

Figure : Parabolic dish collector with a mirror-like reflectors and an absorber at the focal point [Courtesy of SunLabs - Department of Energy]

PARABOLIC DISH COLLECTOR

- A parabolic (paraboloid) dish collector brings solar radiation to a focus point which has a small central volume.
- A dish 6.6m in diameter and it has been made from about 200 curved mirror segments forming a paraboloid surface.
- The absorbed is located at focus and it is made of a zirconium copper alloy with a black chrome selective coating.
- The heat transport fluid flown into and out of the absorber cavity through pipes.
- This heat energy is then converted to mechanical power. An electric generator or alternator converts the mechanical power into electrical power.

PARABOLIC DISH COLLECTOR

- The dish can be turned automatically about two axes(up-down and left-right) so that the sun is always kept in line with the focus.
- The concentration ratios(30-100) are very high in case of parabolic dish system and therefore high temperatures (300-500°C)can be achieved.
- A parabolic dish system uses a computer to track the sun and concentrate the sun's rays onto a receiver located at the focal point in front of the dish.
- In some systems, a heat engine, such as a Stirling engine, is linked to the receiver to generate electricity.
- Parabolic dish systems can reach 1000 °C at the receiver, and achieve the highest efficiencies for converting solar energy to electricity in the small-power capacity range .

The right figure shows the solar dish stirling engine.

Figure :Solar dish stirling engine

Power tower system (or) Central receiver system

- A heliostat uses a field of dual axis sun trackers that direct solar energy to a large absorber located on a tower.

The Power tower system is shown in the figure below.

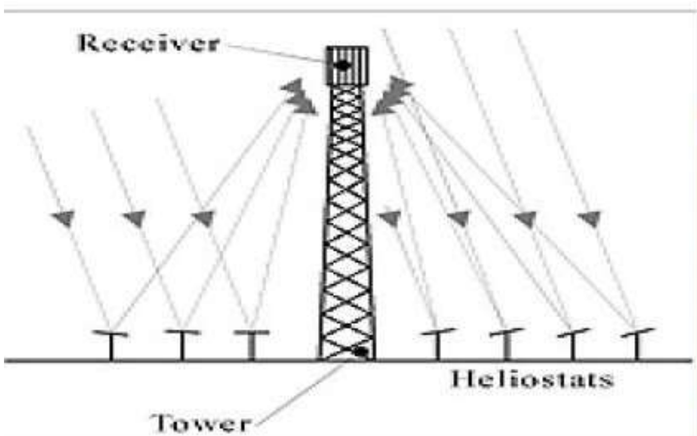
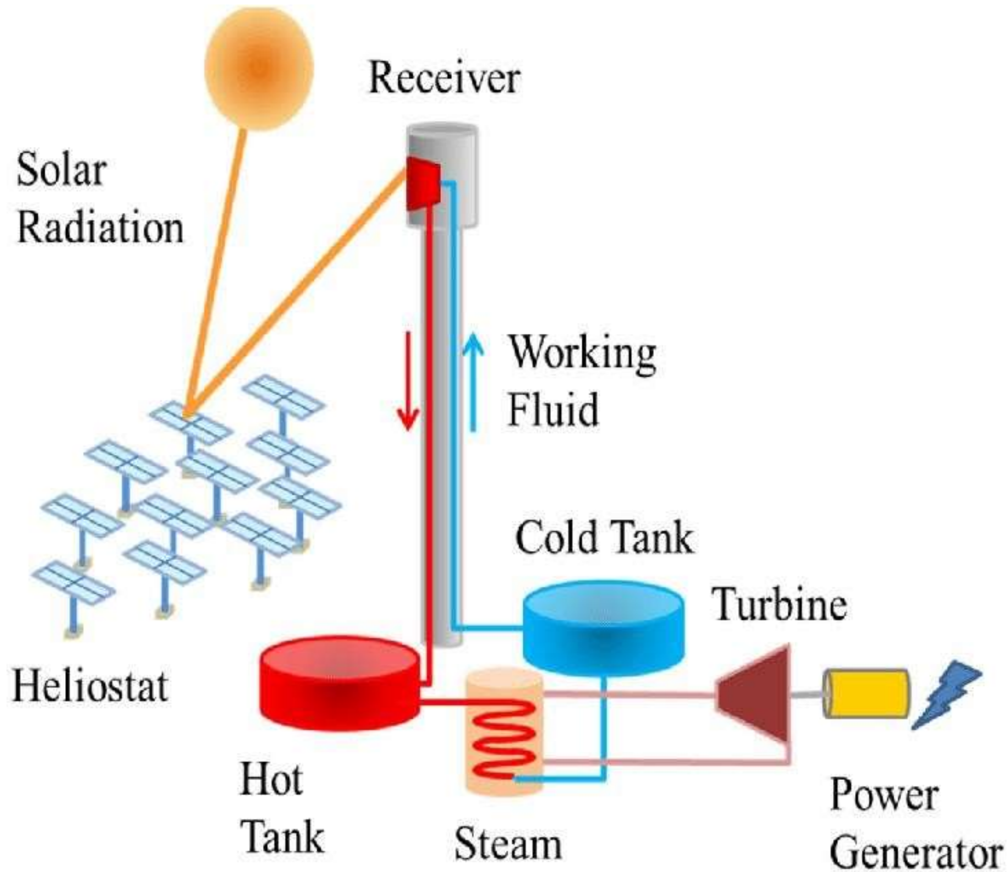


Figure :Power tower system .

Heliostats are shown in the figure below.

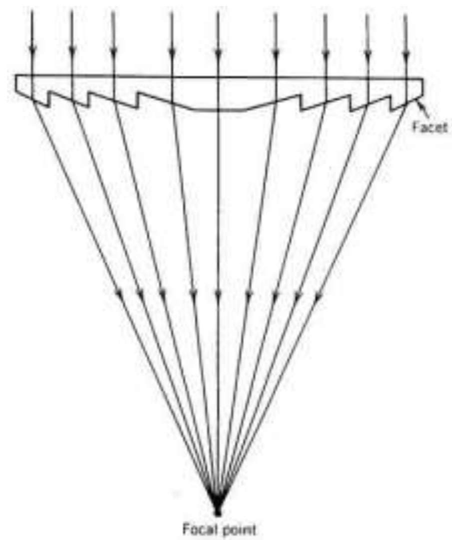
Figure: Heliostats

Power tower system



Fresnel Lens Collector

- The radiation is refracted and focused onto the absorber plate.
- The facets are used to refract sunlight and to concentrate on solar cell.



Fresnel Lens Collector

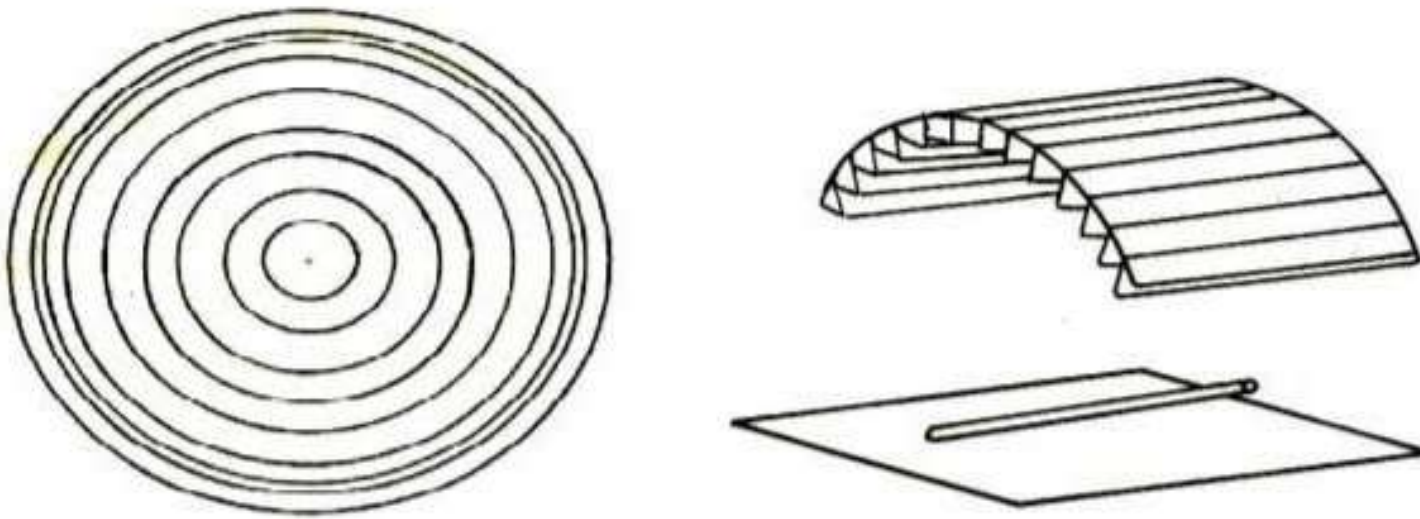
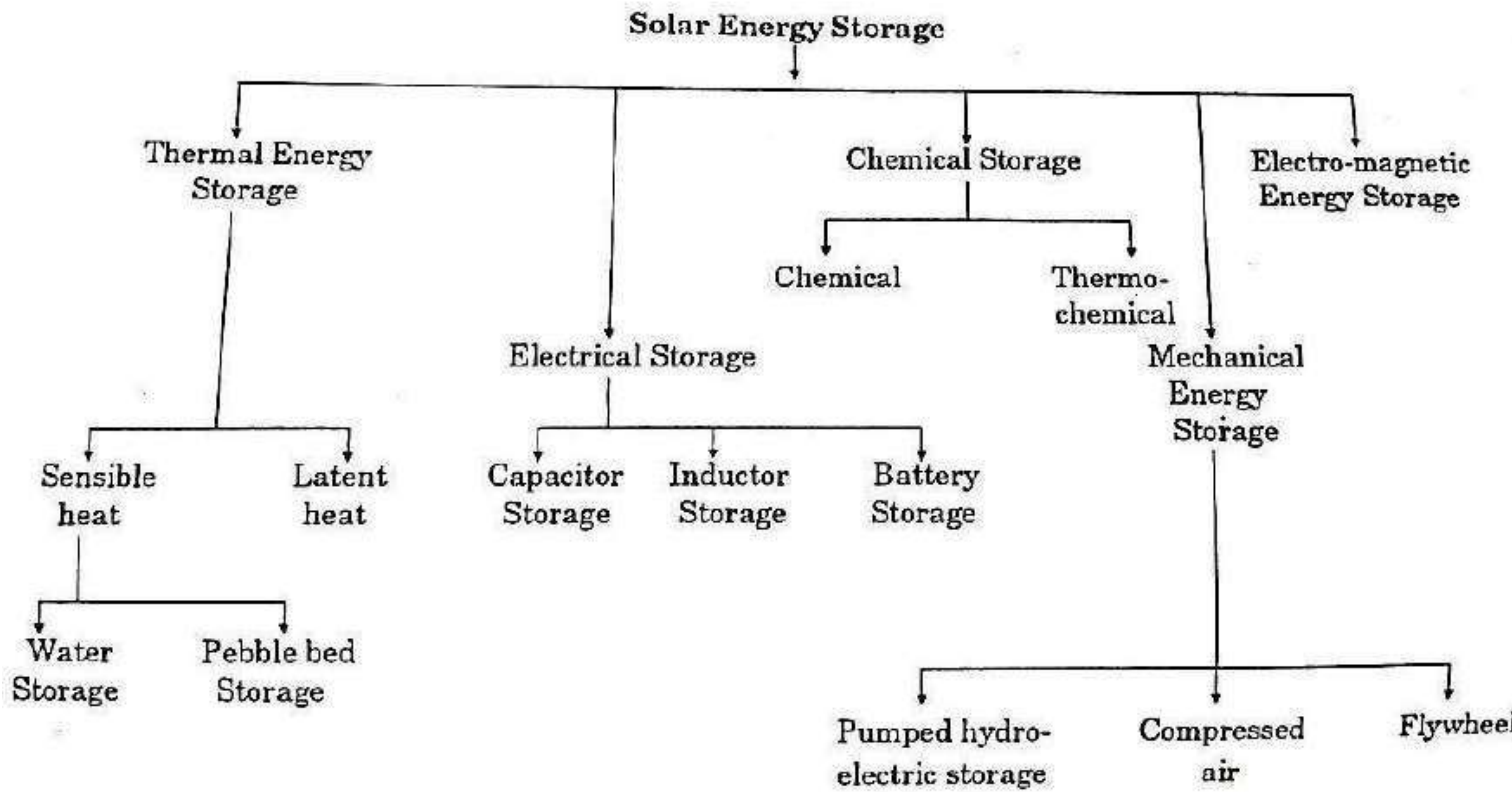


Fig a) Point focus b) Line Focus

Fresnel Lens Collector

STORAGE OF SOLAR ENERGY

- The thermal energy of sun can be stored in a well-insulated fluids or solids.
- It is either stored as i) **Sensible heat** – by virtue of the heat capacity of the storage medium, or as ii) **Latent heat** – by virtue of the latent heat of change of phase of the medium or both.
- In the first type of storage the temp of the medium changes during charging or discharging of the storage whereas in the second type the temp of the medium remains more or less constant since it undergoes a phase transformation.
- An overview of the major techniques of storage of solar energy is as shown in the fig.

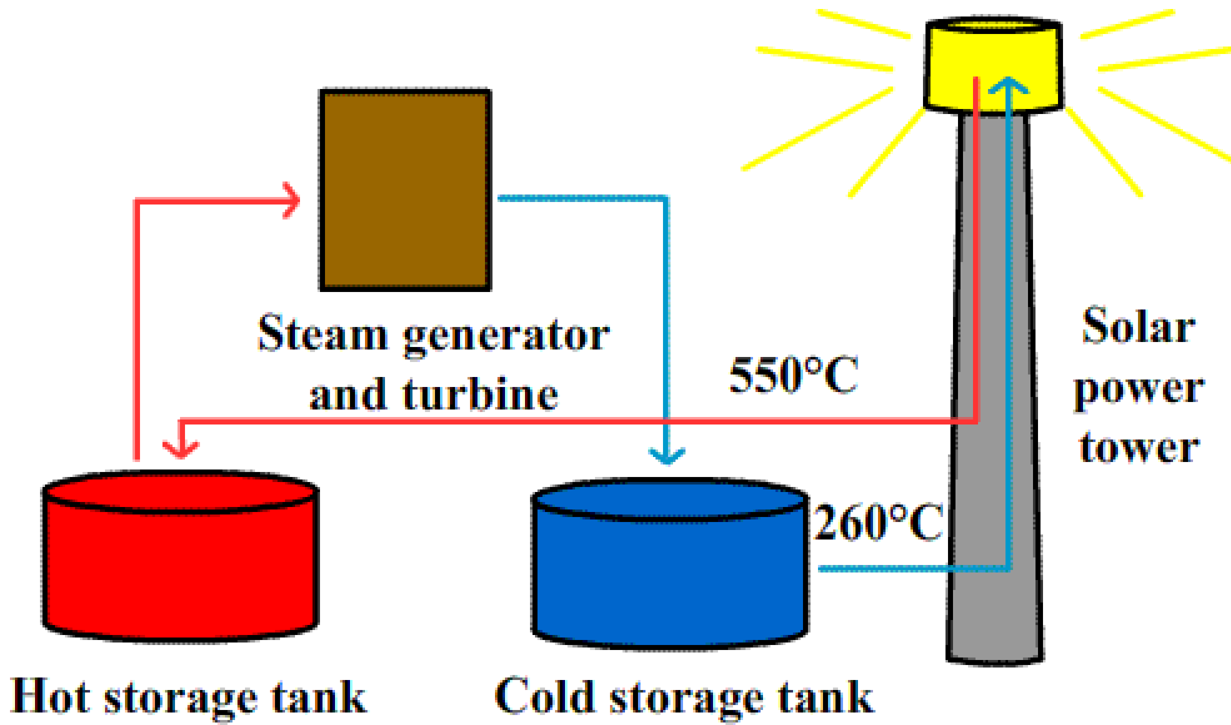

Solar Energy Storage
Thermal Energy Storage
Electrical Storage
Chemical Storage
Mechanical Energy Storage
Electro-magnetic Energy Storage
Chemical
Thermo-chemical
Sensible heat
Latent heat
Capacitor Storage
Inductor Storage
Battery Storage
Water Storage
Pebble bed Storage
Pumped hydro-electric storage
Compressed air
Flywheel

Classification According to Storage	
Electrical energy storage	Directly electricity storage in devices such as capacitors or super-conducting magnetic devices. Those storage methods have the advantage of quickly discharging the energy stored.
Mechanical energy storage	Storage of electrical energy in the form of kinetic energy such as flywheel or potential energy such as pumped hydroelectric storage (PHS) or compressed air energy storage (CAES).
Chemical energy storage	Storage in chemical energy form as in batteries, fuel cells and flow batteries. Chemical energy storage usually has small losses during storage.

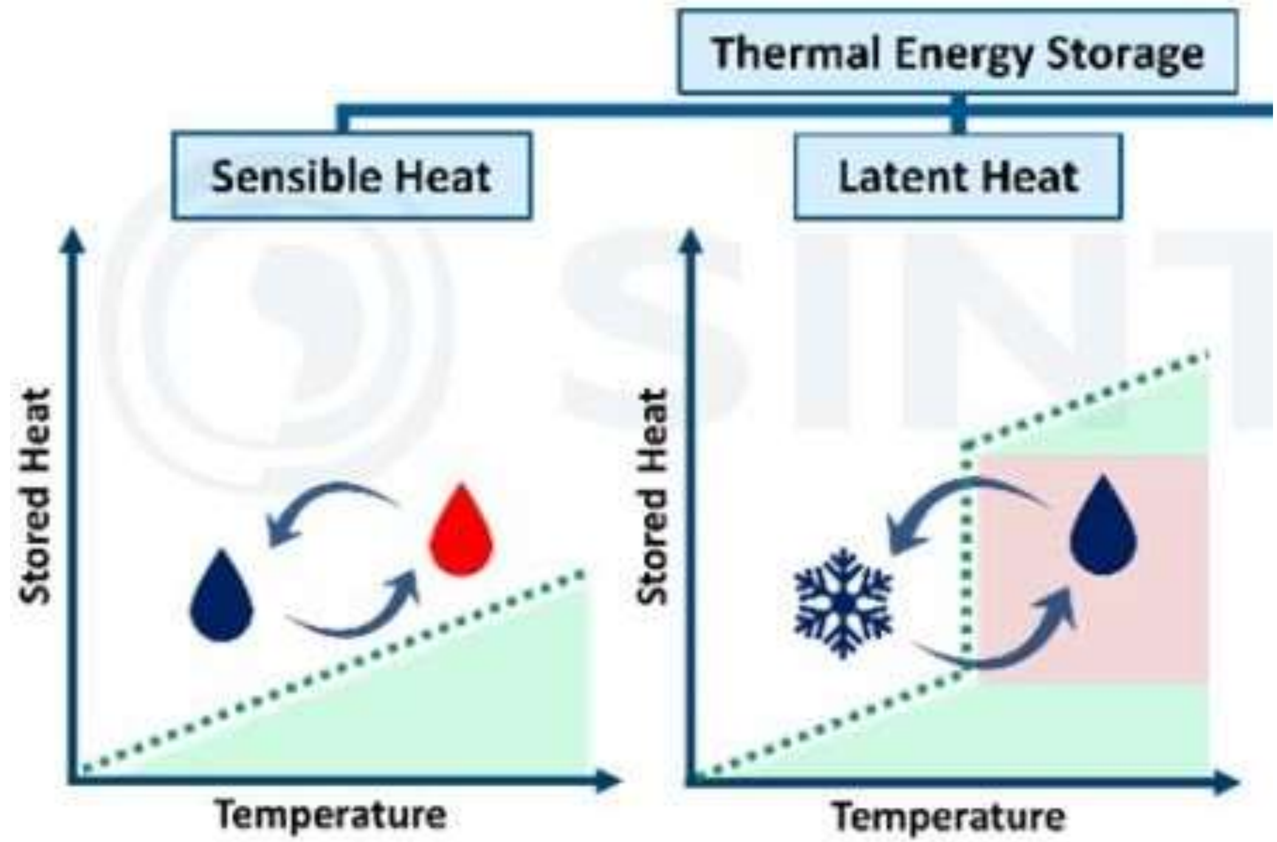
Thermal Energy Storage

- Thermal energy storage is a family of technologies in which a fluid, such as water or molten salt, or other material is used to store heat.
- This thermal storage material is then stored in an insulated tank until the energy is needed.
- The energy may be used directly for heating and cooling, or it can be used to generate electricity.
- In thermal energy storage systems intended for electricity, the heat is used to boil water.
- The resulting steam drives a turbine and produces electrical power using the same equipment that is used in conventional electricity generating stations.
- Thermal energy storage is useful in CSP (concentrated solar power) plants, which focus sunlight onto a receiver to heat a working fluid.

Thermal Energy Storage



Thermal Energy Storage



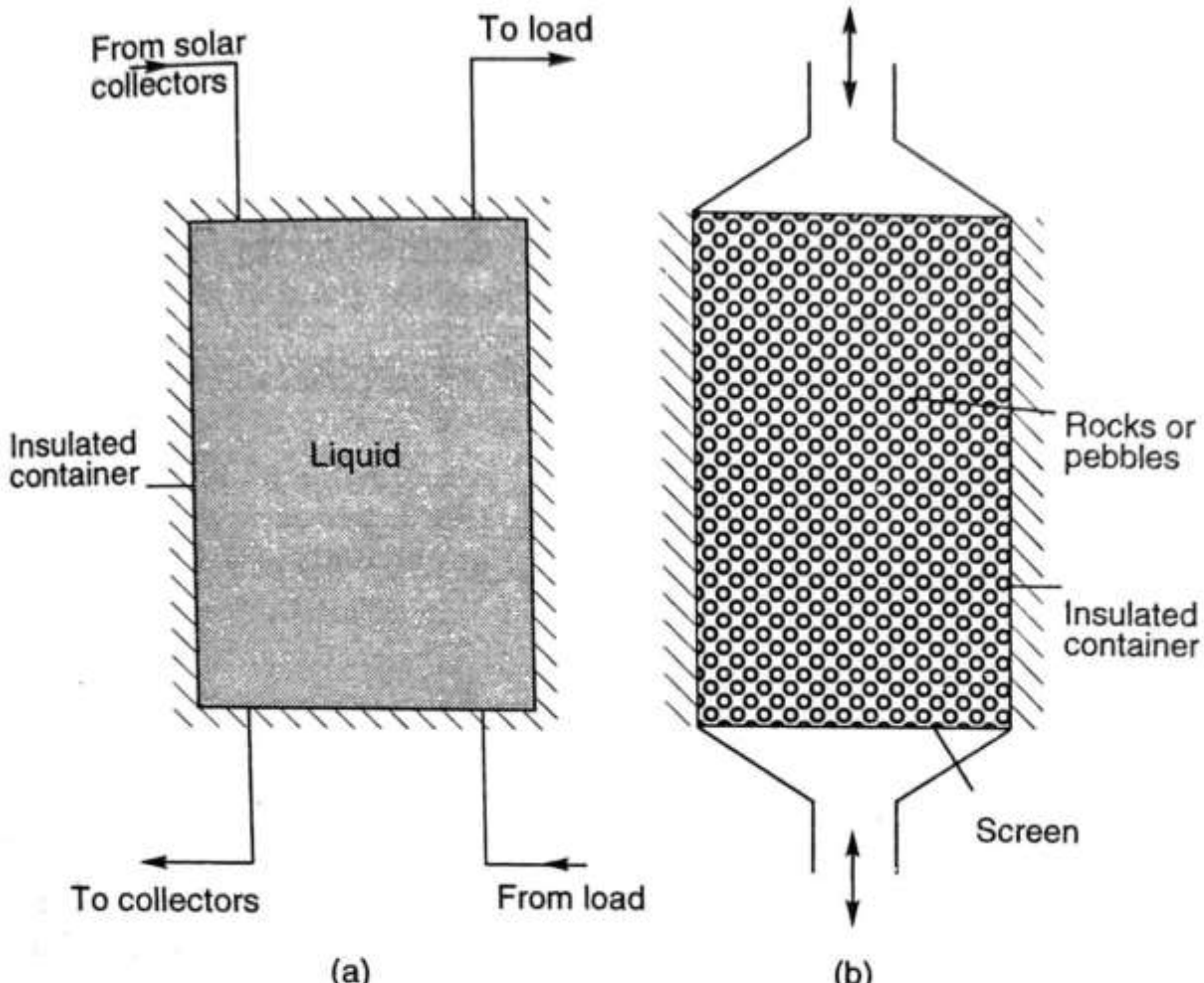
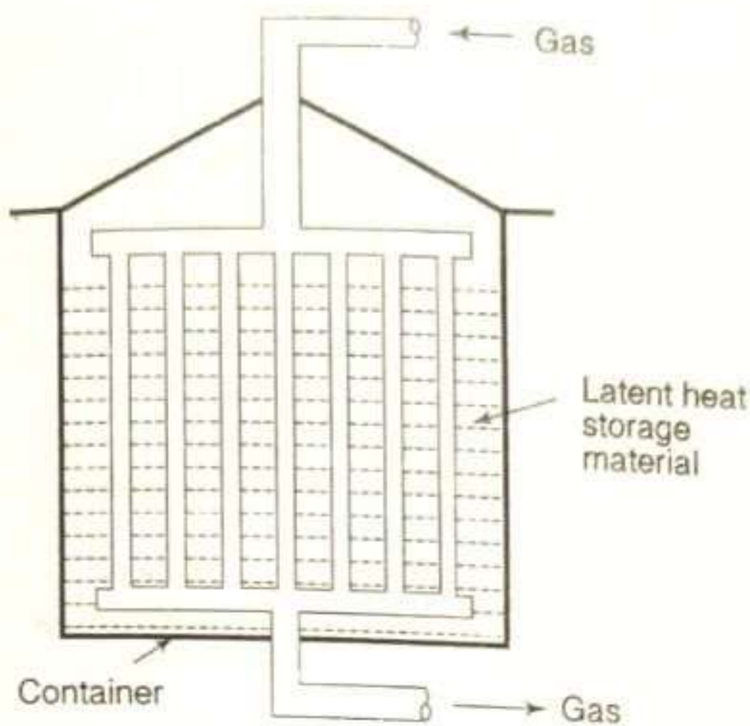


Fig. 2.5 Schematics of Two Forms of Sensible Heat Storage—(a) Liquid, (b) Porous Solid

LATENT HEAT STORAGE



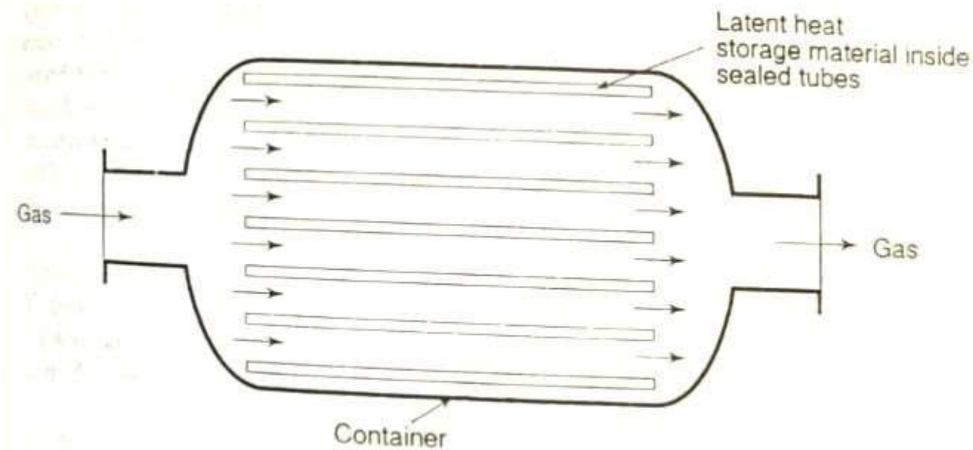


Fig. 7.10 Latent Heat Storage Arrangements