Energy, Ecology & Social development →

→ Modern services such as electricity, natural gas, modern cooking fuel are mechanical power are necessary for improved health & education, better access to information & industrial as well as agriculture productivity.

→ There are four major energy end use sectors –

- Commercial
- Industrial
- Residential
- Transportation

→ Per capita energy consumption of a country is an index of standard of living or prosperity of people of country.

S. No.	Country	Population	Average electrical energy per capita (kwh/year)	Per capita GDP (in USD)
1.	USA	32 Crore	12,071	54,629
2.	Russia	14 Crore	7,481	10,743
3.	Japan	13 Crore	7,371	36,194
4.	China	140 crore	4,475	7,593
5.	India	135 Crore	1,181	1,630

By 2012, USA (4.4% of world's population) → 16% energy while India (17% of pop.) → 6% of energy

Oil crisis of 1973 →

→ OAPEC (org of Arab Petroleum Exporting Countries & Egypt, syria & tunisia

→ 1973 → 3 $ per barrel

1980 → 37 $ per barrel

Classification of Energy Sources →

1) Based on usability of energy → based on human made conversion

$$\text{Energy yield ratio} = \frac{\text{Energy received from raw energy source}}{\text{Energy spent to obtain it}}$$

a) Primary → wood, coal, sunlight, wind, rivers, uranium

b) Secondary → Electrical, Thermal

2) Based on traditional use →

a) Conventional → before 1973 oil crisis. Eg- fossil, nuclear & hydro

b) Non-Conventional → after 1973. Eg → Solar, biomass, wind

3) Based on long term availability →

a) Non-renewable

b) Renewable

4) Based on Commercial Application →

a) Commercial → Electricity, coal & petroleum products

b) Non-Commercial → Firewood, cattle dung & agri wastes

5) Based on origin →

a) fossil b) Nuclear c) Hydro d) Solar

e) wind f) geothermal g) ocean h) biomass

Consumption trend of primary energy sources →

Coal - 27 %, Natural gas - 24 %, Hydro - 7 %, Nuclear - 4 %, Oil - 34 %, others (renewable) - 4 %

India → Coal - 54 %

Large hydro - 12.6 %

Wind - 10 %

Solar - 8.7 %

Gas - 6.9 %

Nuclear - 2 %

Biomass - 2.7 %

Energy scenario in India →

→ Largest thermal power station → Vindhyachal (4760 MW) – M.P. – NTPC
- 2nd → Mundra T.P.S. – Gujarat – Adani
- 3rd – Mundra ultra mega – " – Coastal Gujarat power ltd.
- 4th – Sasan " – M.P. – Reliance
- 5th – Tiroda T.P.P. – Maharashtra – Adani
- 6th – Talcher Super T.P.S. – Odisha – NTPC

→ Largest hydro power plant → Tehri (2400 MW) – UK (Ganga)
- 2nd – Koyna (1960 MW) – MH (Koyna)
- 3rd – Srisailam (1670 MW) – A.P. (Krishna)
- 4th – Nathpa Jhakri (1500 MW) – H.P. (Satluj)
- 5th – Sardar Sarovar (1450 MW) – Gujarat (Narmada)
- Hirakud dam (350 MW) – Odisha (Mahanadi)

biggest in odisha – upper indravati (600 MW) – Indr
Balimela (510 MW) – Sileru

Salient features of NCES →

Merits →
1. Freely available
2. Pollution free
3. Inexhaustible
4. Low gestation (development) period

Demerits →
1. Available in dilute form
2. Uncertainty of availability
3. Harnessing cost is high
4. Transportation is difficult
5. Difficulty in storage

Energy - Environment - Economy →

Conditions for sustainable development →

1. The consumption rate of R.E.S. is not higher than recovery rate
2. The cons. rate of non-ren resources is not higher than rate of ↑ in ren. resources supply.
3. The emission of pollutants is within the absorption capacity of environment.

Common forms of energy →

1) Electrical → 30-40% energy in world is fed through it

2) Mechanical

3) Thermal →

a) High grade (500-1000°c or higher) → can be converted into mech.

b) Medium (150-500°c) → with very difficulty

c) Low (80-150°c) → used for heating purpose only

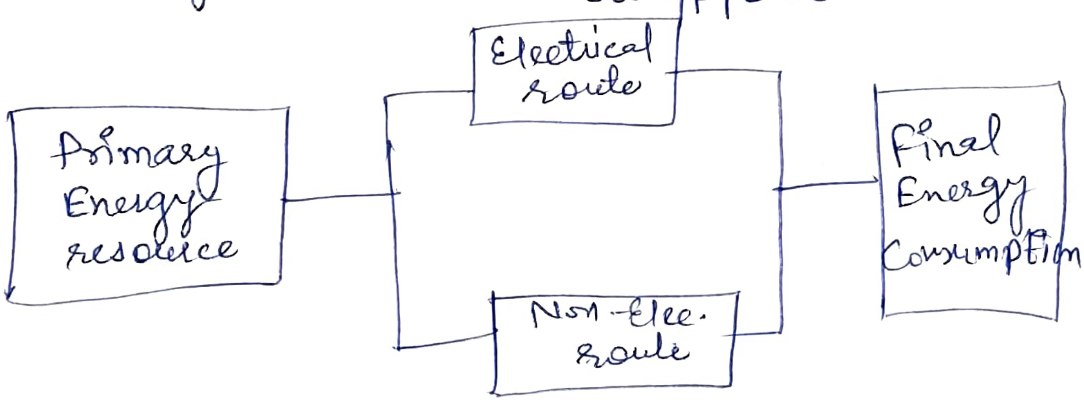
4) Chemical → Fuels & organic matter contains it. Exothermic reacⁿ release heat energy. It is dir. converted into electrical using fuel cells, storage batteries etc.

Energy chain → We can't use primary source of energy directly. It is known as raw energy.

The seq. of energy transformation b/w primary & sec. energy is known as energy chain or energy route.

Primary energy —(Transf. stages)→ Electrical Energy —(Transmission line)→ Consumer

P.E. —(Trans. stages)→ usable fuel —(Transported by rail/road/Ocean/pipeline)→ Consumer



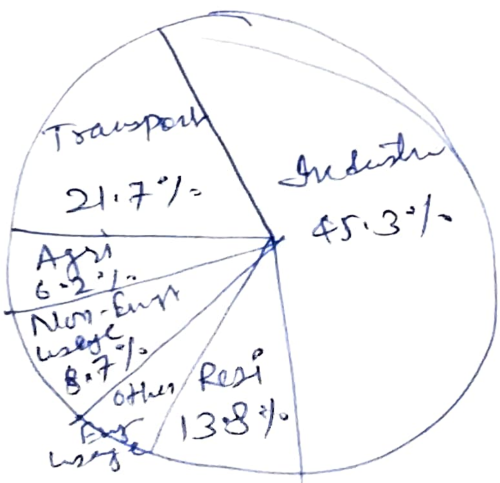
~~Impact of Jets~~ → Energy conservation & storage

Salient Features of Energy conservation act, 2001 →

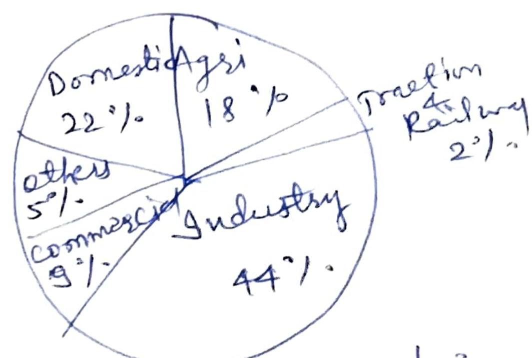
- Establishment of BEE in place of Energy mgmt center (EMC)
- Declaration of a user or a class of users of energy as consumer.
- To lay down min energy consump standards and labelling for identified appliances/equipment & norms for industrial processes for energy intensive industries.
- Formation of energy consumption codes
- Dissemination of information & best practices
- Estb. of energy conserv^n fund both at center & state
- Provision of penalties & adjudication
- ~~The BEE~~

Various aspects of energy conservation → Reduction in energy consumption by red^n in losses & wastage

1. Economic Aspect →
   a) Reduction in cost of product → Energy cost ~~30~~ 36 – 65 % of product cost
   b) New job opportunities →
2. Environment Aspect → Adoption of energy conserv^n means can utilize the damage to environment as less loss of heat will takes place.
3. Conservation of Non-Renewable Energy assets →



Commercial energy balance



Electricity Consumpt^n in various sectors in 2013-14

Energy conservation opportunities →

General Electrical ECO's →

1. Class A : Simple Elec ECO's
2. Class B : Intermediate
3. class C : Comprehensive

Solar Energy

- Sun radiates energy in all drs in the form of electromagnetic waves.
- Output of sun – 2.8×10^{23} kW
  Energy reaching earth – 1.5×10^{18} kWh/year

Sun as source of energy →

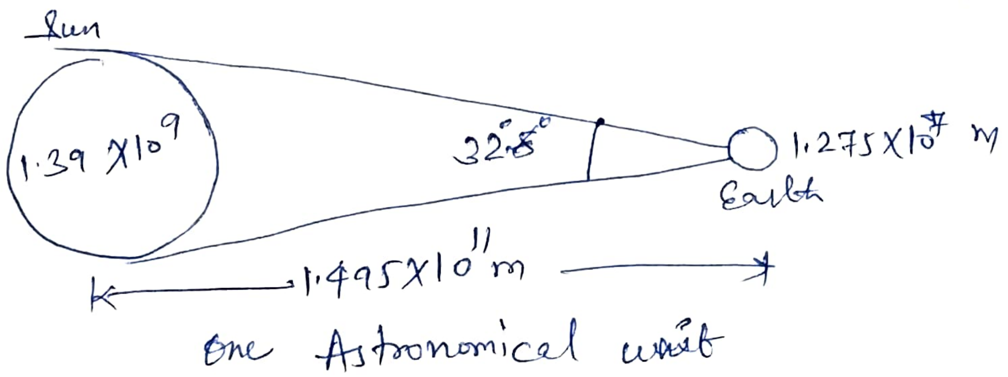
- Sun is a sphere of intensely hot gaseous matter with diameter of 1.39×10^{9} m & is at a distance of 1.495×10^{11} m from earth. Dia of earth is 1.275×10^{7} m or radius is 6378 km.
- At core of sun, tempr is $8 \times 10^{6} - 40 \times 10^{6}$ K. & has a density of
- 100 times of water & pressure of 10^{9} atm.
- Fusion reacn cause the release of so much high energy.

$$4\,({}_{1}H^{1}) \rightarrow {}_{2}He^{4} + 26.7 \text{ MeV}$$

- Surface of sun is maintained at 5800 K.

The Earth →

- It is shaped as an oblate spheroid – a sphere flattened at poles & bulged in plane normal to planes (equator)
- Its axis is inclined at an angle of 23.5°.
- Earth reflects about 30% of radn falling on it. It is known as earth's albedo.



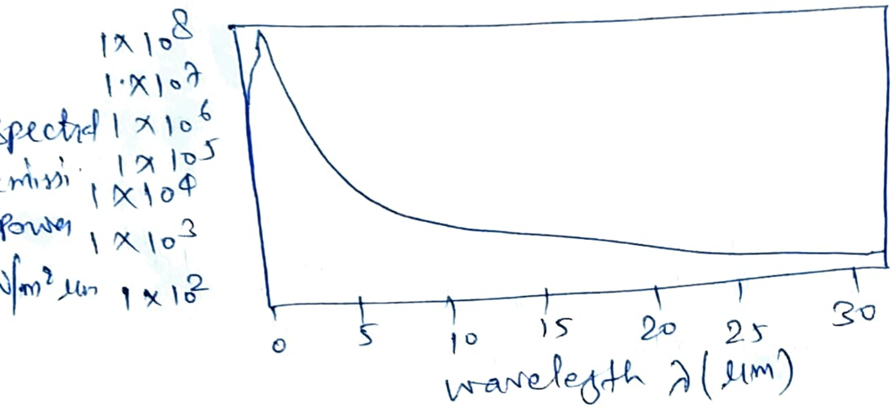
- Dist. b/w earth & sun varies by ±1.7% due to earth's tilt.

Sun, Earth Radiation Spectrum →

Wavelength distn of radn emitted by black body acc. to Planck's law

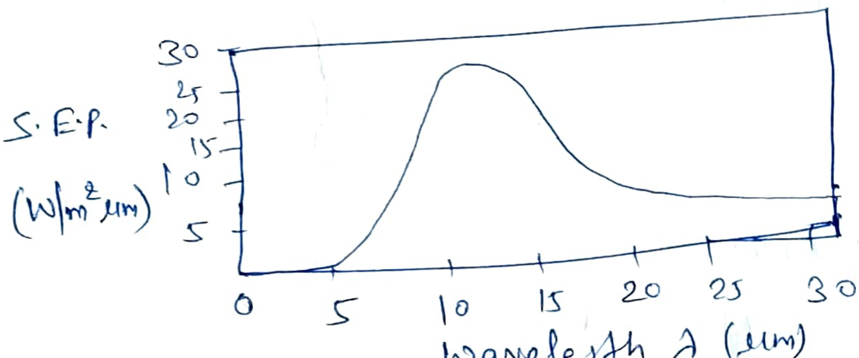
$$W_\lambda = \frac{C_1 \lambda^{-5}}{\exp(C_2/\lambda T)-1} \quad (W/m^2\text{- unit wavelength})$$

$C_1 = 3.74 \times 10^{-16}\ W/m^2$] Planck's 1st & 2nd radn constant
$C_2 = 0.01439\ mK$



at Tempr $T = 5760K$ (surface of sun)

peak is at 0.48 μm



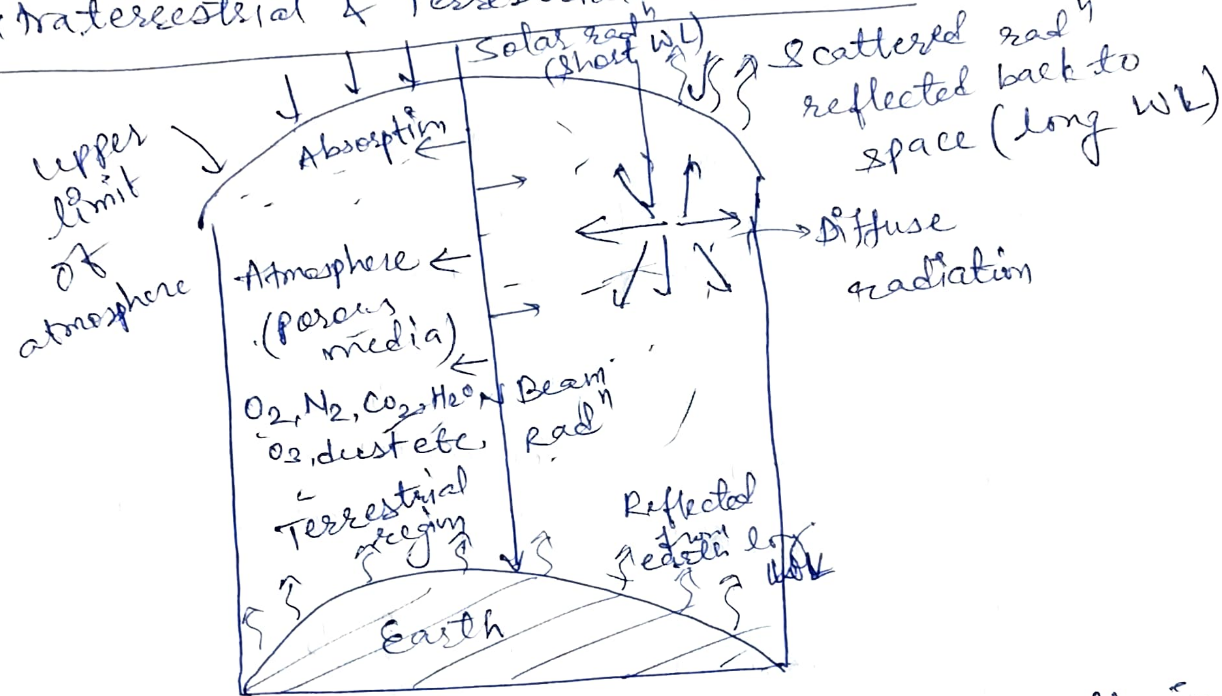
at Tempr $T = 288\ K$ (surface of earth)

peak is at 10 μm

Solar Constant (I_{sc}) → Energy received from sun per unit time, on a unit area of surface ⊥r to ds of propagation of radn, at the earth's mean distance from sun.

• World radn center has adopted a value of 1367 W/m^2.

Extraterrestrial & Terrestrial radiation →



- Solar rad^n incident on outer atm. of earth is extraterrestrial I_{ext}

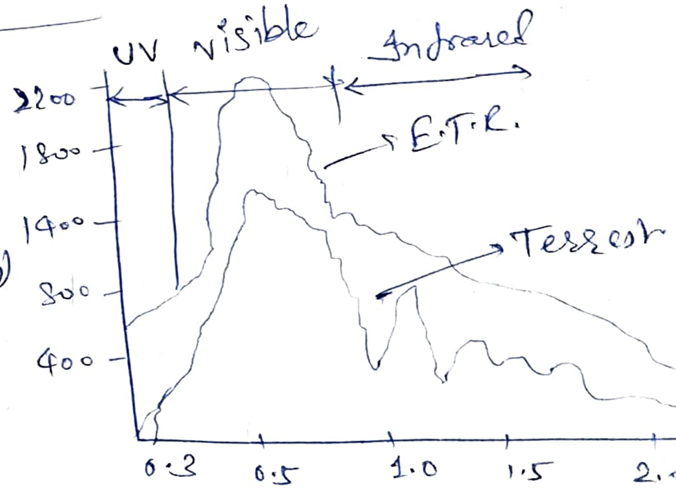
$$I_{ext} = I_{sc}\left[1 + 0.033 \cos\left(\frac{360n}{365}\right)\right] \ W/m^2$$

$n \rightarrow$ No. of day start from Jan 1

- Solar radiation that reaches earth surface after p.t. earth's atmosphere is known as terrestrial radiation.
- Terrestrial rad per unit time per unit area — solar irradiation (W/m^2)
- Solar insolation → solar rad^n energy received ~~for unit~~ a ~~given~~ unit area in given time (J/m^2 or kWh/m^2)

Spectral power distribution of solar rad^n →

- 99% of extraterr. → 0.2–4 µm with max^m at 0.48 µm (Green of visible)
- 6.4% of E.T.R. → ultraviolet ($\lambda < 0.38\,\mu m$)
- 48% of E.T.R. → visible ($0.38 < \lambda < 0.78\,\mu m$)
- 45.6% of E.T.R. → Infrared ($\lambda > 0.78\,\mu m$)
- Complete absorption of ($\lambda < 0.29\,\mu m$ & $\lambda > 2.3\,\mu m$) in atmosphere
- 0.29 – 2.3 µm is significant



Spectral solar irradation

Depletion of solar radiation →

① Absorption →

→ N_2, O_2 & other gases absorb X-rays & extreme UV rays.
→ O_3 absorbs a signifi UV radⁿ ($\lambda < 0.38\ \mu m$)
→ Water vapour & CO_2 absorb IR ($\lambda > 2.3\ \mu m$) & deplete the radⁿ near IR below this range
→ Dust & air absorb a part of solar radⁿ irrespective of wavelgth

② Scattering → by dust particles & air molecules

→ A part is lost (reflected) to space while left is directed towards earth (diffused radiation)
→ It is scattered sunlight that makes the sky blue. without atm, the sky would appear black like on moon.

→ In Cloudy atm → i) Reflection to atm by clouds
ii) absorbed by clouds
iii) transmitted to earth as diffused

→ Reflected to space by → i) Reflection from clouds
ii) scattering by dust particles & air
iii) albedo of earth

→ Components of solar radiation :-
i) Beam or direct radⁿ → str. line & received w/o change in dir i.e. in line with sun
ii) Diffuse radⁿ → radⁿ scattered by dust & air molecules is referred as.
iii) Global or Total → Beam + diffused

→ Air Mass → Ratio of path length through the atmosphere, which the solar beam actually traverses upto ground to the vertical path length (which is minimum) through the atmosp.
→ at sea level, air mass is unity when sun is at zenith.

$$\text{air mass}, m = \frac{\text{Pathlength traversed by beam rad}^n}{\text{vertical path length of atmosphere}}$$

AM0 → No atmosphere (zero)

AM1 → $m = 1$ (sun overhead, $\theta_z = 0$)

AM2 → $m = 2$ ($\theta_z = 60^\circ$)

$m = BA/CA$

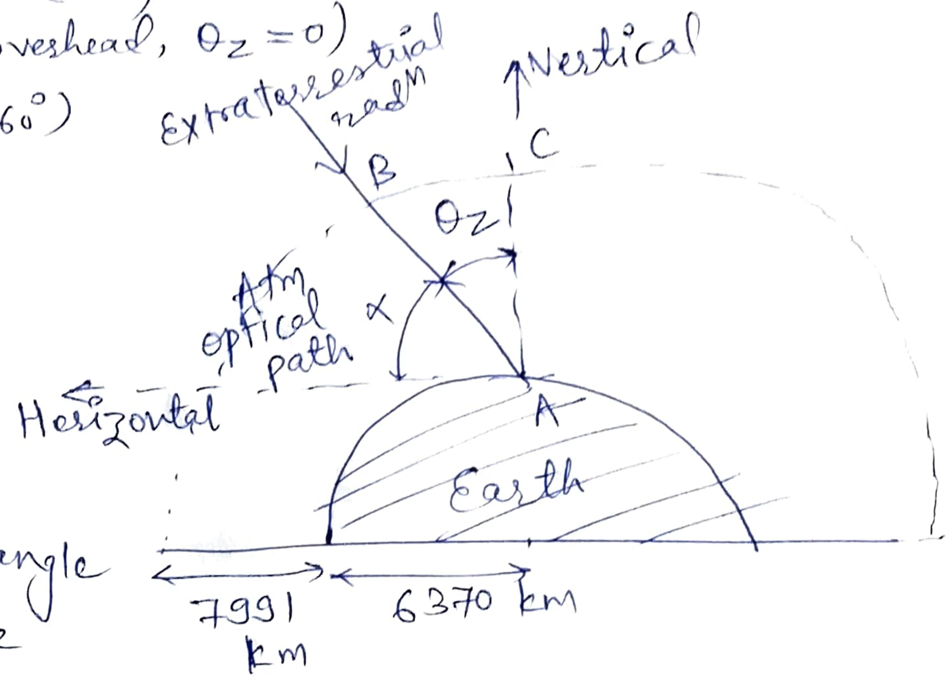
$m = \sec \theta_z$

$\Rightarrow \boxed{m = \operatorname{cosec} \alpha}$

as $\alpha + \theta_z = 90^\circ$

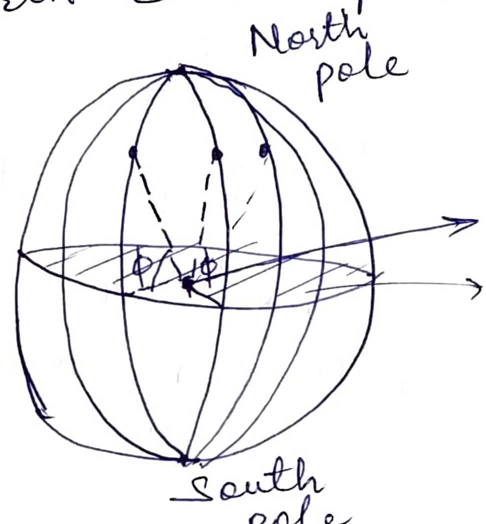
α → Inclination angle

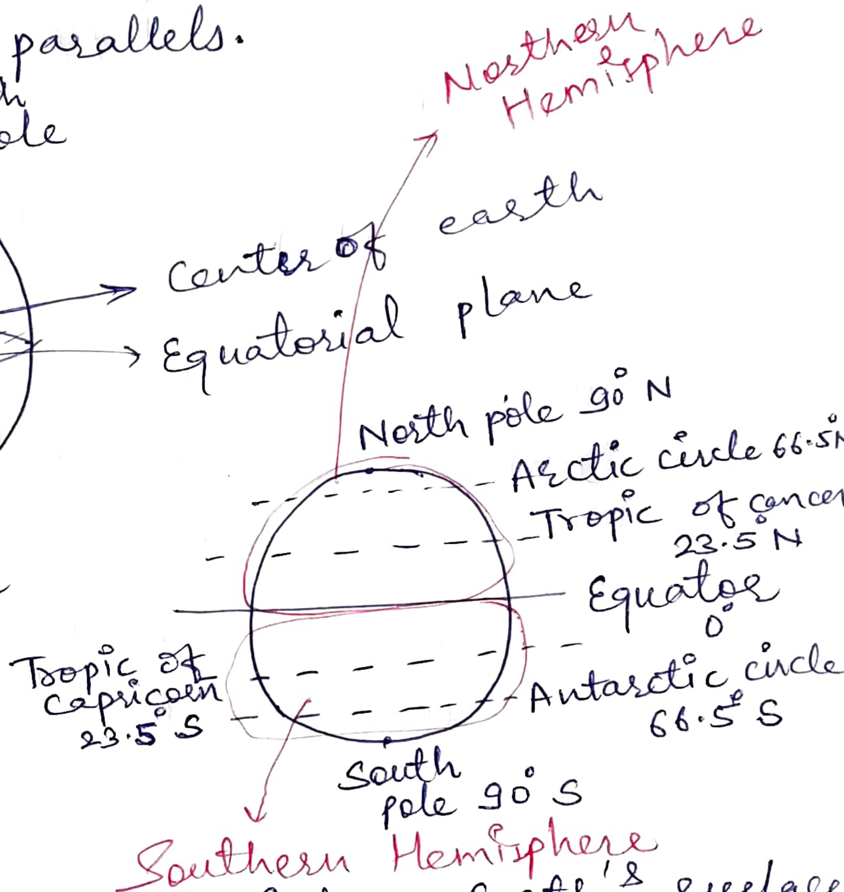
θ_z → Zenith angle



Sun - Earth Geometry

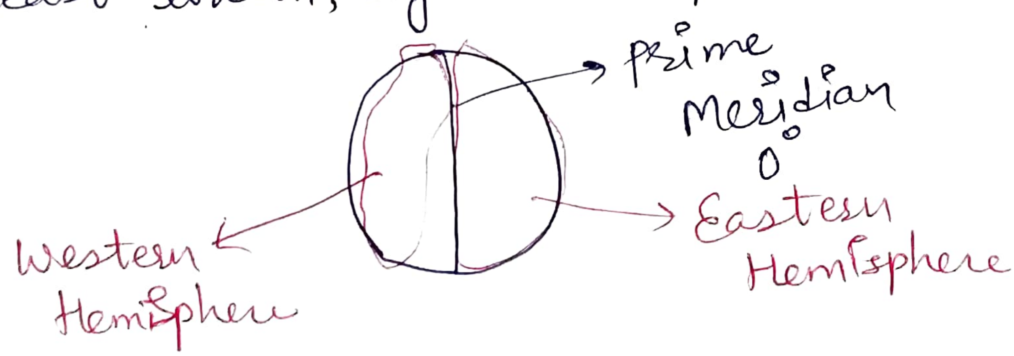
Latitude → It is the angle between the equatorial plane and the straight lines that passes through the point and through the center of earth.
Lines joining pts of same latitude trace circles on surface of earth called parallels.



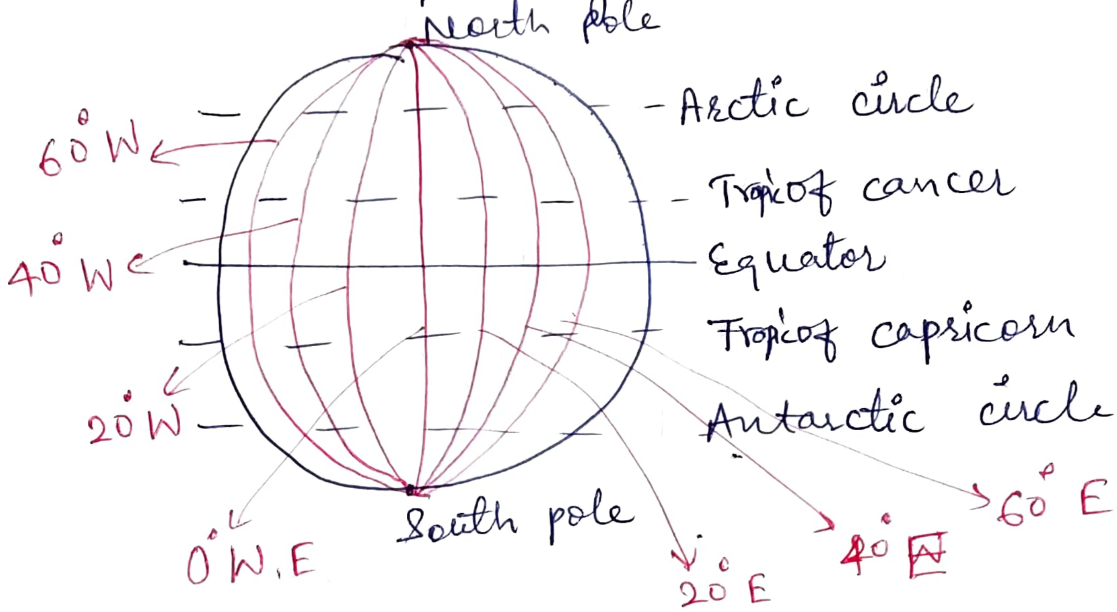


Longitude → The longitudes of a point on Earth's surface is the angle east or west of a reference meridian (prime meridian) to another meridian that passes through that point.

→ The meridian of British Royal observatory in Greenwich in southeast london, England is prime meridian.



→ So, basically latitudes & longitudes are horizontal & vertical lines respectively on earth surface.



→ As we know that ~~sun~~ earth rotates about its own axis in 24 hours, that means it will complete a rotation of 360° in 24 hours.

$$360^\circ = 24 \text{ hours}$$

$$\Rightarrow 360^\circ = 24 \times 60 \text{ minutes}$$

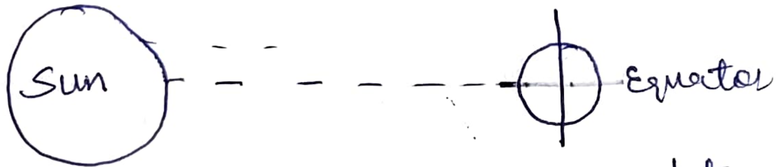
$$\Rightarrow 1^\circ = \frac{24 \times 60}{360} = 4 \text{ minutes}$$

Therefore earth will make 1° rotation in each 4 minutes.

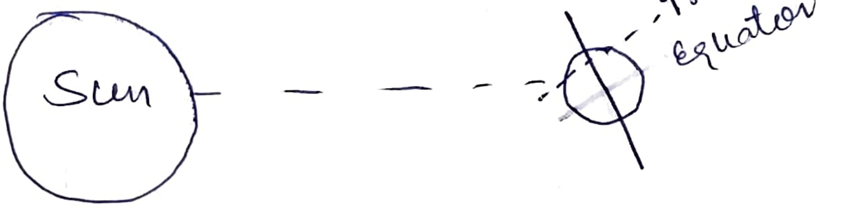
→ Earth rotates about its axis from west to east. An axis is an imaginary lines that runs from North pole to south pole. If you look on earth from north pole, it rotates counter clockwise (anti clockwise).

Seasons in a year → It is present because of tilt of earth with the normal.

21 March →
↓
Spring/Vernal equinox → Equal hours of day & night

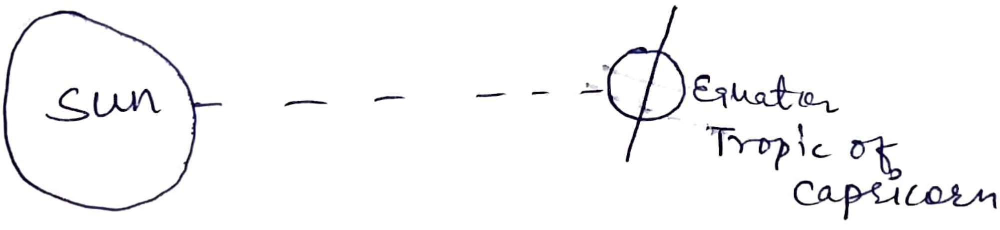


21 June →
↓
Summer Solistice



22 September →
↓
Autumnal equinox → Equal hours of day & night

21 December →
↓
winter Solistice



Introduction of solar energy

- In modern world, energy is primary requirement for human culture. The country in which more energy produce is more developed then other.

- Energy is very important for doing any work. All the energy sources that are being used today can be classified into two groups; renewable and non-renewable. Renewable energy is derived by natural processes and that are resupply carious forms, it derives directly from the sun.

- Energy generated from solar, wind, ocean, tidal, hydropower, biomass, geothermal resources, bio fuels and hydrogen is renewable resources.

- Non-renewable energy is energy sources that cannot resupply in the near future such as coal, oil, petroleum and natural gas. Renewable and non-renewable energy sources can be used to produce secondary energy sources as electricity.

- Every day, the sun radiates (sends out) an enormous amount of energy- called solar energy. It radius more energy in one day than the world use in one year. This energy comes from within the sun itself.

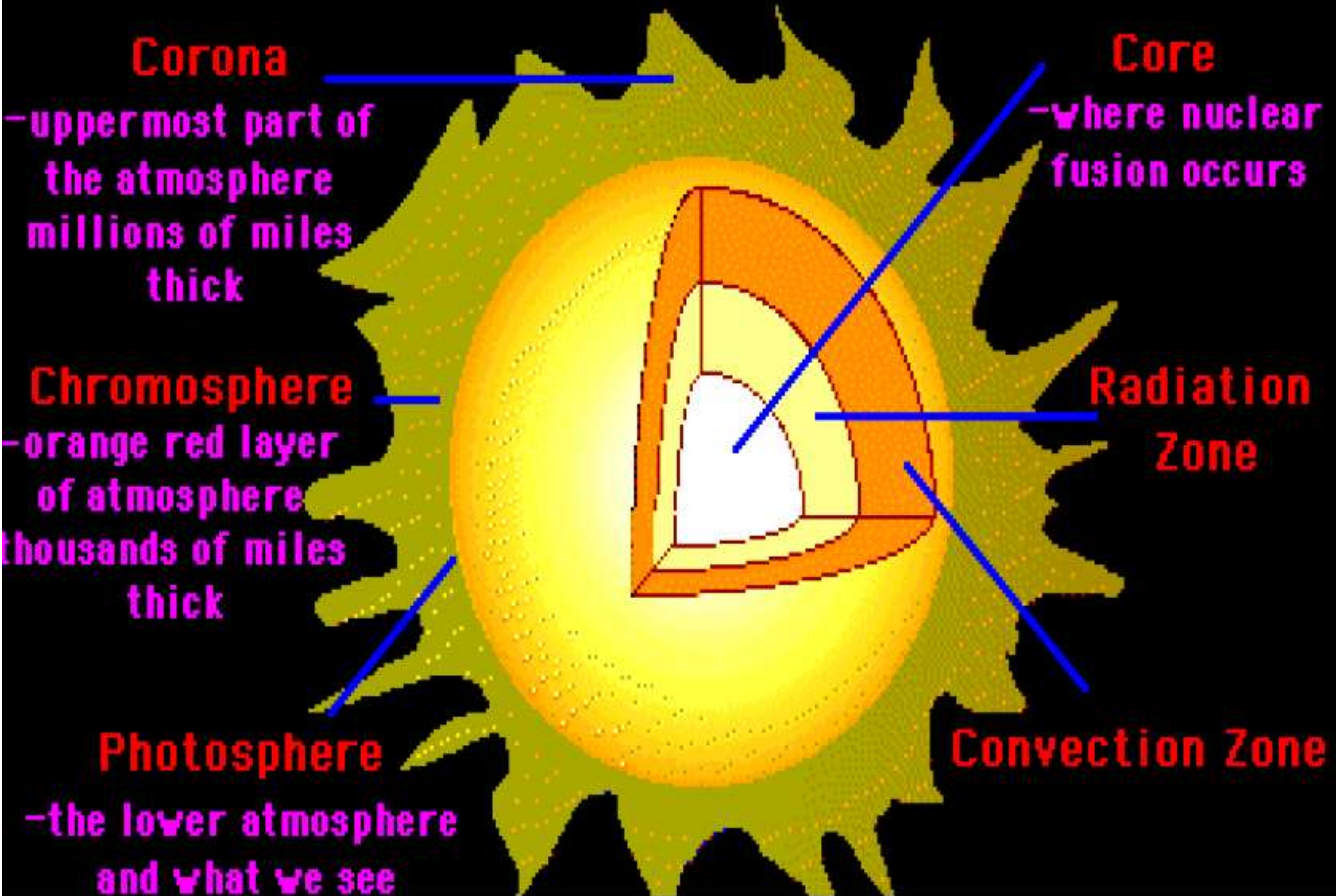
- Like most stars, the sun is big gas ball made up mostly of hydrogen and helium gas. The sun makes energy in its inner core in a process called nuclear fusion. It takes the sun's energy just a little over eight minutes to travel the 93 million miles to earth. Solar energy travels at the speed of light, or 18600 miles per second, or 3.0×10^8 meters per second.

- Only a small part of the visible radiant energy (light) that the sun emits into space ever reaches the earth, but that is more than enough to supply all our energy needs. Every hour enough solar energy reaches the earth to supply our nation's energy needs for a year. Solar energy considered a renewable energy source due to this fact.

- **Largest member** of the solar system
- **Diameter** : 1.39×10^9 m
- An **average distance** of 1.495×10^{11} m from the earth.
- At the innermost region, the **core temperature** is estimated between 8×10^6 to 40×10^6 K. the core has a density of about 100 times that of water and pressure of 10^9 atm.
- The most **abundant element** in sun is **hydrogen**.
- It is an **plasma** state.
- Due to high temperature and pressure , the sun continuously generating heat by thermonuclear fusion reaction (two light nuclei combine and produce a heavier nucleus) which convert hydrogen atoms to helium atoms. The energy released in accordance with following reaction.

$$4\,{}_1H^1 \longrightarrow 2He^4 + 26.7\ \text{Mev}$$

The Structure of the Sun



Solar radiation and solar constant

- All substances solids , liquids and gases at temperature above zero emit energy in form of electromagnetic waves. This energy is called radiation. Radiation is a process by which heat flows from a body at a higher temperature to a body at a lower temperature when the bodies are separated them.
- A perfect radiator (called black body) emits energy from its surface at a rate Q is given by

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

- Where ,

  σ = stefan boltzman constant = $5.67 \times 10^{-8}\ {}^{W}/_{m^2K^4}$

  A = heat transfer surface area of the body , m^2

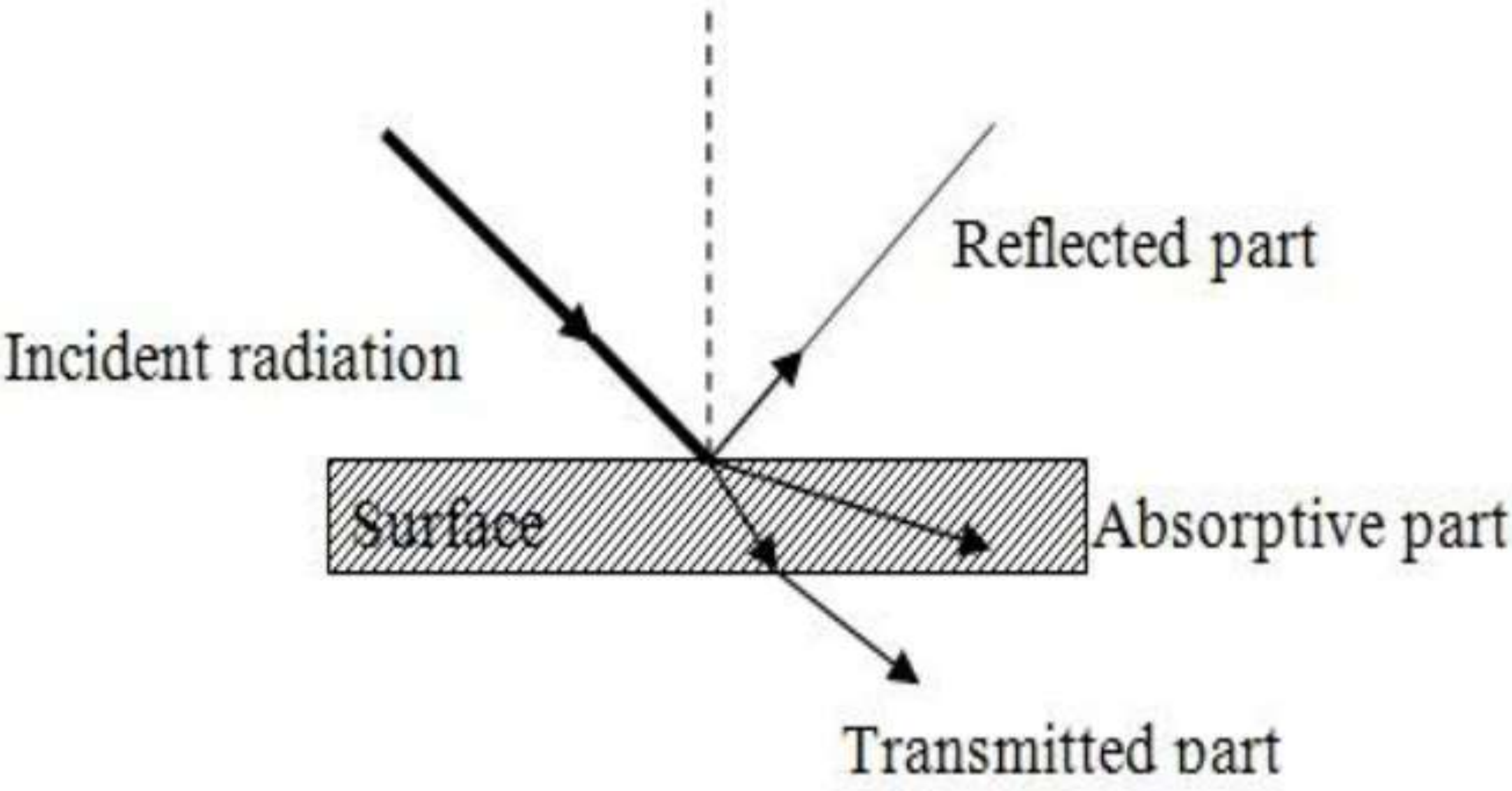
  T = absolute temperature of body , K

- For a real body , $Q = \epsilon\, \sigma A T^4$

$$\epsilon = \frac{Radiation\ emission\ of\ a\ real\ body}{radiation\ emission\ of\ a\ balck\ body}$$

where , ϵ = Emissivity of the surface

Absorptivity , reflectivity and transmissivity



Solar constant (I_{SC})

- **Solar constant (I_{SC}) :** 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.

- a standard value of solar constant is $1353\ {}^{W}/_{m^2}$.

- The earth is closet to the sun in the summer and furthest away in the winter. This variation in distance produces a nearly sinusoidal varation in the intensity of solar radiation I that reaches earth.

- The value on any day can be calculated from the equation ,

$$\frac{I}{I_{SC}} = 1 + 0.33\cos\left[\frac{360n}{365}\right]$$

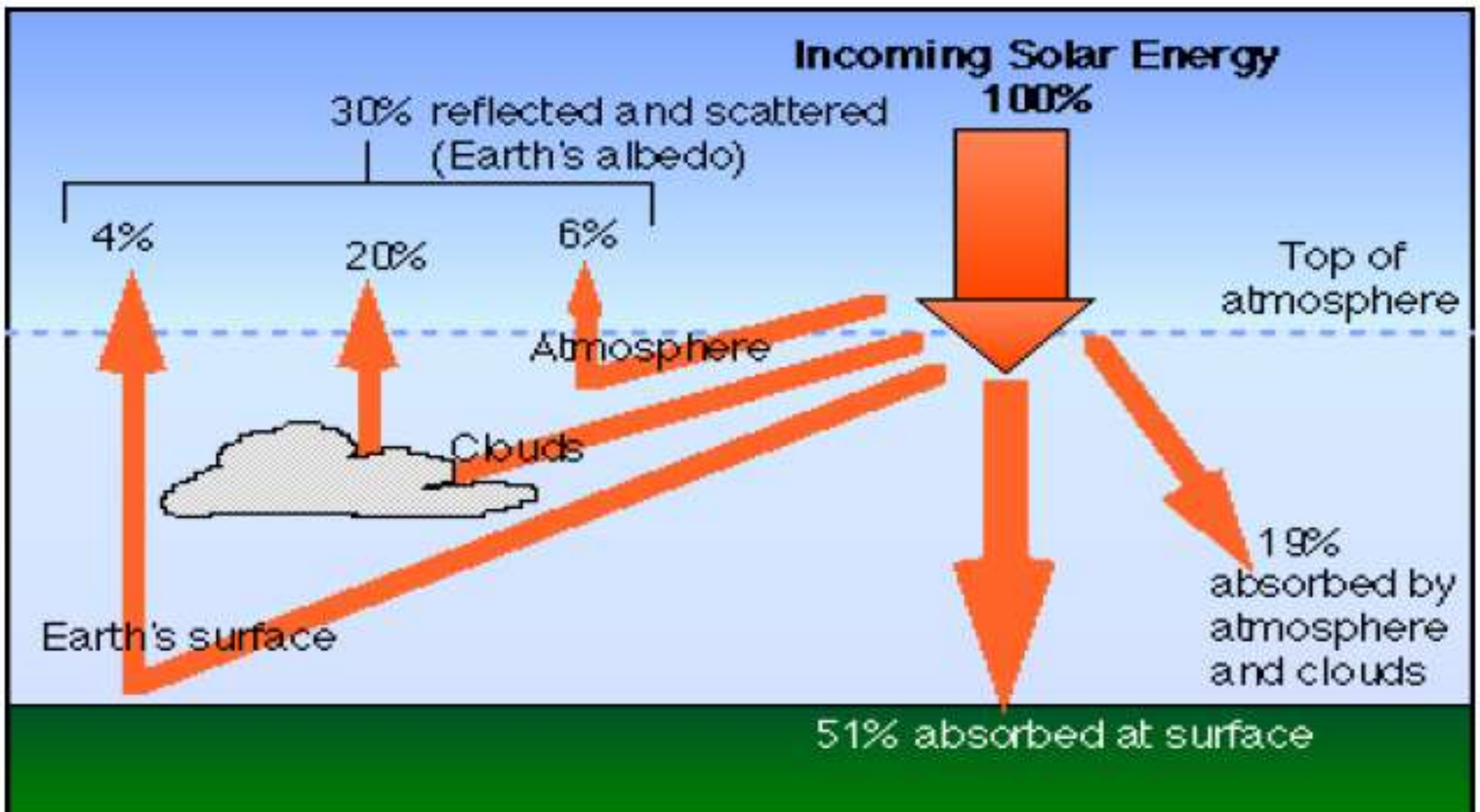
Where, n = the day of year

Extraterrestrial radiation (solar radiation outside the earth's atmosphere)

- Solar radiation incident on the outer atmosphere of earth is known as extraterestrial radiation.
- The extraterestrial radiation available at mean sun-earth distance for zero air mass and 1353 W/m^2 as the solar constant.
- About 99% of the extraterestrial radiation has wavelengths in the range from 0.2 to 4 μm with maximum spectral intensity at 0.48 μm (green portion of visible range).
- About 6.4% of extraterestrial radiation energy is contained in the ultraviolet region ($\lambda > 0.38$), another 48% is contained in the visible region (0.38 μm < λ < 0.78 μm) and the remaining 45.6% is contained in the infrared region ($\lambda > 0.78$).

Solar radiation at the earth's surface (Terrestrial radiation)

- The solar radiation that reaches the earth surface after passing through the earth's atmosphere is known as terrestrial radiation.



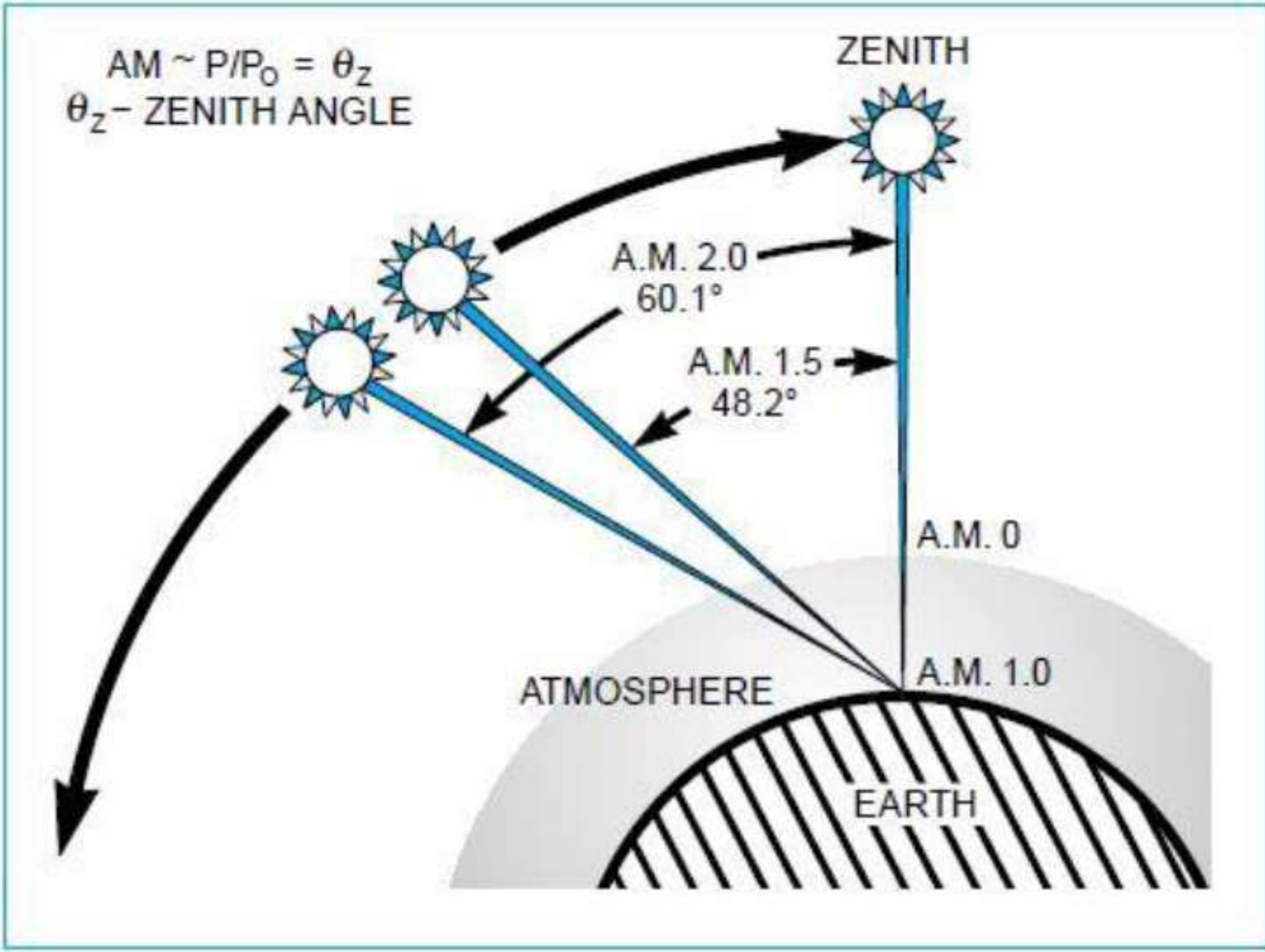
- A selective absorption of various wavelengths occurs different molecules. The absorbed radiation increases the energy of the absorbing molecule and hence rising their temperatures. Ozone absorb an ultraviolet radiation, N_2, O_2 and other atmospheric gases absorb the X-rays and extreme ultraviolet radiations. H_2O and CO_2 absorb almost completely the infrared radiation. Dust particles and air molecules also absorb a part of solar radiation irrespective of wavelength.

- Solar radiation propagation in a straight line and received at the earth surface without change of direction called **direct or beam radiation.**

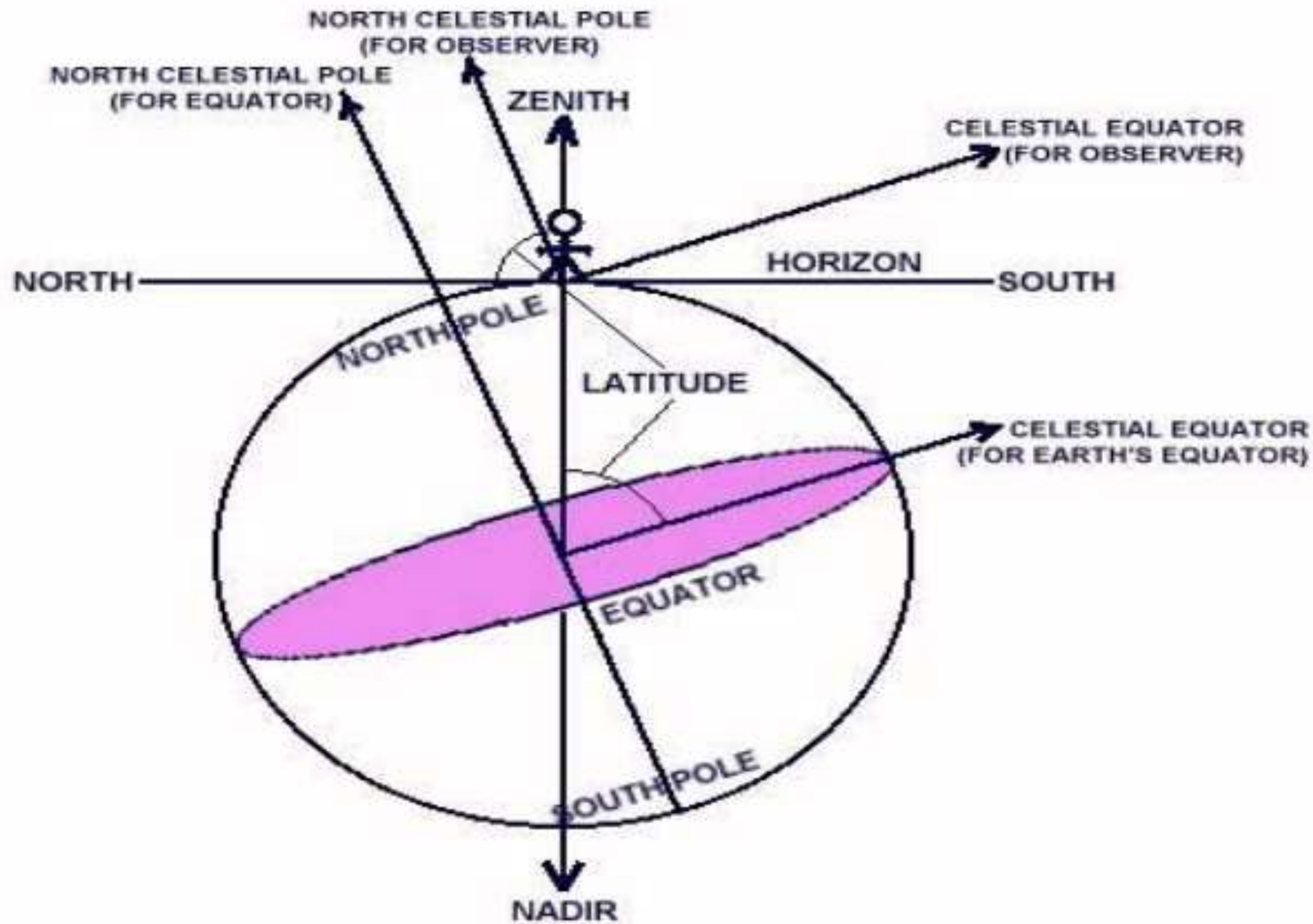
- Solar radiation scattered by dust particle and air molecules (or gaseous particle of different sizes) is lost (reflected back) to space and the remaining is directed down ward to the earth's surface from different direction is called **diffuse radiation.**

- The energy reflected back to the space by reflection from cloud, scattering by the atmospheric gases and dust particle, and by reflection from earth surface is called **albedo** of earth atmospheric system and has a value of about 30% of the incoming solar radiation for the earth as a whole.
- The sum of beam and diffuse radiation is referred to as '**total** or **global radiation (insulation) .**
- The radiation, therefore, available on the earth's surface (terrestrial radiation) is less that what is received outside the earth's atmosphere (extraterrestrial radiation).
- This reduction in intensity depends on atmospheric condition and distance travelled by beam radiation through the atmosphere before it reaches a location on the earth's surface.
- A term called **air mass(m)** is often used as a measure of the distance travelled by beam radiation through the atmosphere before it reaches a location on the earth's surface.

$$air\ mass, m = \frac{path\ length\ traversed\ by\ beam\ radiation}{vertical\ path\ lenth\ of\ atmosphere}$$


AM ~ P/P$_O$ = θ_Z
θ_Z – ZENITH ANGLE
ZENITH
A.M. 2.0
60.1°
A.M. 1.5
48.2°
A.M. 0
A.M. 1.0
ATMOSPHERE
EARTH

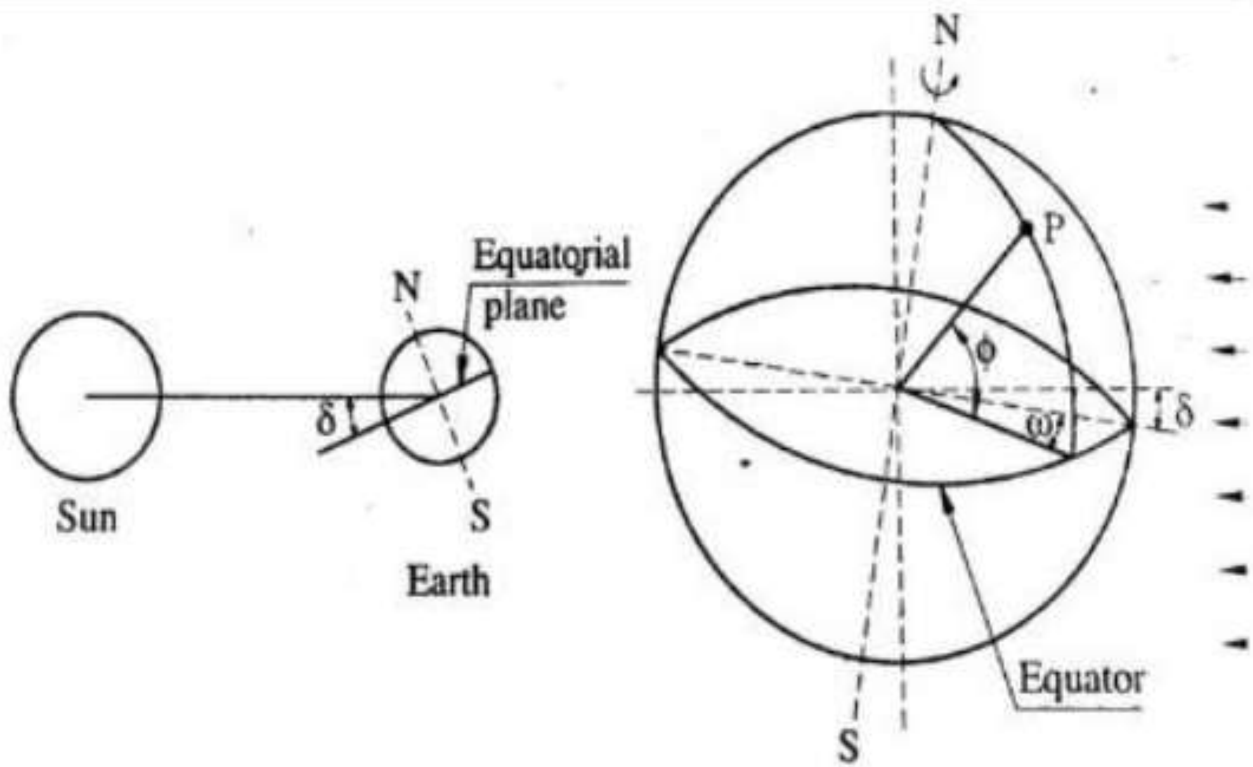
Solar geometry (basic terms)



Celestial sphere: During the clear night, in the sky, the stars, planets, moon etc. are all located the same distance away from the observer. The sky may conveniently be assumed be a large sphere. This imaginary transparent sphere surrounding the earth is called the celestial sphere.

- **Zenith**: it is a point on the celestial sphere over the observer's head.
- **Nadir**: It is a point on the celestial sphere diametrically opposite to the zenith.
- **Visible horizon:** It appears to an observer that the celestial sphere meets the ground, the location of this apparent meeting is called the visible horizon.
- **Astronomical horizon:** It is circle on celestial sphere, the plane of which passes through the central of the earth normal to the line joining the centre of the earth and the zenith.
- **Poles of earth:** The points mark on the earth surface at and of the axis of rotation of the earth are called poles of the earth, one as North, while the other as a South.
- **Earth's equator:** The earth's equator is an great circle normal to the earth's axis, dividing the distance between earth's poles along its surface into two equal parts.
- **Meridian:** An imaginary great circle passing through reference point (Royal observatory Greenwich, outside the London) and the two poles, intersecting the equator at right angle, is called the prime (or Greenwich) meridian.
- **Longitude:** It is the angular distance of the location, measured east or west from the prime meridian.

Basic earth-sun angles



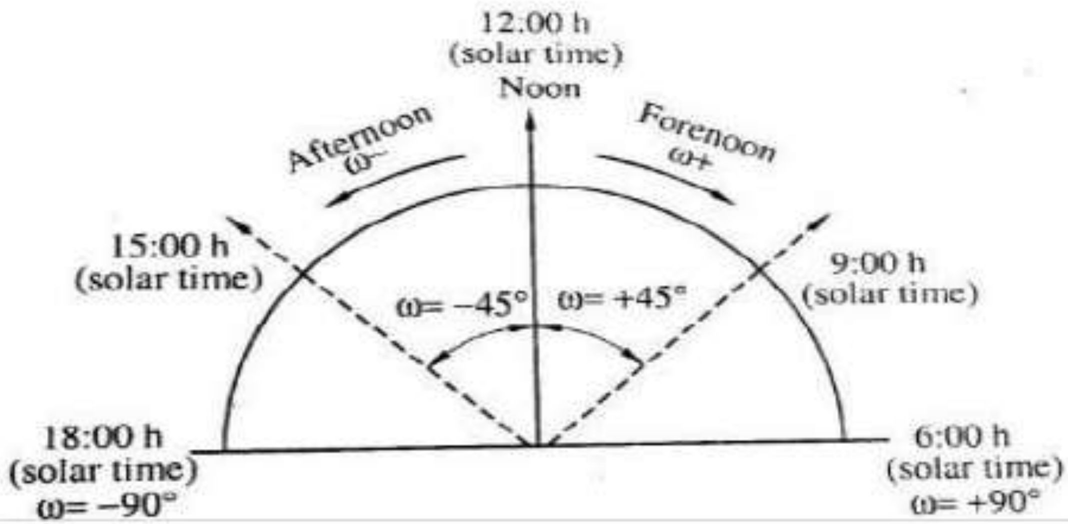
Angle of latitude(Φ): It is the vertical angle between the lining joining that point of location to the centre of the earth and its projection on an equatorial plane. When the point is north of equator the angle is positive and when south is negative.

- **Declination angle (δ)** : it is the angle between a line extending from the centre of the sun to the centre of the earth, and the projection of this line upon the earth's equatorial plane.
- It is positive when measured above the equatorial plane in the northern hemisphere.

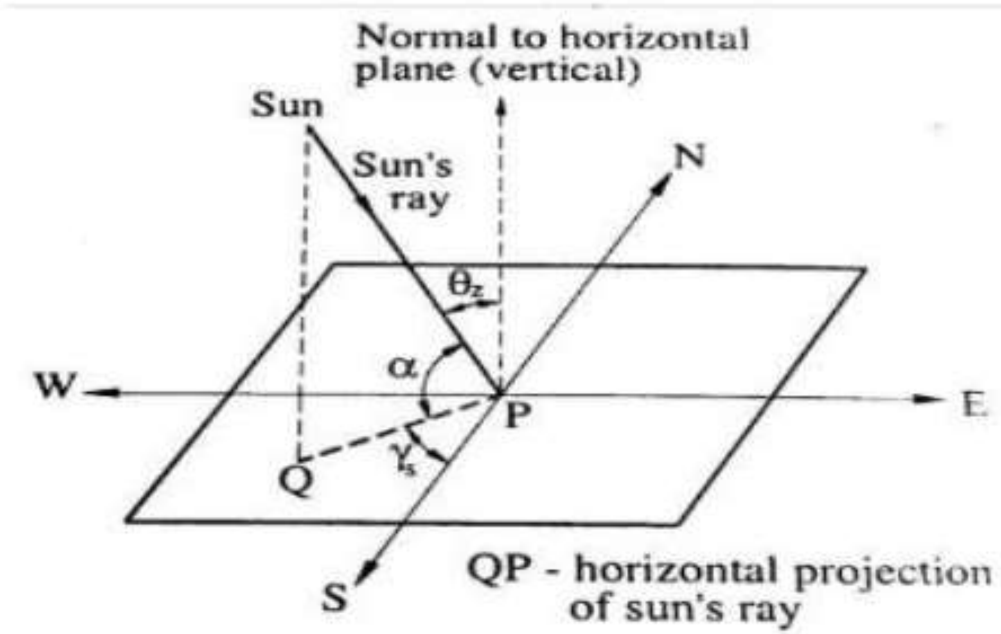
$$\delta = 23.45 \sin\left[\frac{360(284+n)}{365}\right]$$

- **Hour angle(ω) :** 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.

$$\text{Hour angle}(\omega) = \pm[\,12{:}00 - \textit{solar time}\,]\ (\text{in hours}) \times 15^0$$



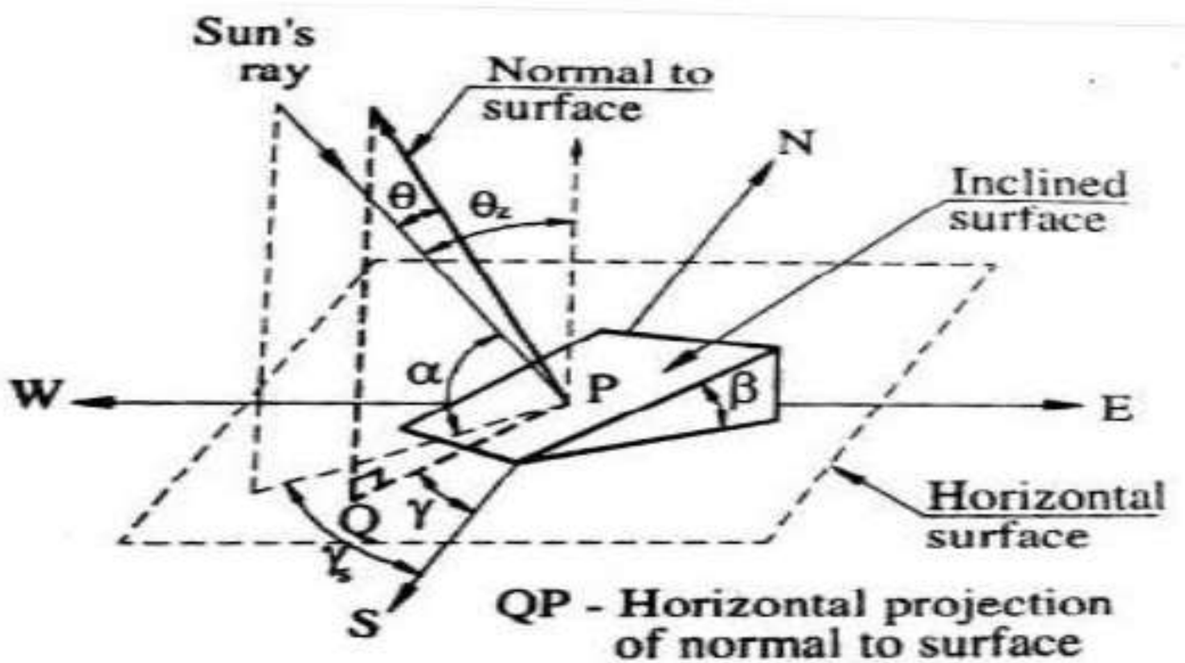
- **Inclination angle (altitude),α** :The angle between the sun's ray and its projection on a horizontal surface is known as the inclination angle as shown in figure. It could be seen that the sunrise and at sunset the angle α is zero.

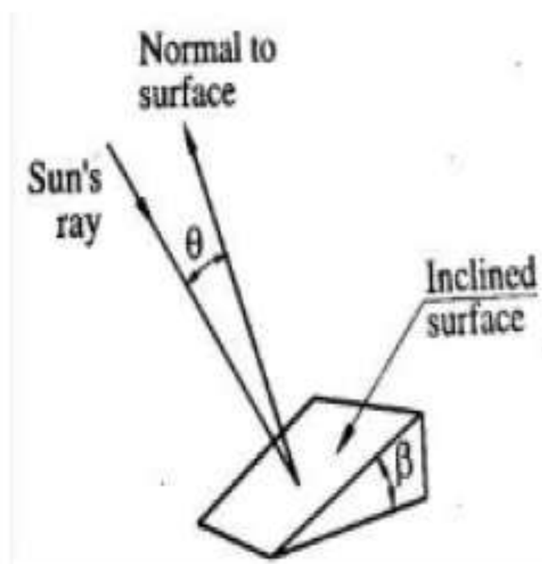


- **Zenith angle(θ_z)** : It is the angle between the sun's ray and the perpendicular (normal) to the horizontal plane as shown in figure. The Zenith angle is the compliment of altitude angle, i.e. $\alpha + \theta_z = 90^0$. Hence at sunrise and sunset the zenith angle $\pm 90^0$. The positive value is for sunrise and negative value for sunset.

- **Solar azimuth angle(Υ_s)** : It is the angle on a horizontal planes, between the line due south and the projection of the sun's ray on the horizontal planes. It is considered a positive when it measured from south toward west as shown in figure.

- **Surface azimuth angle(γ) :** 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. It is considered as positive when it is measured from south toward west as shown in figure.
- **Tilt angle or slop(β) :** It is angle between the inclined plane surface and the horizontal plane. It is considered positive for the surface sloping towards south as shown in figure.
- **Angle of incidence(θ) :** It is an angle between sun's ray incident on plane surface and normal to that surface as shown in figure.





Relationship between angle of incidence (θ), declination (δ), surface azimuth angle (γ), slope (β), angle of latitude (Φ), and hour angle (ω)

$$\cos\theta = \sin\Phi\,(\sin\delta.\cos\beta + \cos\delta.\cos\gamma.\cos\omega.\cos\beta) + \cos\Phi(\cos\delta.\cos\beta.\cos\omega - \sin\delta.\cos\gamma.\sin\beta) + \cos\delta.\sin\gamma.\sin\omega.\sin\beta$$

- If inclined surface is facing due south, $\gamma = 0$

$$\cos\theta = \cos\delta.\cos\omega.\cos(\Phi-\beta) + \sin\delta.\sin(\Phi-\beta)$$

- As also noon ω being zero

$$\cos\theta = \cos\delta.\cos(\Phi-\beta) + \sin\delta.\sin(\Phi-\beta) \text{ at solar noon}$$

- If the surface is horizontal and facing due south, $\beta=0$, $\theta=\theta_z$ and $\gamma=0$

$$\cos\theta = \cos\theta_z = \cos\delta.\cos\omega.\cos\Phi + \sin\delta.\sin\Phi$$

- If the surface is vertical and facing due south, $\beta=90^0$ and $\gamma=0$

$$\cos\theta = \cos\delta.\cos\omega.\cos\Phi + \sin\delta.\sin\Phi$$

Sunrise , sunset and day length

- Sunrise hour , sunset hour and day length depend upon latitude of the location season and day in the year.
- As the angle of latitude increases (from equator to north pole) the difference in day length between summer and winter becomes more and more prominent.

➢ **For horizontal surface and facing due south :**

$$\cos\theta = \cos\delta.\cos\omega.\cos\Phi + \sin\delta.\sin\Phi$$

- At sunrise or sunset , $\theta = 90^0$
- The Hour angle(ω) at sunrise or sunset for horizontal surfaces is determined by below equation ,

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

+ for sunset

- for sunrise

➢ Day length given by ,

$$\text{Day length} = \left(\frac{2}{15}\cos^{-1}[-\tan\Phi.\tan\delta]\right)\ \text{hour}$$

- **For inclined surface due south:**

$$\cos\theta = \cos\delta.\cos\omega.\cos(\Phi-\beta) + \sin\delta.\sin(\Phi-\beta)$$

- At sunrise or sunset , $\theta = 90^0$

$$\text{Hour angle}(\omega) = \cos^{-1}[-\tan(\Phi - \beta).\tan\delta\,]$$

- **Hence , ω for an inclined surface facing south ($\Upsilon = 0^0$) is given by**

$$\omega = \text{minimum of } \{\cos^{-1}[-\tan\Phi.\tan\delta\,]\,,\ \cos^{-1}[-\tan(\Phi - \beta).\tan\delta\,]\}$$

Solar time

- Greenwich meridian (Zero longitude) is taken as reference for time reckoned from mid night is known as universal time or Greenwich civil time (GCT or GMT). This time is expressed on an hour scale from 0 hour to 24 hours.
- All the values of time in solar energy computational are represented by apparent solar time. It also known as **local solar time (LST)** or **local apparent time (LAT).**
- Local Apparent Time (LAT)

  = [local civil time] + [Equation of time or Time correction]
- But , Local Civil Time (LCT)

  = [Standard clock time] ± [(Standard Longitude for clock time) – (Longitude of location)]

$$\mathbf{LCT = IST \pm [(L_{st} - L_{local}) \times 4]}$$

$$LST \text{ or } LAT = IST \pm [(L_{st} - L_{local}) \times 4] + E$$

$$E = 229.18(0.000075 + 0.001868 \cos B - 0.032077 \sin B - 0.014615 \cos 2B - 0.04089 \sin 2B)$$

Where ,$B = \frac{(n-1)360}{365}$ and n is say of the year.

Where, E = Equation of time correction in minutes

L_{st} = Standard meridian for local time zone

L_{local}) = Longitude of the location in degree West or East

+ sign for Western hemisphere

-sign for Eastern hemisphere

Solar radiation measurements

- Three types of instruments are generally used to measure three different aspects of solar radiation as follow :

- **To measure global or diffuse radiation:** A **Pyranometer** is designed to measure global radiation, usually on a horizontal surface, but can also be used on an inclined surface. Pyranometer also measure diffused radiation by using a shading ring.

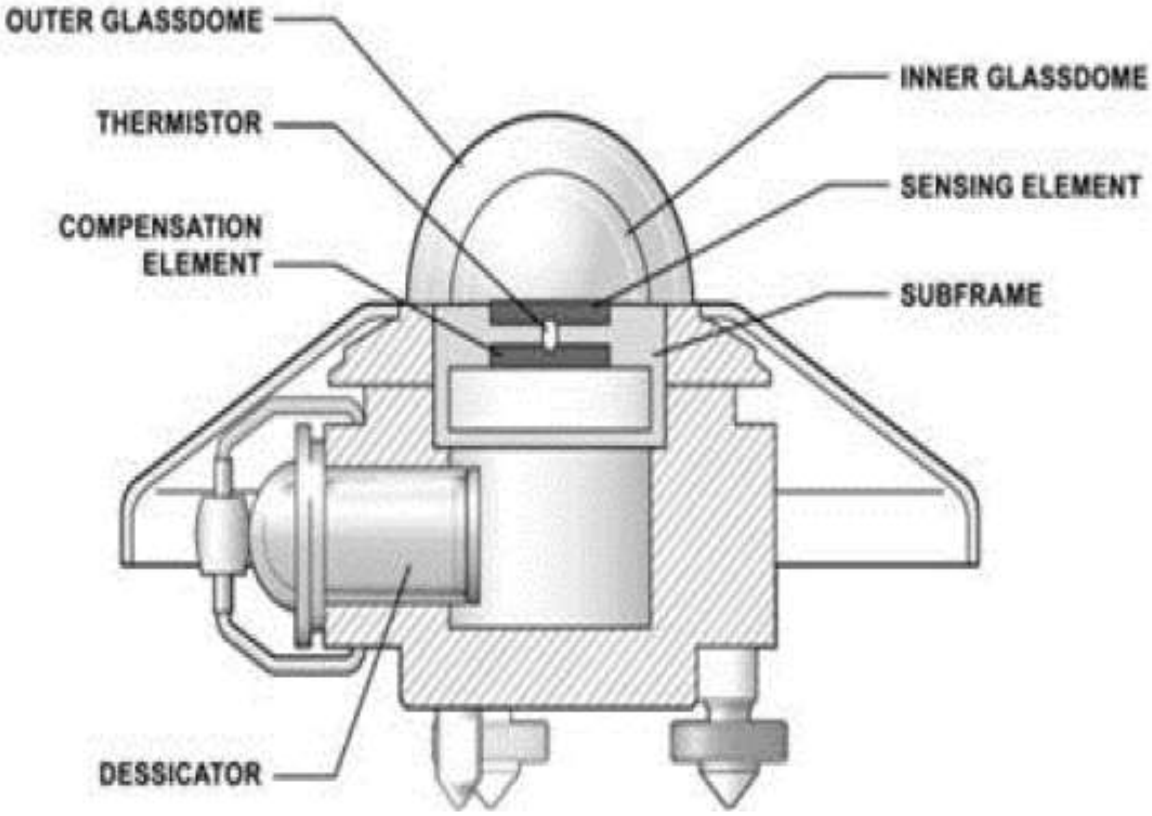
- **To measure beam or direct radiation:** A **pyrheliometer** is used to measure beam radiation by using a long narrow tube to collect only beam radiation from the sun at normal incidence.

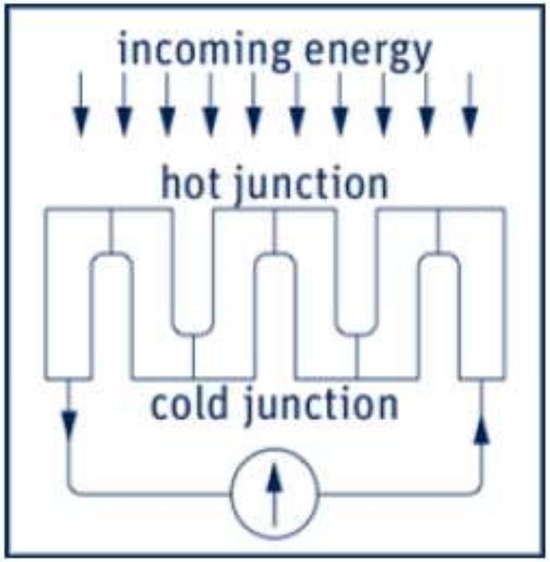
- **To measure sunshine hours in a day:** A **sunshine recorder** is used to measure the duration in hours or bright sunshine during the course of the day.

- **To measure terrestrial radiation:** A **pyregeometry** is used to measure terrestrial radiation.

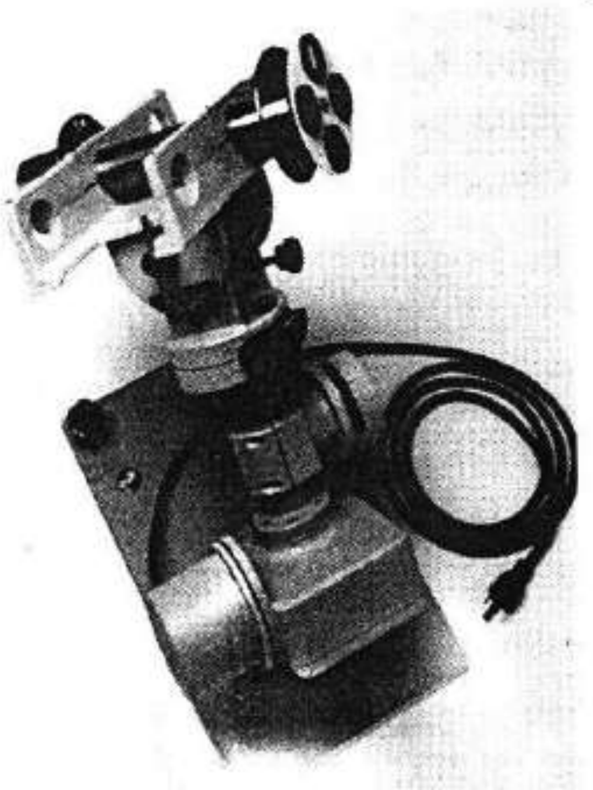
- **To measure both solar and terrestrial radiation:** A **pyradiometer** is used to measure both solar and terrestrial radiation.

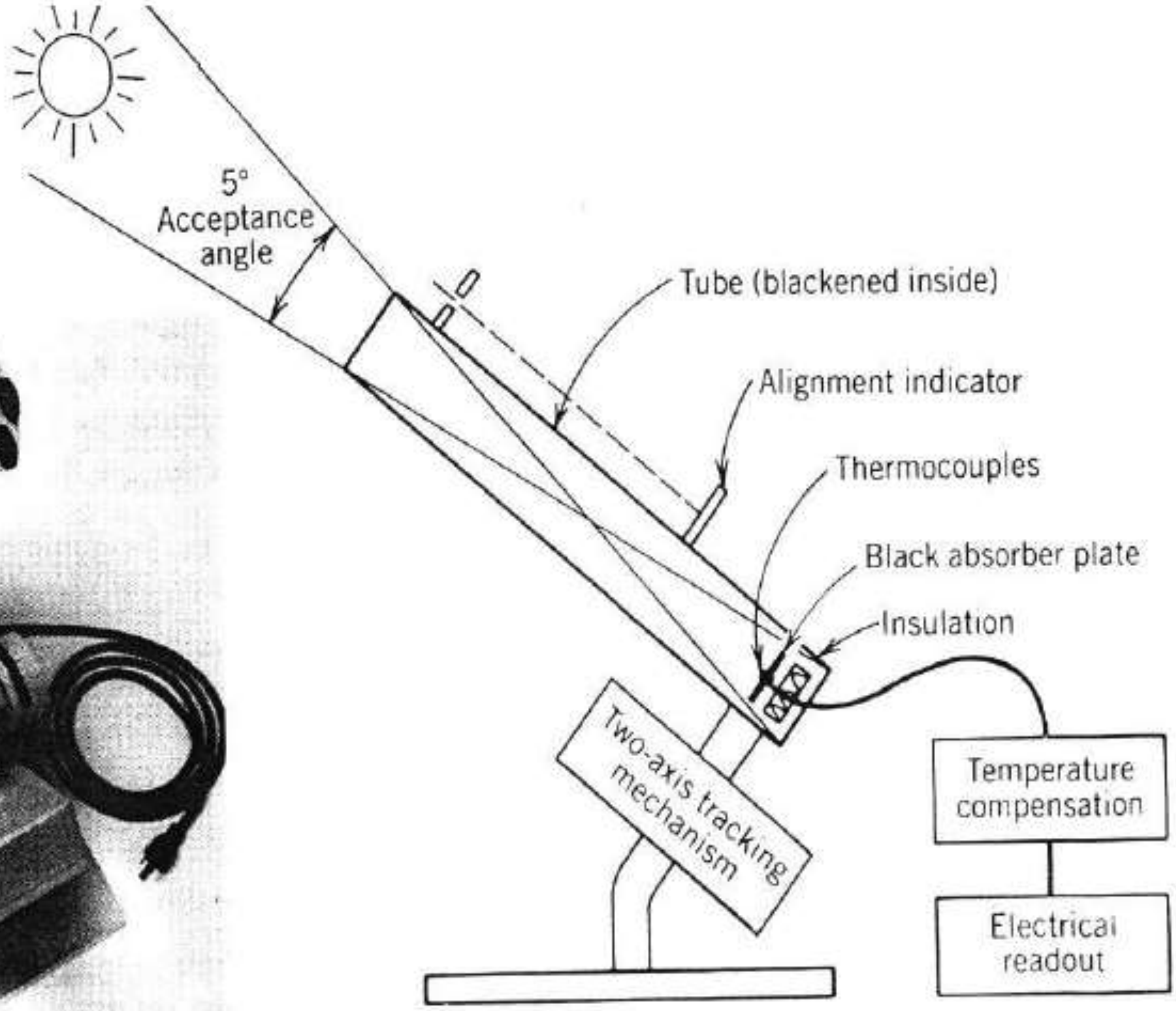
Pyranometer





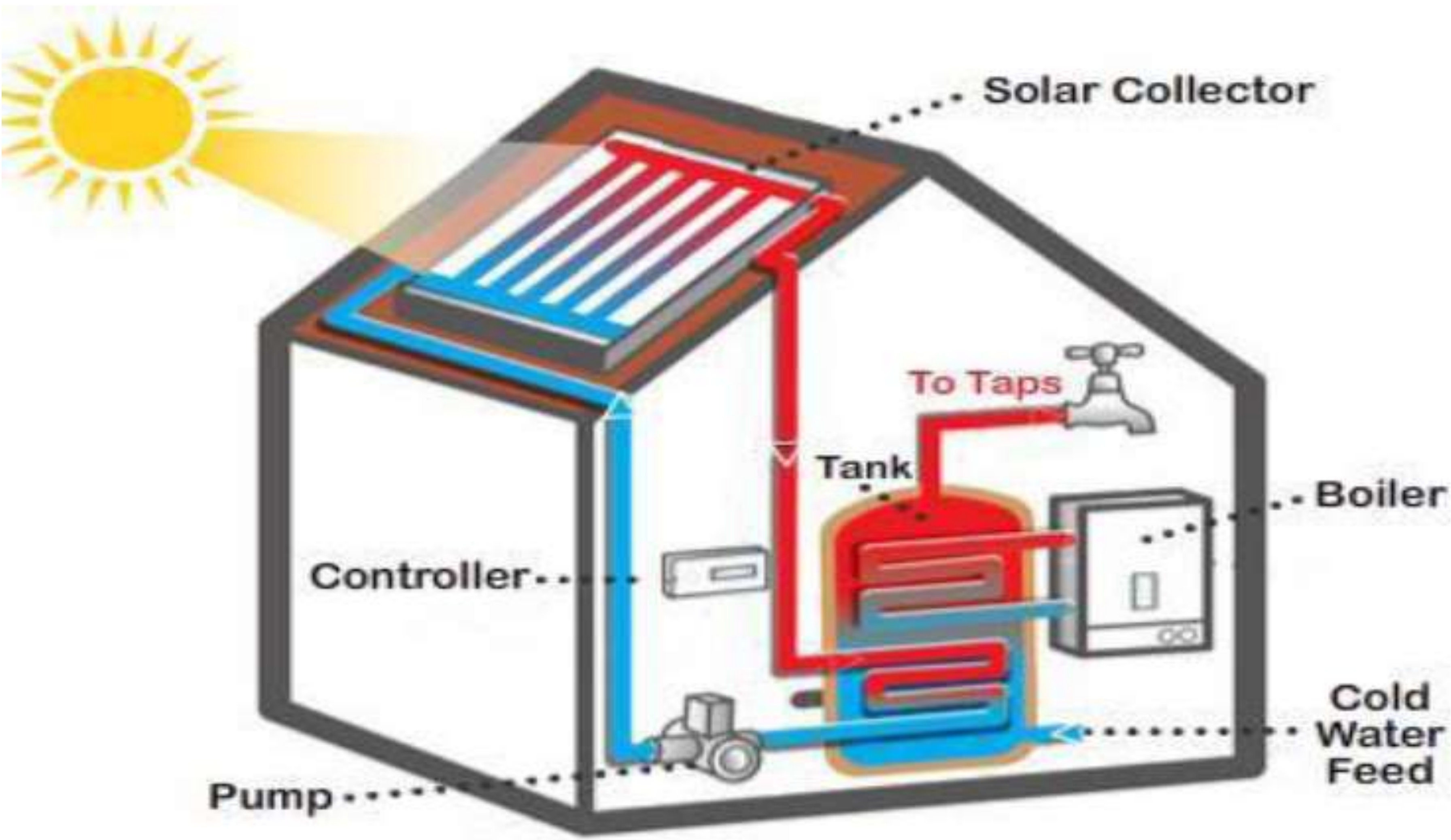
pyrheliometer





Sunshine recorder

Solar thermal system



SOLAR ENERGY COLLECTORS

- Low density per unit area (1kW/m2 – 0.1kW/m2)
- Collected by covering large area
- Solar energy as heat
- Transfer to heat transport fluid
- Thermal storage tank/boiler/heat exchanger

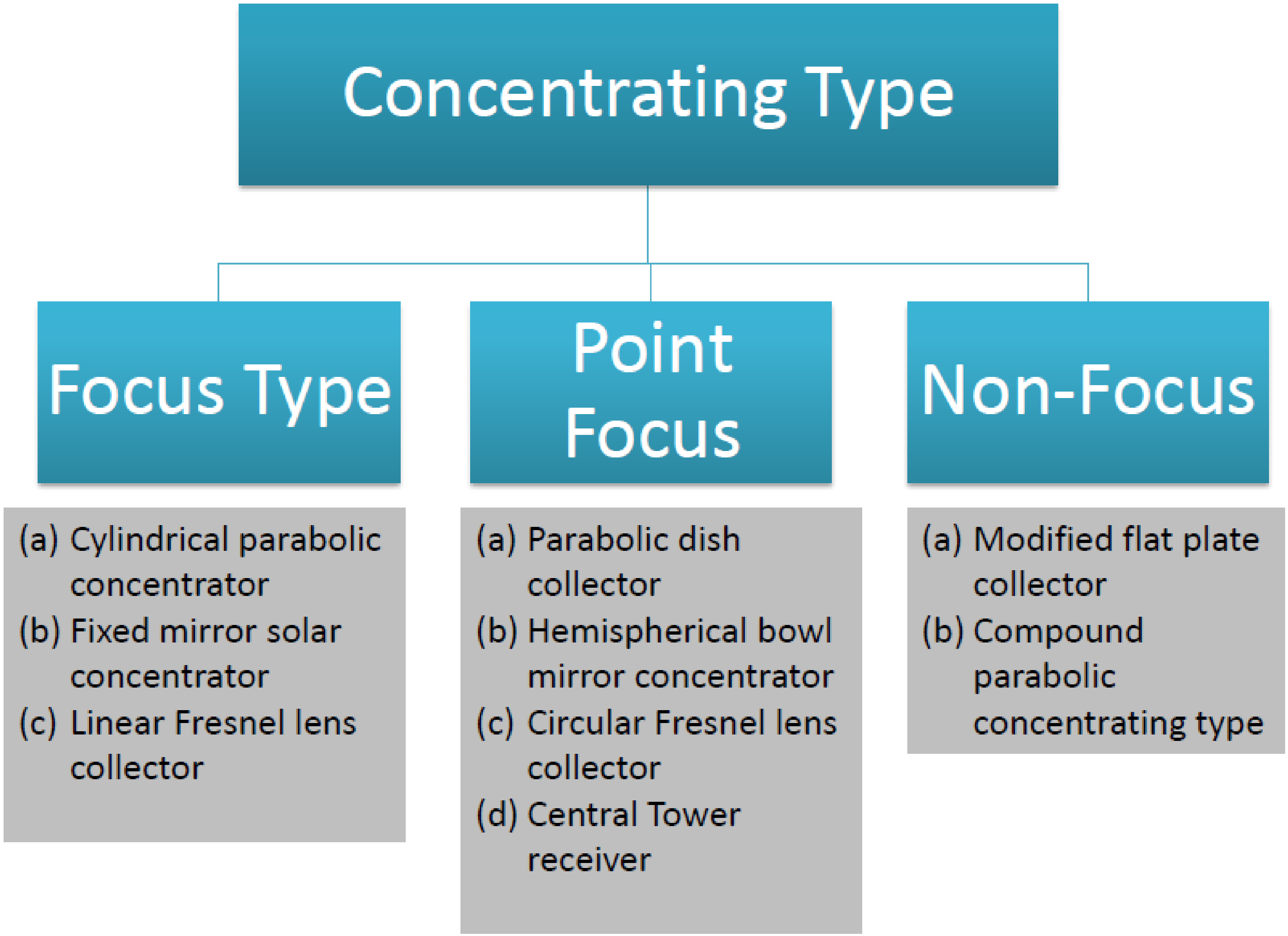
Classifications

Solar Collectors

- Non – concentrating type
- Concentrating type

(a) Liquid flat-plate collector

(b) Flat-plate air-heating collector


Concentrating Type
Focus Type
Point Focus
Non-Focus
(a) Cylindrical parabolic concentrator
(b) Fixed mirror solar concentrator
(c) Linear Fresnel lens collector
(a) Parabolic dish collector
(b) Hemispherical bowl mirror concentrator
(c) Circular Fresnel lens collector
(d) Central Tower receiver
(a) Modified flat plate collector
(b) Compound parabolic concentrating type

Performance Indices

- Collector efficiency: Ratio of the energy actually absorbed and transferred to the heat-transport fluid by the collector (useful energy) to the energy incident on the collector.
- Concentration ratio: ratio of the area of aperture of the system to the area of the receiver. Aperture of the system is the projected area of the collector facing the beam.
- Temperature range: range of temperature to which the heat-transport fluid is heated up by the collector.

Non-concentrating type

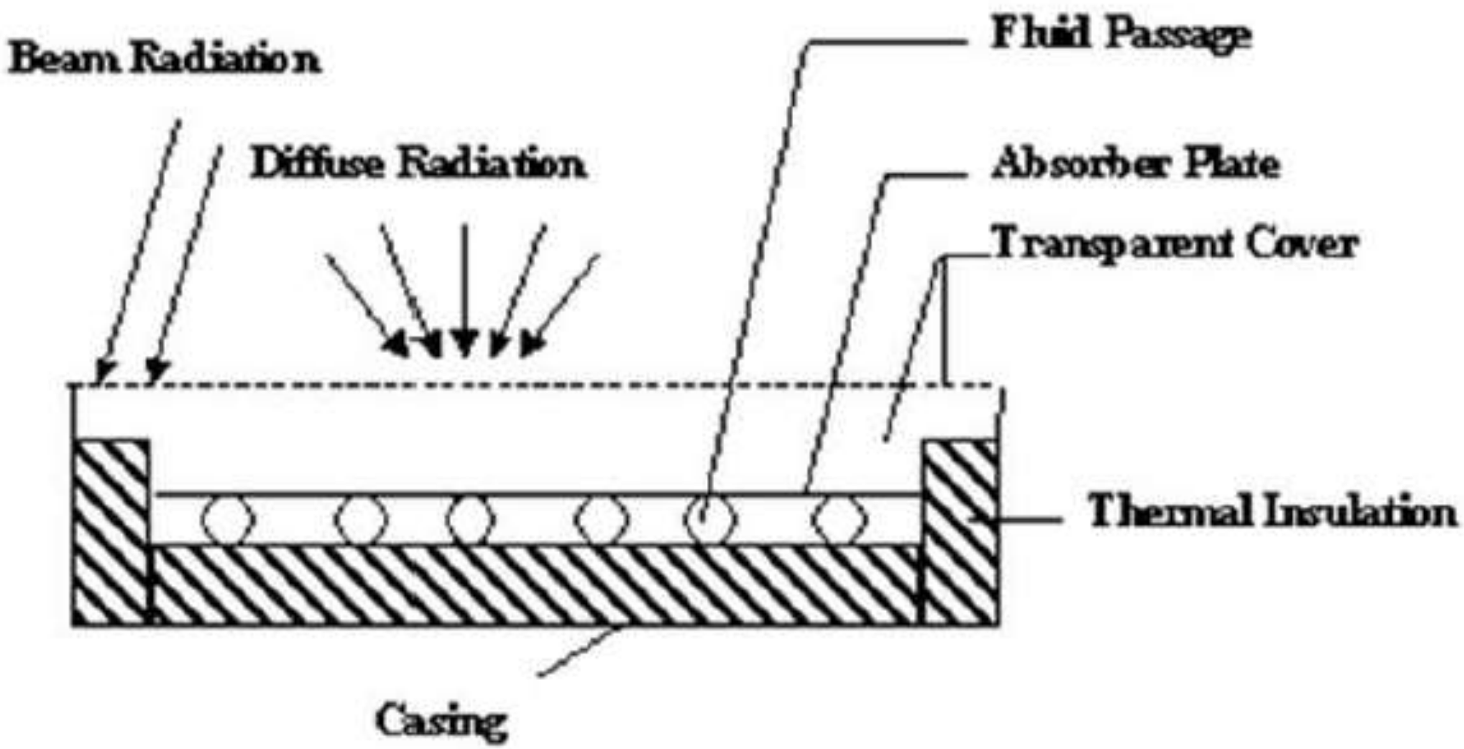
- Absorb radiation received on surface
- Both beam &diffused radiation
- No optical concentration method
- No need of solar tracking
- Simple and compact construction
- Fixed on rigid platform- maintanenence free
- High temp cannot be achieved

Concentrating type

- Converging solar radiation from large area to small area
- Beam radiation utilized
- Optical methods(reflection,refraction)
- Solar tracking required
- Diffused radiation cannot be concentrated
- High temp attained.
- Flexible construction

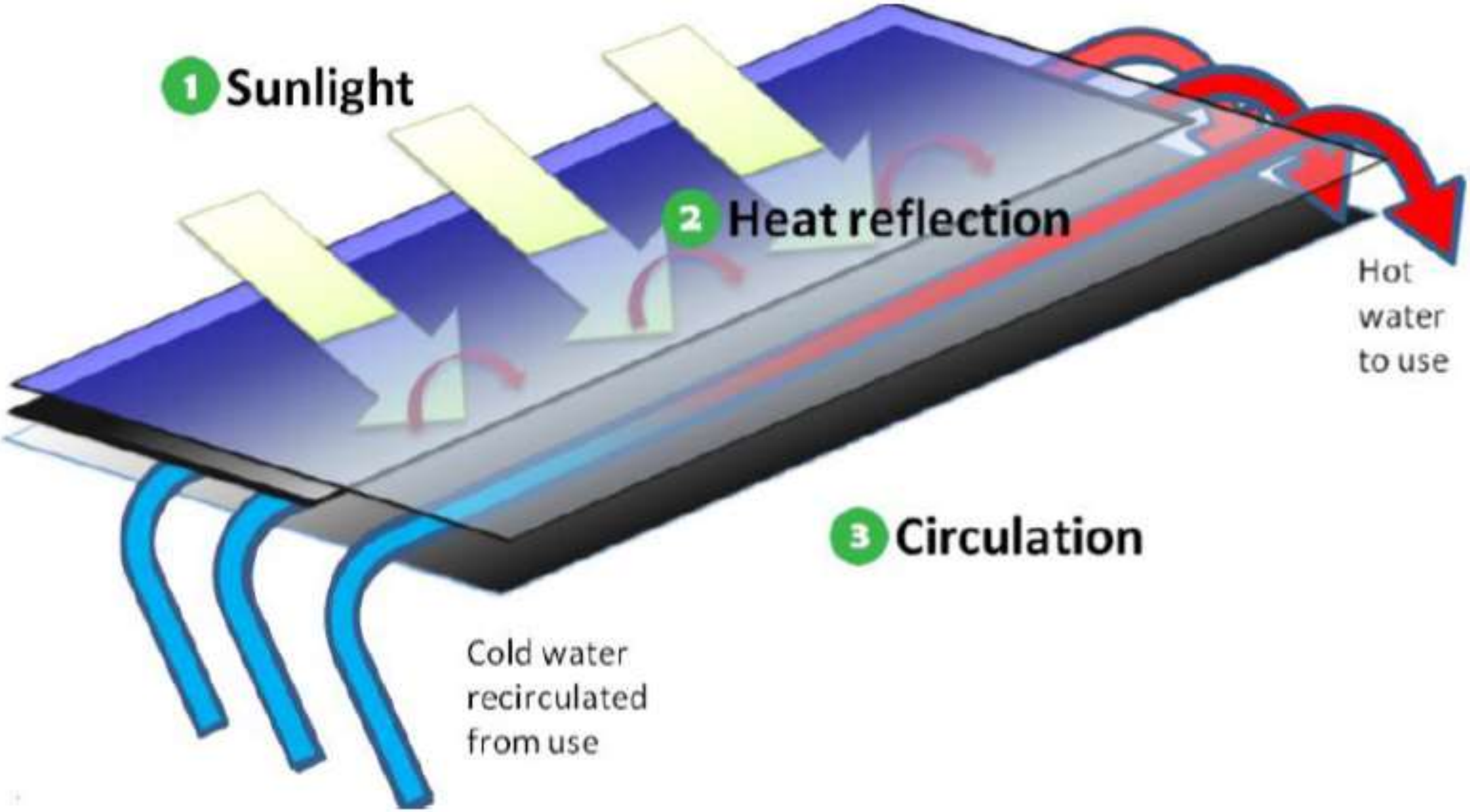
Flat Plate Collector

- Less than 100˚C
- Both beam and diffused radiation

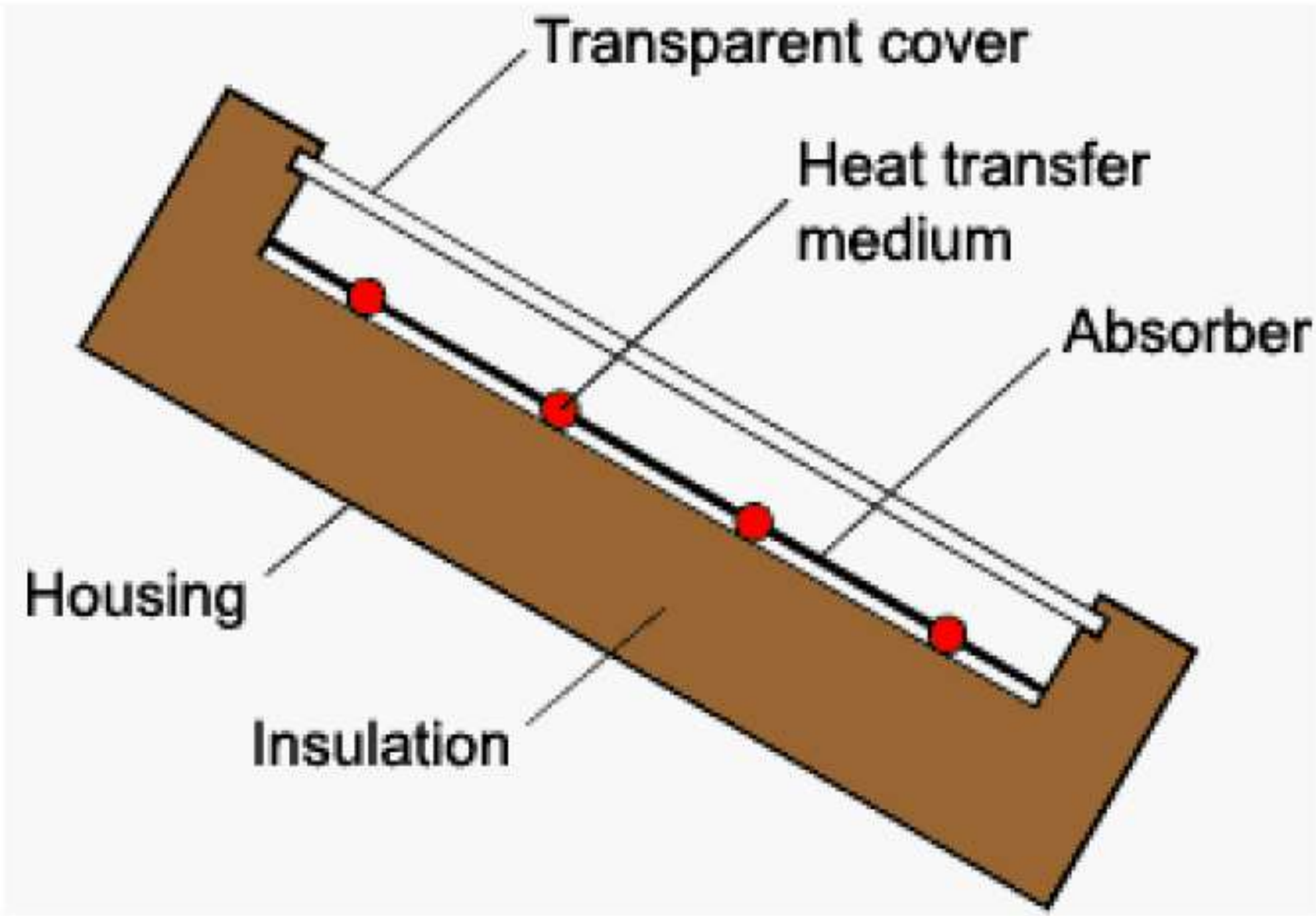


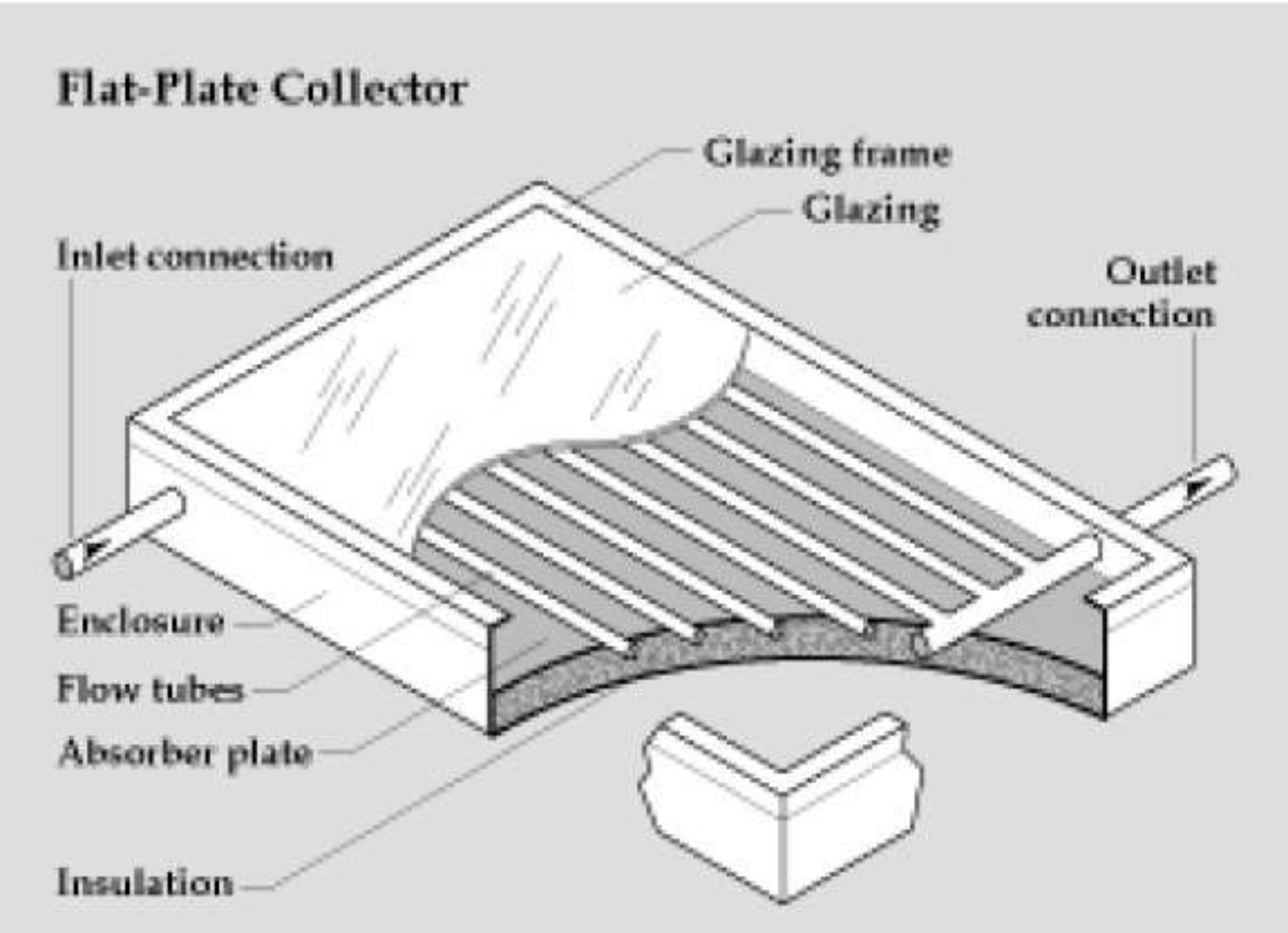
Liquid Flat-plate Collector

Flat plate collector



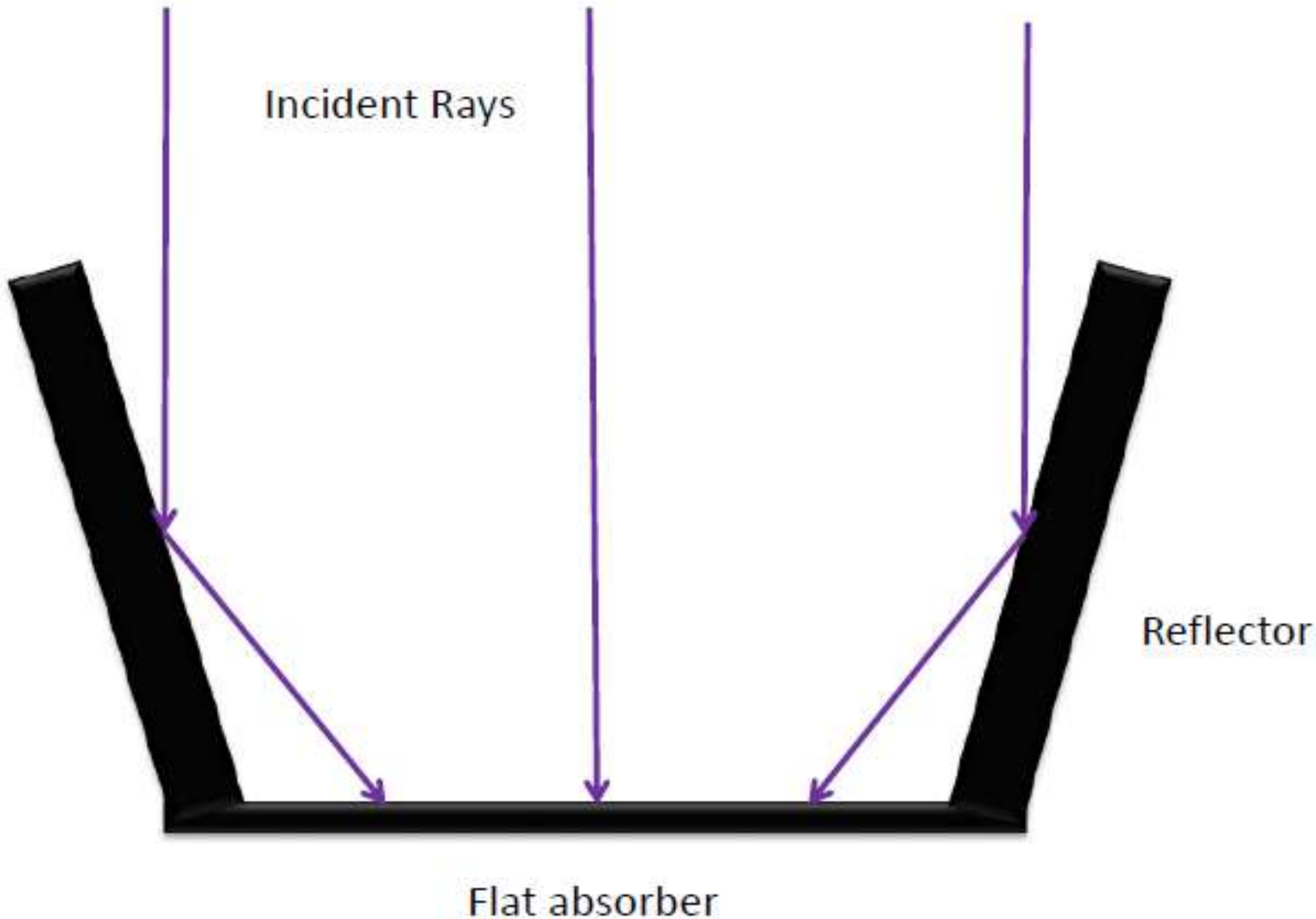
Liquid flat plat collector



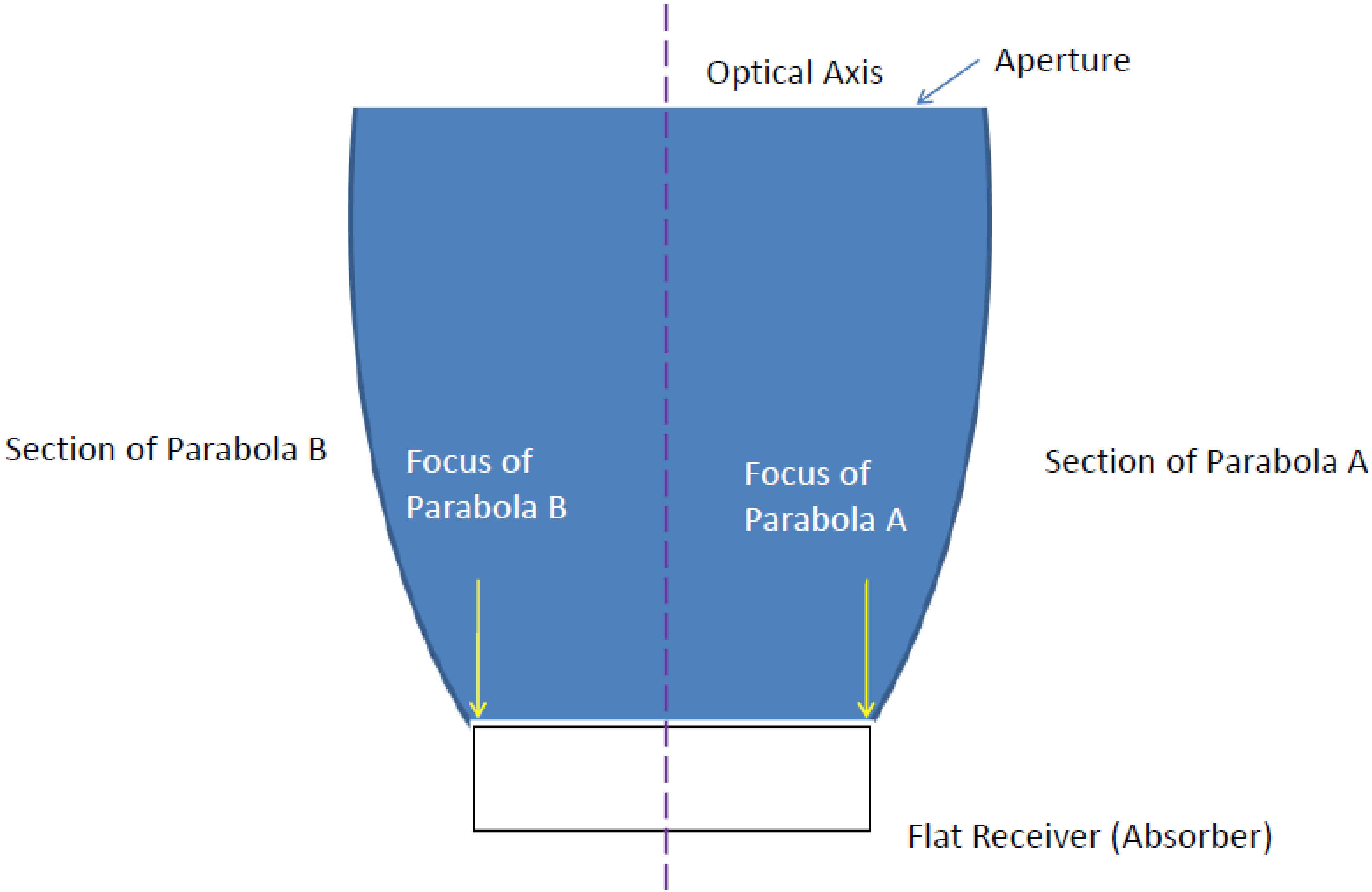

Flat-Plate Collector
Glazing frame
Glazing
Inlet connection
Outlet connection
Enclosure
Flow tubes
Absorber plate
Insulation


coolant outlet
solar radiation +
frame
coolant inlet
www.visualdictionaryonline.com
glass
flow tube
absorbing plate
insulation

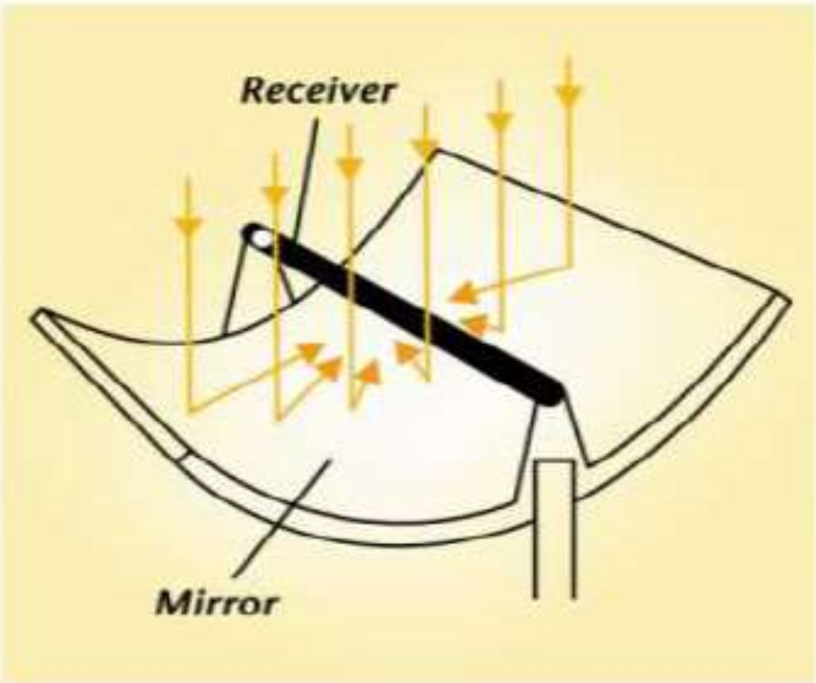
Modified Flat Plate Collector



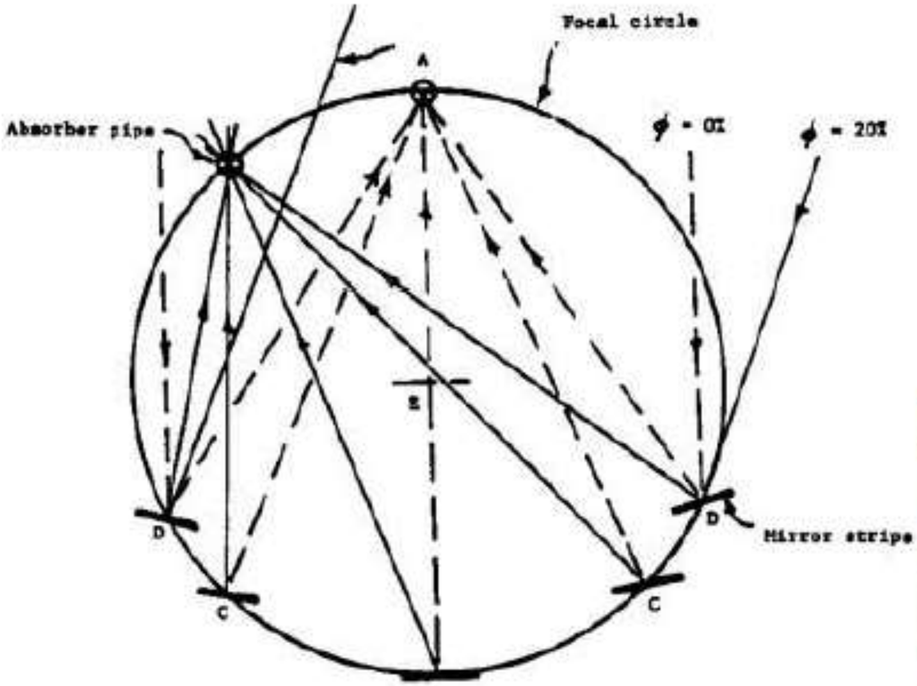
Compound Parabolic Concentrator



Cylindrical Parabolic Concentrator



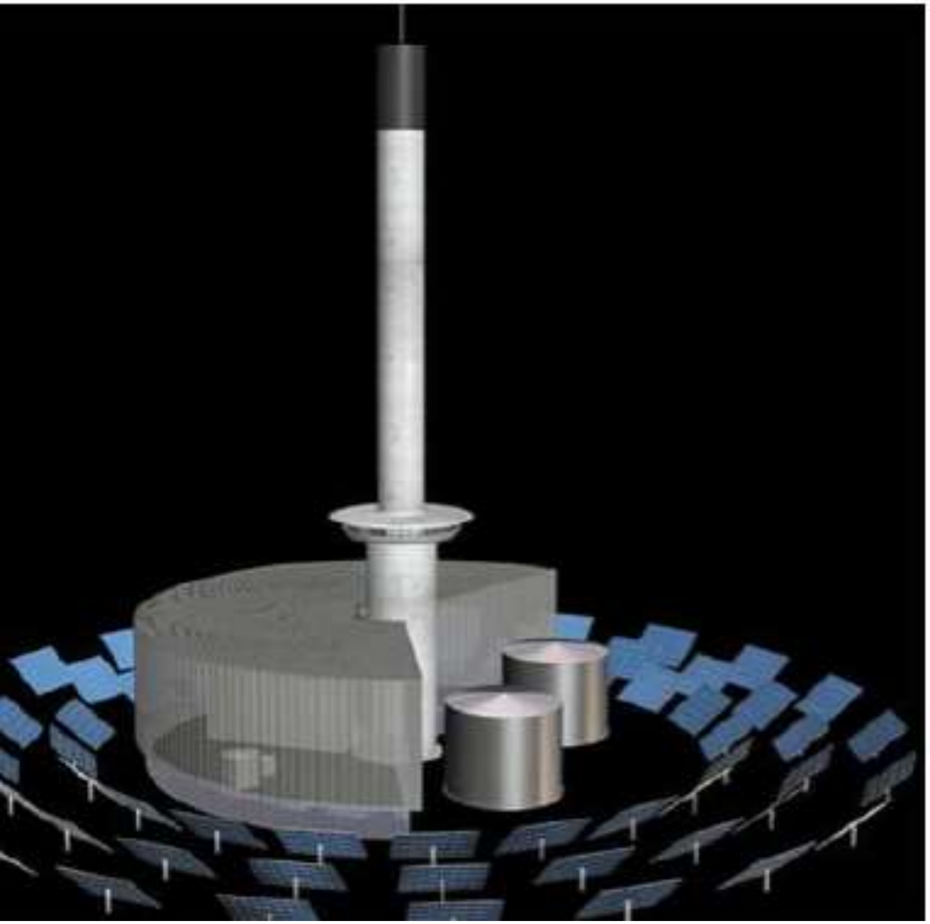
Fixed Mirror Solar Concentrator



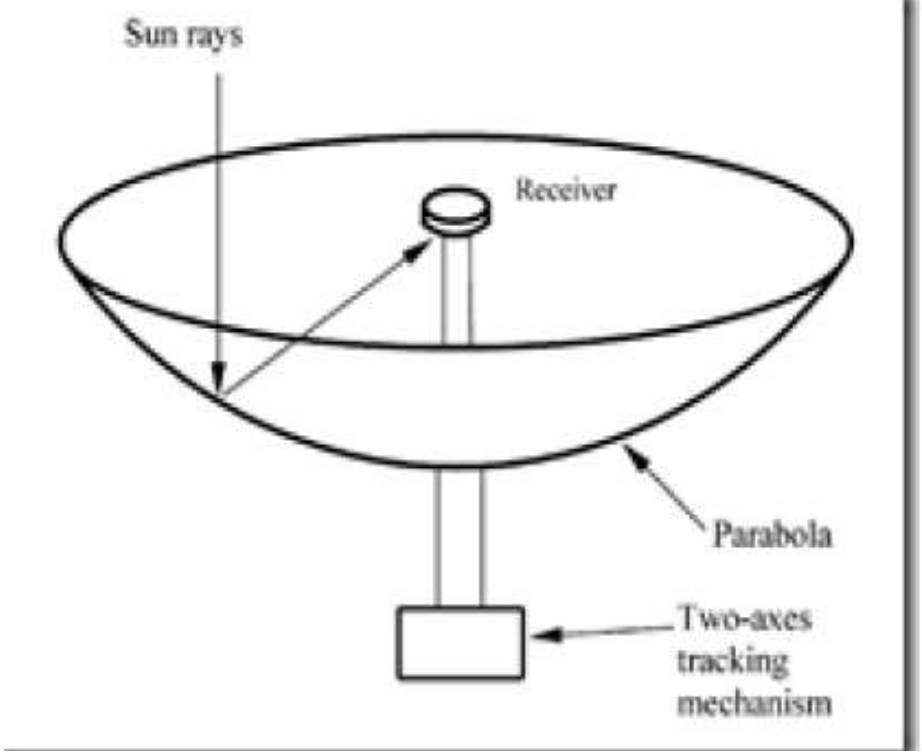
Linear Fresnel Lens Collector

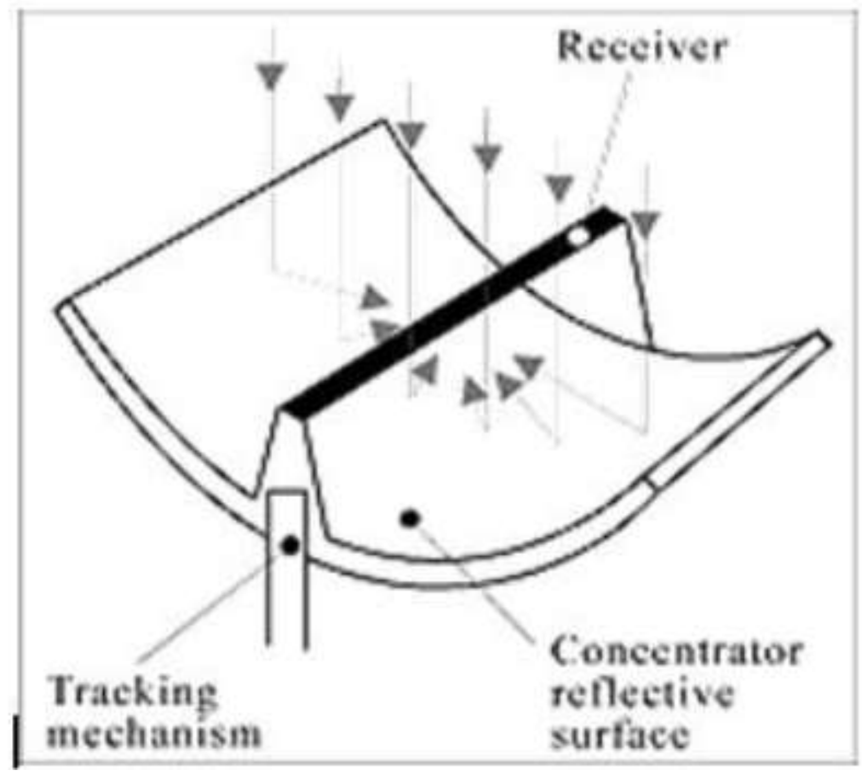
Parabolic Dish Collector

Central Tower Receiver

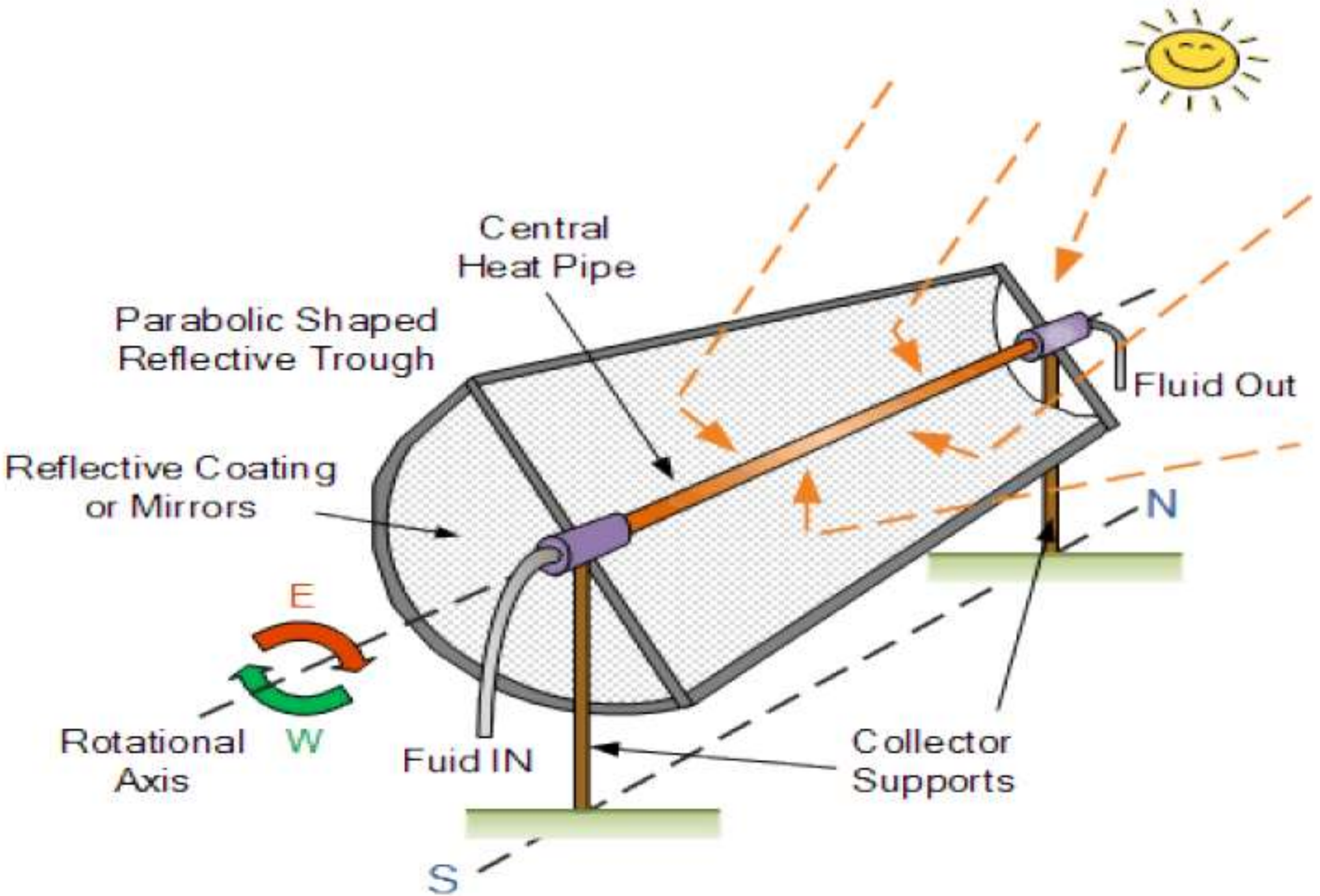


Concentrating type



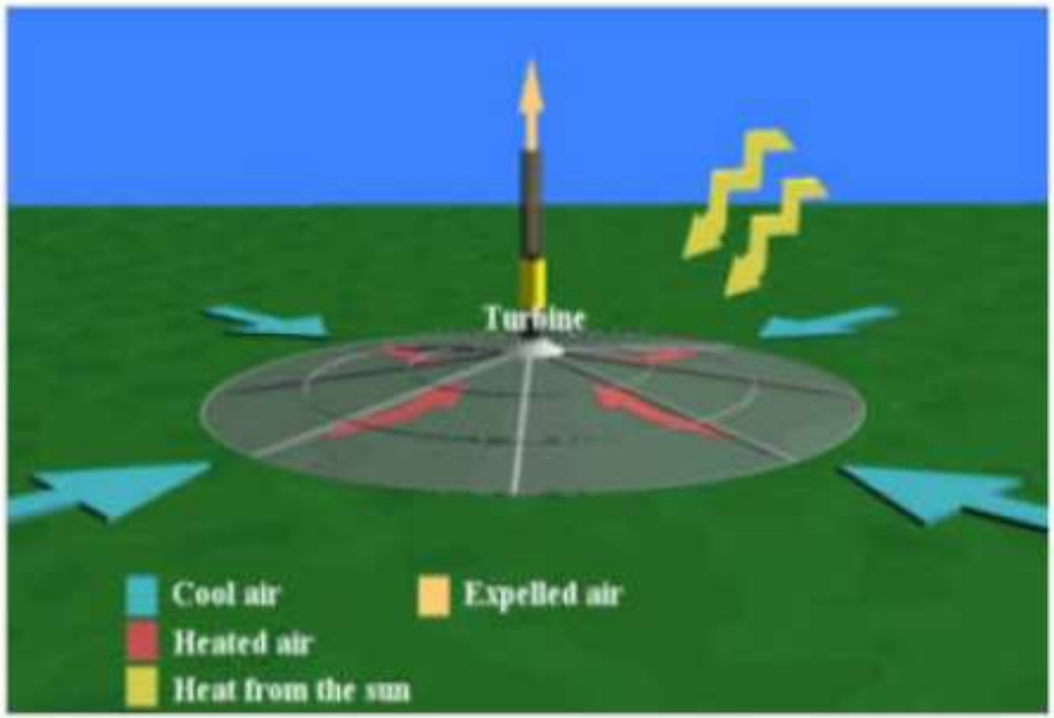


Cylindrical parabolic concentrator



Solar chimney

- A solar chimney is a solar thermal power plant where air passes under a very large agricultural glass house (between 2 and 30 kilometers in diameter).



General concept of proposed solar chimney power station

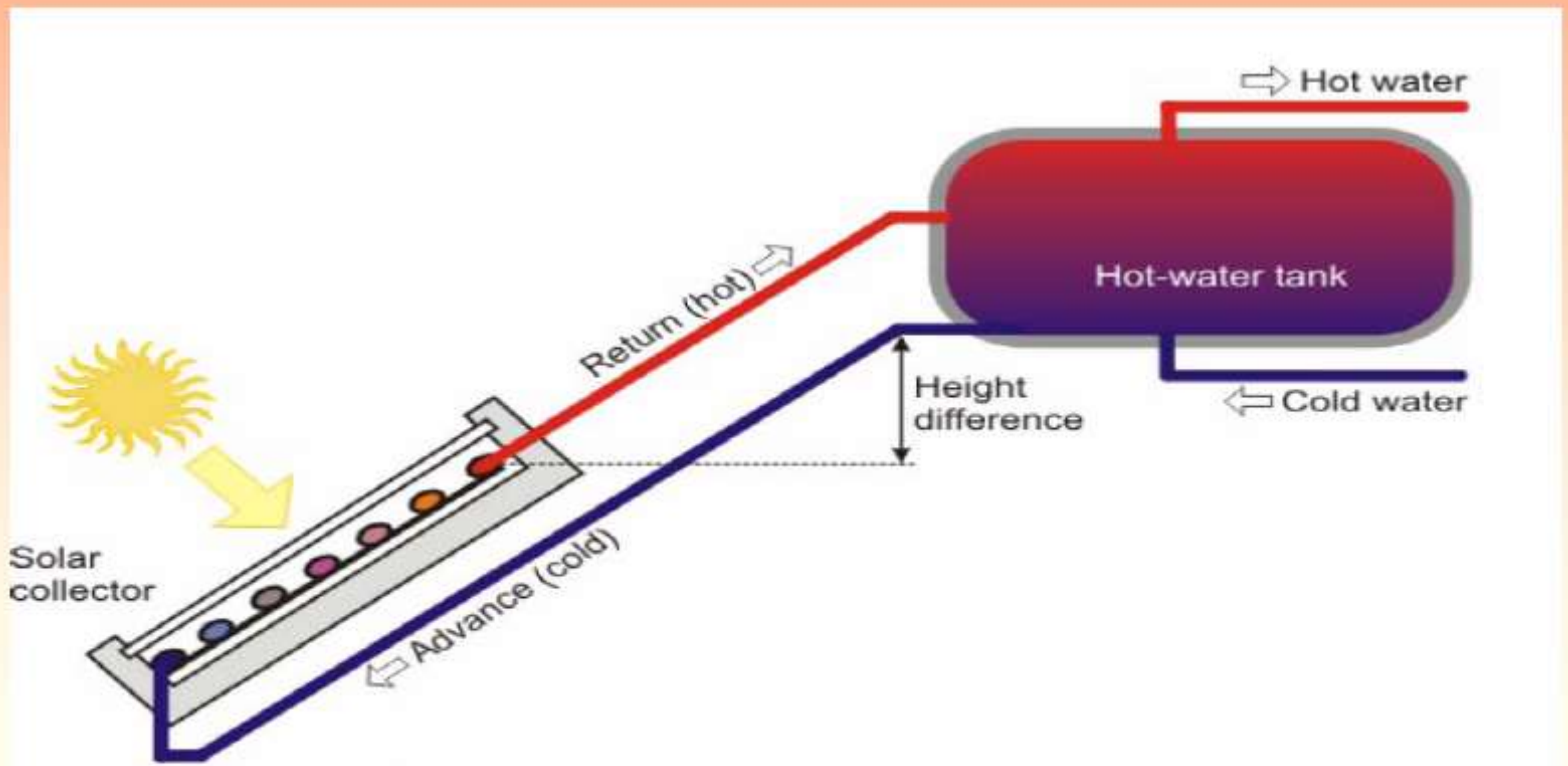
- The air is heated by the sun and channeled upwards towards a convection tower.
- It then rises naturally and is used to drive turbines, which generate electricity.
- A **solar chimney** is an apparatus for harnessing solar energy by convection of heated air.
- In its simplest form, it simply consists of a black-painted chimney.
- During the daytime, solar energy heats the chimney and thereby heats the air within it, resulting in an updraft of air within the chimney.

- The suction this creates at the chimney base can also be used to ventilate, and thereby cool, the building below .
- In most parts of the world, it is easier to harness wind power for such ventilation, but on hot windless days such a chimney can provide ventilation where there would otherwise be none.
- This principle has been proposed for electric power generation, using a large greenhouse at the base rather than relying on heating of the chimney itself.
- The main problem with this approach is the relatively small difference in temperature between the highest and lowest temperatures in the system.

Water heating

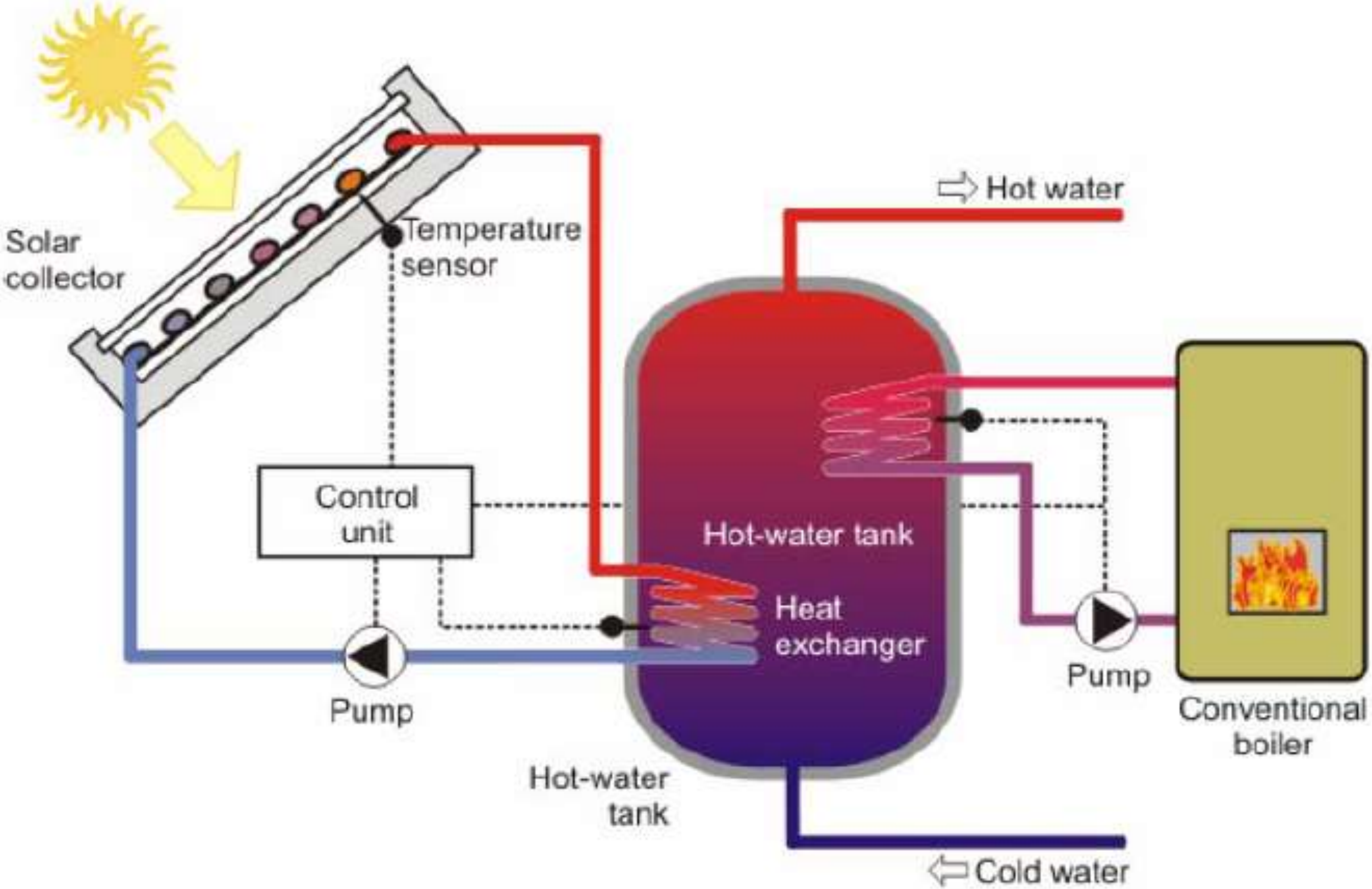
- Water heating is required in most countries of the world for both domestic and commercial use.
- The simplest solar water heater is a piece of black plastic pipe, filled with water, and laid in the sun for the water to heat up.
- Simple solar water heaters usually comprise a series of pipes, which are painted black, sitting inside an insulated box fronted with a glass panel. This is known as a solar collector.
- The fluid to be heated passes through the collector and into a tank for storage.
- The fluid can be cycled through the tank several times to raise the heat of the fluid to the required temperature.

The ***thermosyphon*** system makes use of the natural tendency of hot water to rise above cold water.



- The tank in such a system is always placed above the top of the collector and as water is heated in the collector it rises and is replaced by cold water from the bottom of the tank.
- This cycle will continue until the temperature of the water in the tank is equal to that of the panel.
- A one-way valve is usually fitted in the system to prevent the reverse occurring at night when the temperature drops.
- As hot water is drawn off for use, fresh cold water is fed into the system from the mains.
- As most solar collectors are fitted on the roofs of houses, this system is not always convenient, as it is difficult to site the tank above the collector, in which case the system will need a pump to circulate the water.

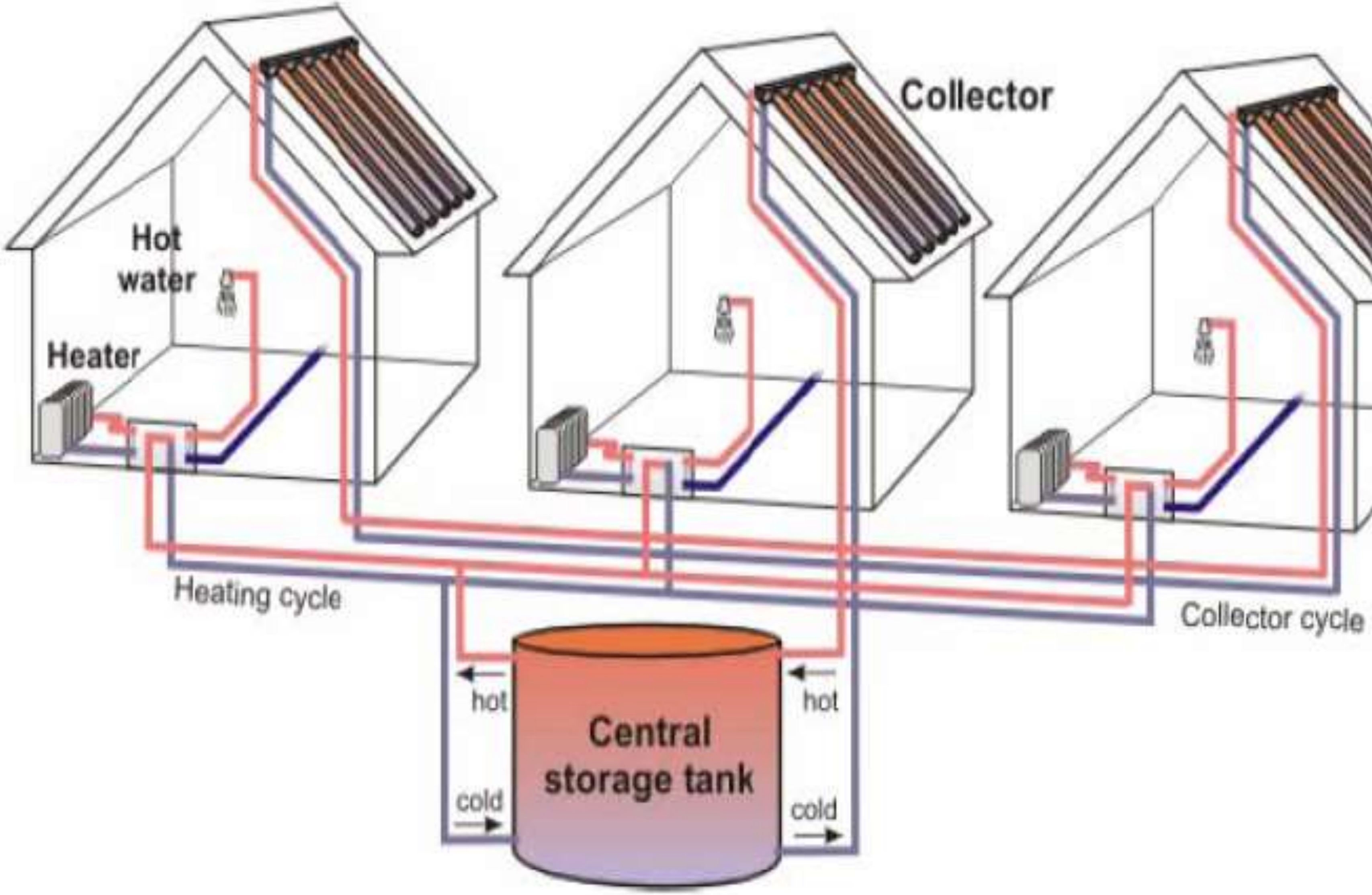
- ***Pumped*** solar water heaters use a pumping device to drive the water through the collector.
- The advantage of this system is that the storage tank can be sited below the collector.
- The disadvantage of course is that electricity is required to drive the pump.
- Often the fluid circulating in the collector will be treated with an anti-corrosive and /or anti-freeze chemical.
- In this case a heat exchanger is required to transfer the heat to the consumers hot water supply.



A double-cycle system with forced circulation with a conventional boiler for back-up neating

Solar District Heating

- If an entire housing estate should be fitted with solar systems, one solution is a solar district heating system (see Figure).
- The collectors are either distributed on the houses, or replaced by a large, central solar collector.
- The collectors then heat up a big central storage tank, from which much of the heat is distributed back to the houses.
- The surface-to-volume ratio of a central storage tank is much better than that for distributed storage systems, so the storage losses are much lower, and even permit seasonal heat storage.
- Solar district heating is also an option if room heating is to be covered by solar energy.



A solar district heating system

Cost Benefits of solar water heating system

- The most cost- effective way to install a solar geyser is to integrate the collector assembly, cold-water supply and piping with the design of a new house under construction.
- Solar geysers can easily be installed in group houses and apartments, especially during construction, if adequate provisions are made for piping, collector assembly and cold-water supply. Proper load matching is required to ensure that the capacity of the system installed is optimized to meet the daily hot water needs of the end-user.
- Current prices of domestic SWHs are around Rest. 20,000 for a 100 litres per day system.

Solar Dryer

- Controlled drying is required for various crops and products, such as grain, coffee, tobacco, fruits vegetables and fish.
- Their quality can be enhanced if the drying is properly carried out.
- Solar thermal technology can be used to assist with the drying of such products.
- Solar drying is in practice since the time imp-memorable for preservation of food and agriculture crops.
- This was done particularly by open sun drying under open the sky.
- In open air Solar drying the heat is supplied by direct absorption of solar radiation by material being dried.

This process has several disadvantages

Disadvantages of mechanical and artificial drying:

- Spoilage of product due to adverse climatic condition like rain, wind etc
- Loss of material due to birds and animals
- Deterioration of the material by decomposition, insects and fungus growth
- Highly energy intensive and expensive.
- Solar dryer make use of solar radiation, ambient temperature, relative humidity.
- Heated air is passed naturally or mechanically circulated to remove moisture from material placed in side the enclosure.

Solar dryer is a very useful device for

- Agriculture crop drying
- Food processing industries for dehydration of fruits, potatoes, onions and other vegetables,
- Dairy industries for production of milk powder, casein etc.
- Seasoning of wood and timber.
- Textile industries for drying of textile materials.

Working of solar dryer

- The main principle of operation is to raise the heat of the product, which is usually held within a compartment or box, while at the same time passing air through the compartment to remove moisture.
- The flow of air is often promoted using the 'stack' effect which takes advantage of the fact that hot air rises and can therefore be drawn upwards through a chimney, while drawing in cooler air from below. Alternatively a fan can be used.
- The size and shape of the compartment varies depending on the product and the scale of the drying system.

- Large systems can use large barns while smaller systems may have a few trays in a small wooden housing.
- Solar crop drying technologies can help reduce environmental degradation caused by the use of fuel wood or fossil fuels for crop drying and can also help to reduce the costs associated with these fuels and hence the cost of the product.

The principal types of solar dryers are enumerated below.

- Solar cabinet dryer.
- Solar green house dryers.
- Indirects sonars drayer.

Solar Distillation/De -salination

Solar Stills

- Solar still is a device to desalinate impure water like brackish or saline water.
- It a simple device to get potable/fresh distilled water from impure water, using solar energy as fuel, for its various applications in domestic, industrial and academic sectors .
- A solar still consist of shallow triangular basin made up of Fiber Reinforced Plastic (FRP).
- Bottom of the basin is painted black so as to absorb solar heat effectively.
- Top of the basin is covered with transparent glass tilt fitted so that maximum solar radiation can be transmitted in to the still.

- Edges of the glass are sealed with the basin using tar tape so that the entire basin becomes airtight.
- Entire assembly is placed on a structure made of MS angle. Out let is connected with a storage container.

Solar Stills have got major advantages over other conventional Distillation / water purification /de-mineralization systems as follows:

- Produces pure water
- No prime movers required
- No conventional energy required
- No skilled operator required
- Local manufacturing/repairing
- Low investment
- Can purify highly saline water (even sea water)

Working of solar still

- Working of solar still is based on simple scientific principle of Evaporation and condensation.
- Brackish or saline water is filled in still basin, which is painted black at the bottom.
- Solar radiation received at the surface is absorbed effectively by the blacken surface and heat is transferred to the water in the basin.
- Temperature of the water increases that increases rate of evaporation.
- Water vapor formed by evaporation rises upward and condenses on the inner surface of the cover glass, which is relatively cold.
- Condensed water vapor trickles down in to troughs from there it is collected in to the storage container.

Solar box cooker

- A **solar box cooker** is an insulated transparent-topped box with a reflective lid.
- It is designed to capture solar power and keep its interior warm.
- The major parts of a solar cooker are enumerated below.

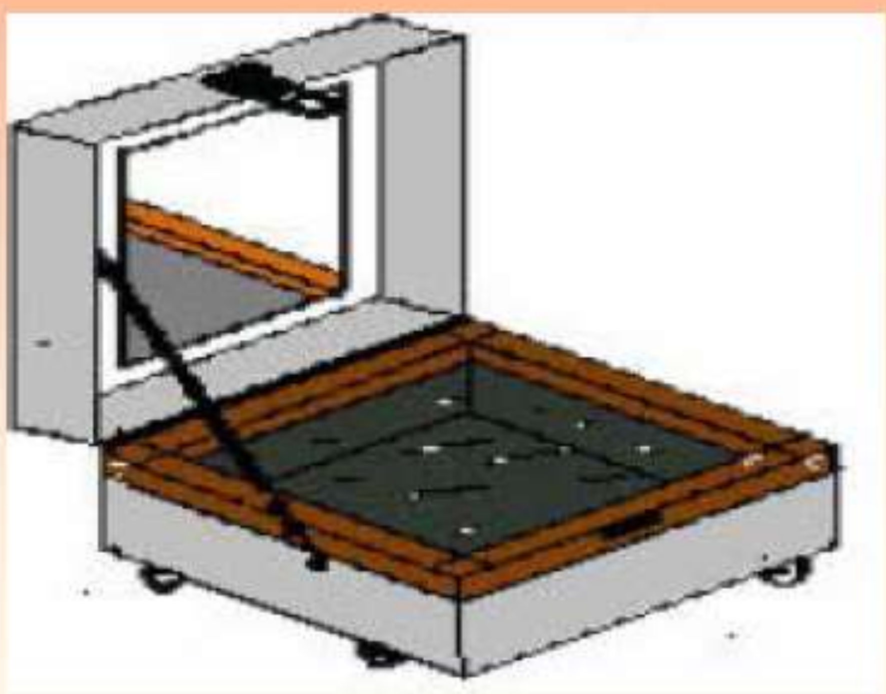
Important Parts of Solar Cooker:

- **Outer Box:** The outer box of a solar cooker is generally made of G.I. or aluminum sheet or fiber reinforced plastic.
- **Inner Cooking Box (Tray):** This is made from aluminum sheet. The inner cooking box is slightly smaller than the outer box. It is coated with black paint so as to easily absorb solar radiation and transfer the heat to the cooking pots.

- **Double Glass Lid:** A double glass lid covers the inner box or tray. This cover is slightly larger than the inner box. The two glass sheets are fixed in an aluminum frame with a spacing of 2 centimeters between the two glasses.
- This space contains air which insulates and prevents heat escaping from inside. A rubber strip is affixed on the edges of the frame to prevent any heat leakage.
- **Thermal Insulator:** The space between the outer box and inner tray including bottom of the tray is packed with insulating material such as glass wool pads to reduce heat losses from the cooker.
- This insulating material should be free from volatile materials.

- **Mirror:** Mirror is used in a solar cooker to increase the radiation input on the absorbing space and is fixed on the inner side of the main cover of the box. Sunlight falling on the mirror gets reflected from it and enters into the tray through the double glass lid.
- This radiation is in addition to the radiation entering the box directly and helps to quicken the cooking process by raising the inside temperature of the cooker.
- Containers: The cooking containers (with cover) are generally made of aluminum or stainless steel.
- These pots are also painted black on the outer surface so that they also absorb solar radiation directly.

- ***Horace de Assure, a Swiss naturalist***, invented solar cookers as early as 1767.

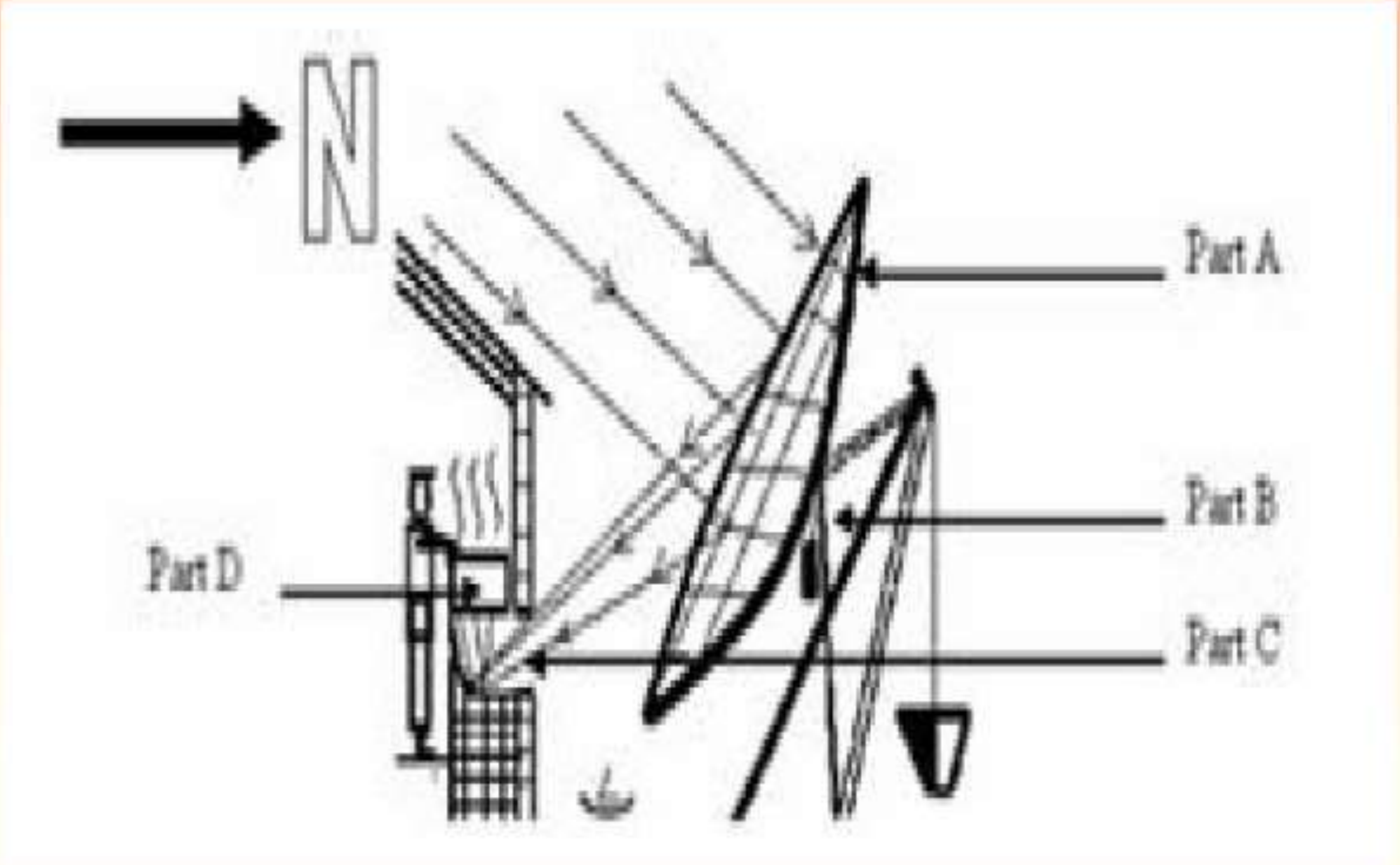


- We can cook a large number of items, like pulses, rice, cheer etc.

- The time taken to cook will depend upon the type of the food, time of the day and solar intensity.
- The time taken to cook some of the dishes in a solar cooker is as follows:
- Rice (45 minutes to one hour),
- Vegetables (about one to two hours),
- Black gram and Raja (about two hours),
- Cake (one hour).

Community Solar Cooker

- Numerous households all over the country are using '**Surry**' Cooker to cook their meals.



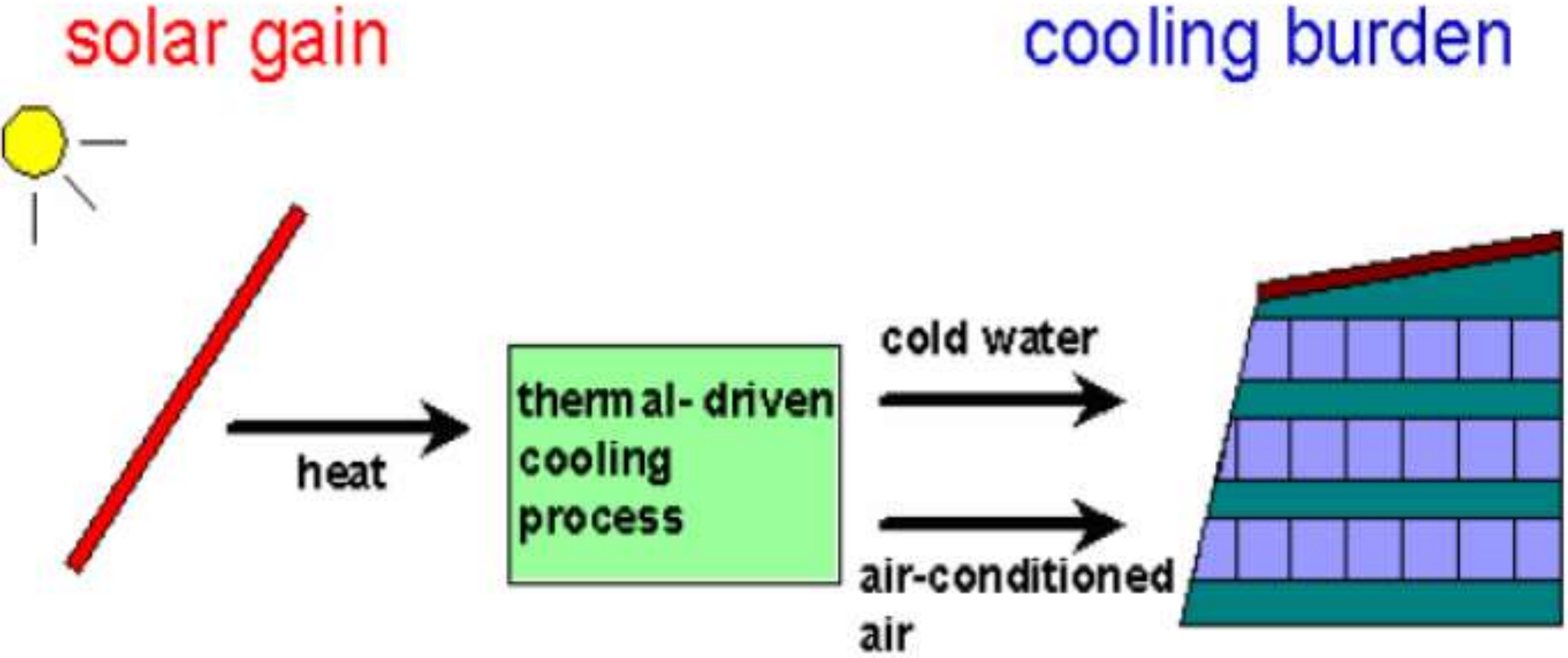
- This family-sized cooker can cook meals for 4-5 persons.
- A larger version of the family size box-type cooker was also developed and used for canteen application.
- Firewood is the most commonly used cooking fuel in community kitchens and traditional woodstove - a "Chula" are the most commonly used cooking device. These chelas have an efficiency of 5-10 % only.
- This Community Solar Cooker employs a parabolic reflecting concentrator that can cook large quantities of food at much faster rate.
- It can replace LPG, kerosene and firewood which are either cumbersome to use, very expensive or which are in short supply.

- This cooker is capable of achieving higher temperature unto 250°C as against 100-125 °C in box type cooker.
- This helps cooking much faster. The conventional cooking arrangement within the kitchen does not require to be changed and the cooking can be done inside the kitchen.
- Additionally roasting & frying can be done with this cooker, which is not possible in the old box type solar cooker.
- The **cost of Cooker**, inclusive of all attachments and installation charges is about Rest. 55,000.

Solar Air conditioning

- The basic principle behind solar thermal driven cooling is the thermo-chemical process of Sorption: a liquid or gaseous substance is either attached to a solid, porous material called **Adsorption** or is taken in by a liquid or solid material called **Absorption**.
- The sorbet, silica gel, a substance with a large inner surface area is provided with heat from a solar heater and is dehumidified.
- After this "drying", the process can be repeated in the opposite direction. Processes are differentiated between closed refrigerant circulation systems, for producing cold water, and open systems according to the way in which the process is carried out. That is, whether or not the refrigerant comes into contact with the atmosphere.

Basic structure of a solar air conditioning system:



Passive solar buildings for cold areas of the Himalayan Range

- Latah is located in the Western Himalayan range of India closed to the Tibetan and Pakistan borders.
- It is a cold desert between 2,800 m and 4,500 m above sea level.
- The winter is very cold, sometimes below - 30°C.Under this extremely cold and dry climate, no trees can grow.
- Therefore, during the winter, the inhabitants, the Leachy, burn dung to cook and warm their homes. Due to the extreme coldness, the space heating needs during the winter are very high.

- The concept used is Passive solar architecture Passive solar architecture is the way to construct a building so that its structure benefits as much as possible from the external climate to make the interior space as comfortable as possible.
- A passive solar building is an insulated building with a high thermal mass coupled with a solar gain component. It is build along an east-west axis.
- The solar radiations are collected trough the south face and trapped inside trough the glazing, greenhouse or any other passive solar component.
- This heat is stored during the day inside the walls and released during the night to maintain the atmosphere warm.

- The building can be designed by some local NGOs (Ledge, Secom, Ledge, LEHO) or administration (PWD) sometimes assisted by resource organization such as TERI, GERES.
- As the thermal efficiency of a passive solar building depends on the quality of the construction, some skilled mason and carpenter have been trained the local and international NGOs.
- The over-cost of the passive solar components is 10 to 20% of the building investment. But no running costs are required and the maintenance is cheap and easy.

SOLAR PHOTOVOLTAIC SYSTEMS

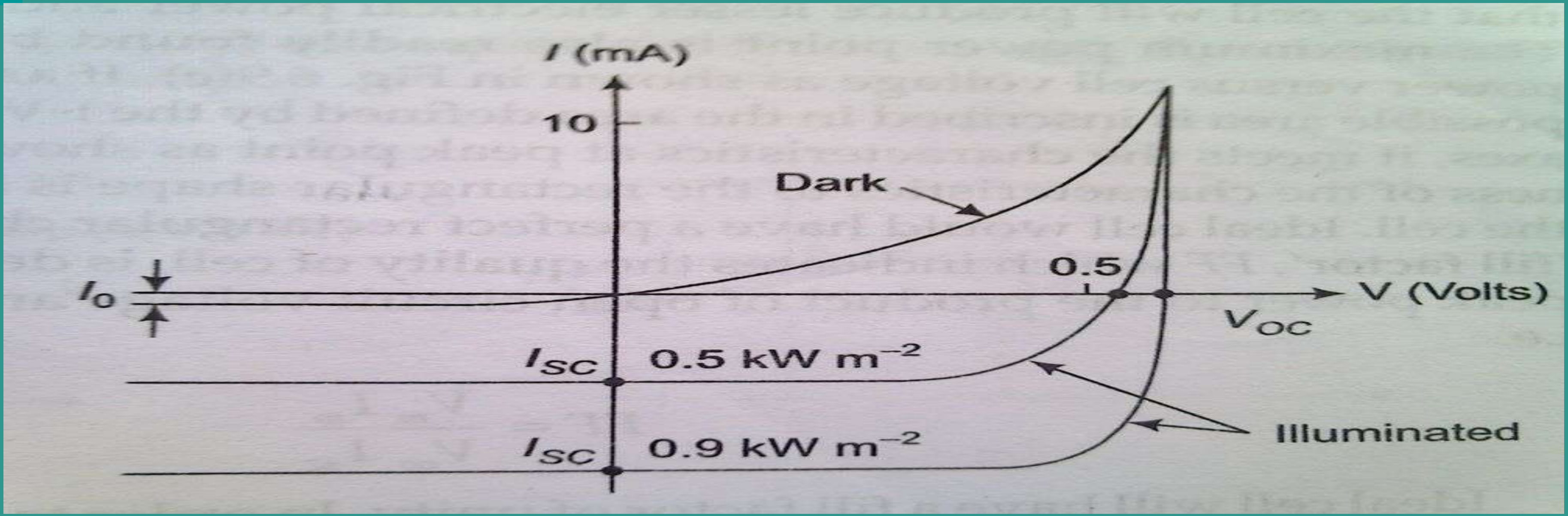
Advantages of Solar PV System

- It converts solar energy directly into electrical energy without going through thermal-mechanical link. It has no moving parts.
- Solar PV systems are reliable , modular , durable and generally maintenance free.
- These Systems are quiet , compatible with almost all environments, expected life span of 20 years or more.
- It can be located at the place of use and hence no distribution network is required.

Disadvantages of Solar PV System

- At present the costs of solar cells are high, making them economically uncompetitive with other conventional power sources.
- The efficiency of solar cells are low.
- Large no. of solar cell modules are required to generate power.
- As solar energy is intermittent, some kind of electrical energy storage is required, which makes the whole system more expensive.

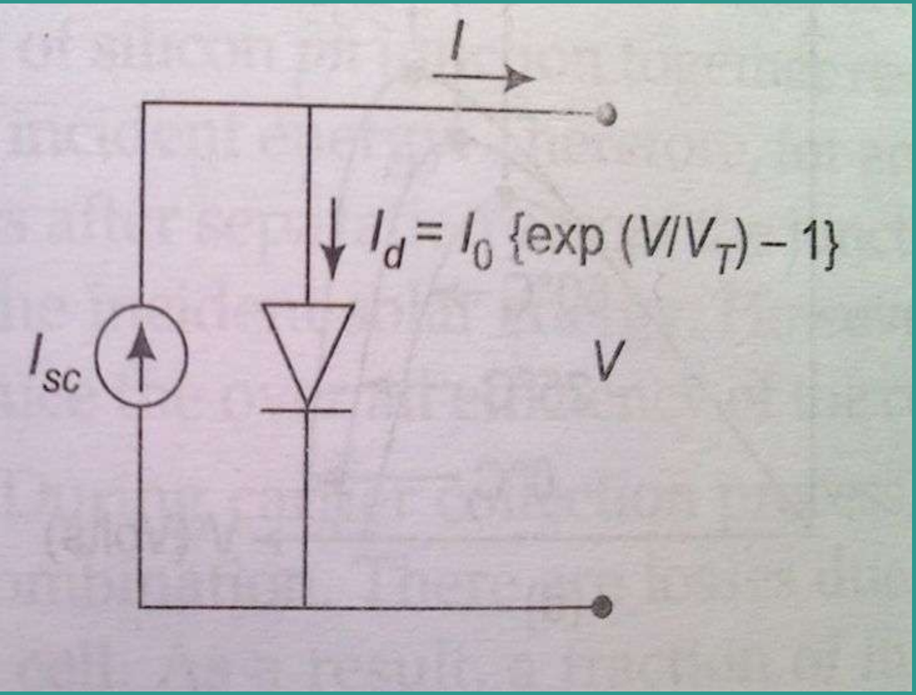
Solar Cell characterisitics

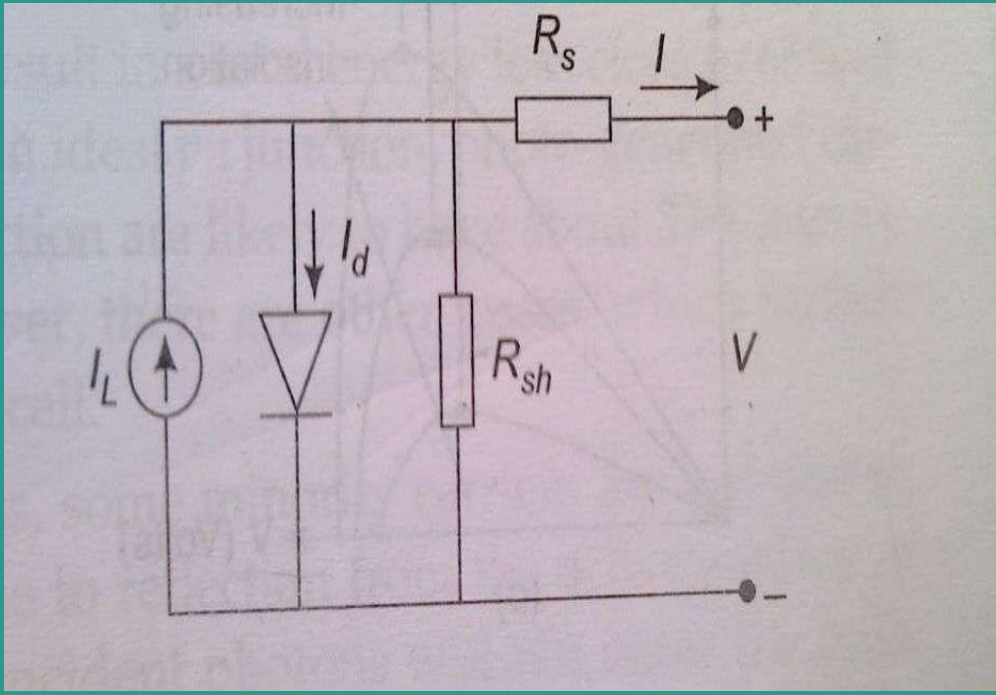


- The above figure shows the I-V characteristics.
- I= Isc-Io {Exp(V/Vt)-1}
- Where Io is the reverse saturation current , Vt is the voltage equivalent of temperature and at room temperature its value is 26 mV.
- We have Vt=KT/q
- Where K is the boltzmann's constant, T is the temperature in °K and q is the charge of an electron.

Equivalent Circuit

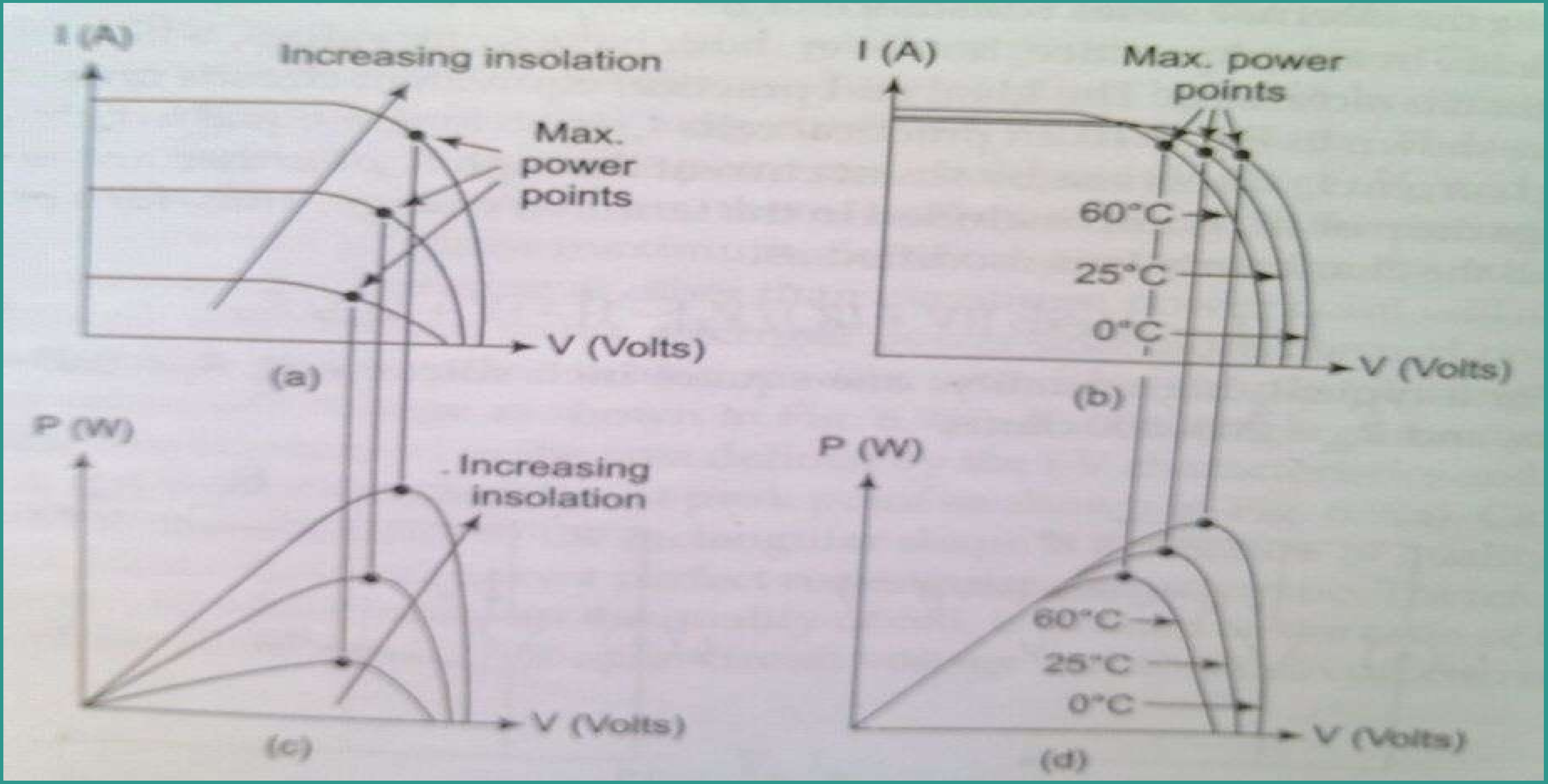
- The I-V characteristics is derived for ideal condition, considering the internal series resistance of the cell is zero and the shunt resistance is infinite.
- In actual practice both have infinite values, so the characteristics are modified.
- An additional shunt current flows in the shunt branch.





Effect of variation of Isolation and Temperature:-

As the isolation varies throughout the day the PV characteristics changes. The short circuit voltage and open circuit current increases with the increase in intensity.



- **Energy Losses and Efficiency:-**The Conversion efficiencies of commercially produced single crystal cells are in the range of 12-15%. Various loss mechanisms lead to limit the conversion efficiency.
- **Maximizing the performances:-**Maximum values of open circuit voltage and short-circuit current, low series resistance and high shunt resistance will lead to high fill factor.
- **Cell Sizes:-** Size of the cell affects the performance of the cell. So as per current industry standards cells are of various types:- round single crystalline, square single crystalline, square multicrystalline.

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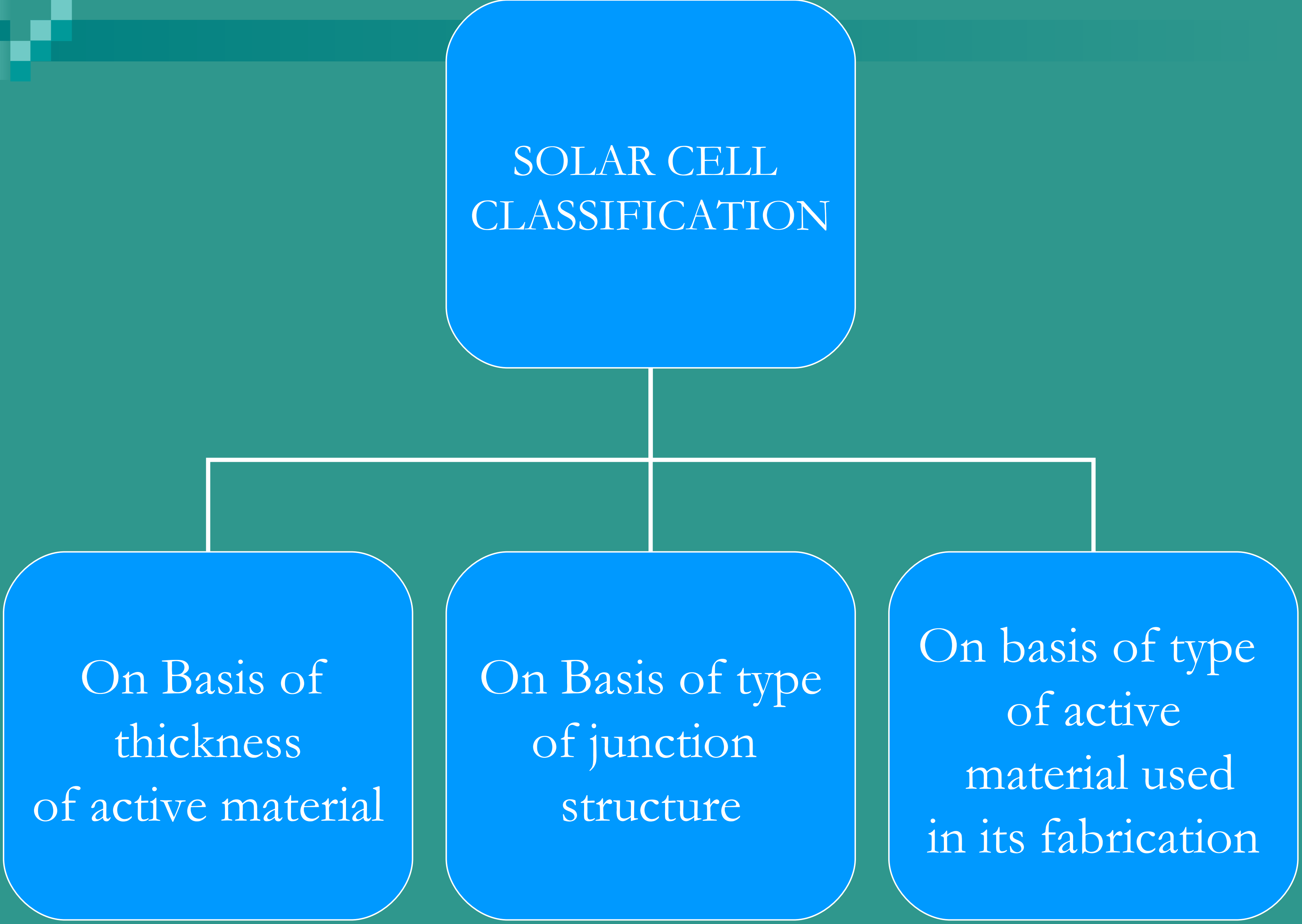

SOLAR CELL CLASSIFICATION
On Basis of thickness of active material
On Basis of type of junction structure
On basis of type of active material used in its fabrication

- **On basis of thickness of Active material**

  1)bulk material where the base material is itself an active material.

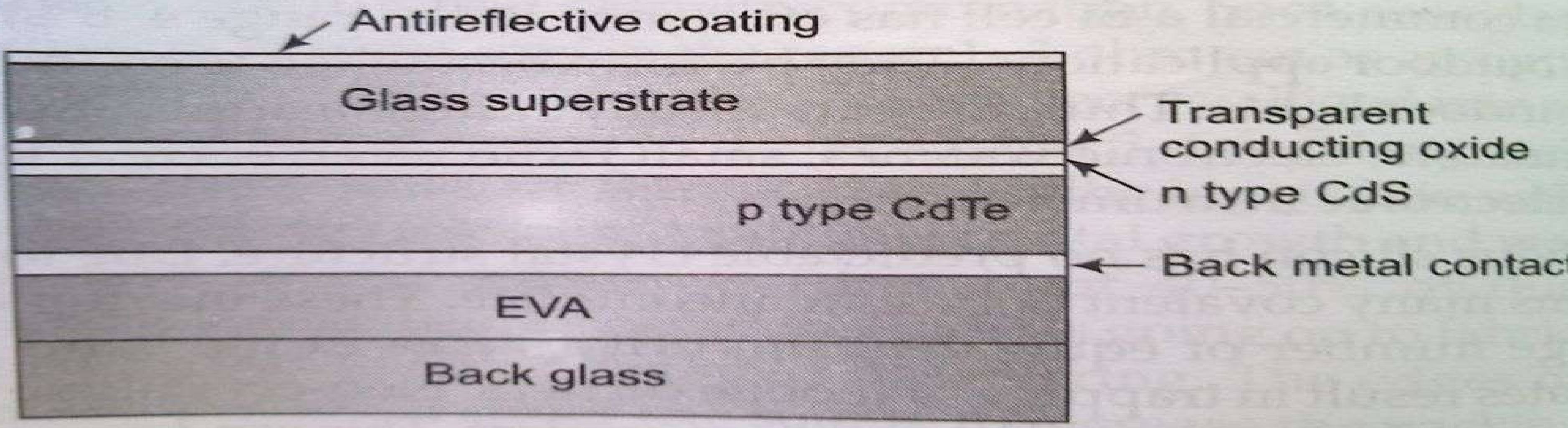
  2)thin film cell where a deposition of active material substrate is there.

- **On basis of type of junction structure**

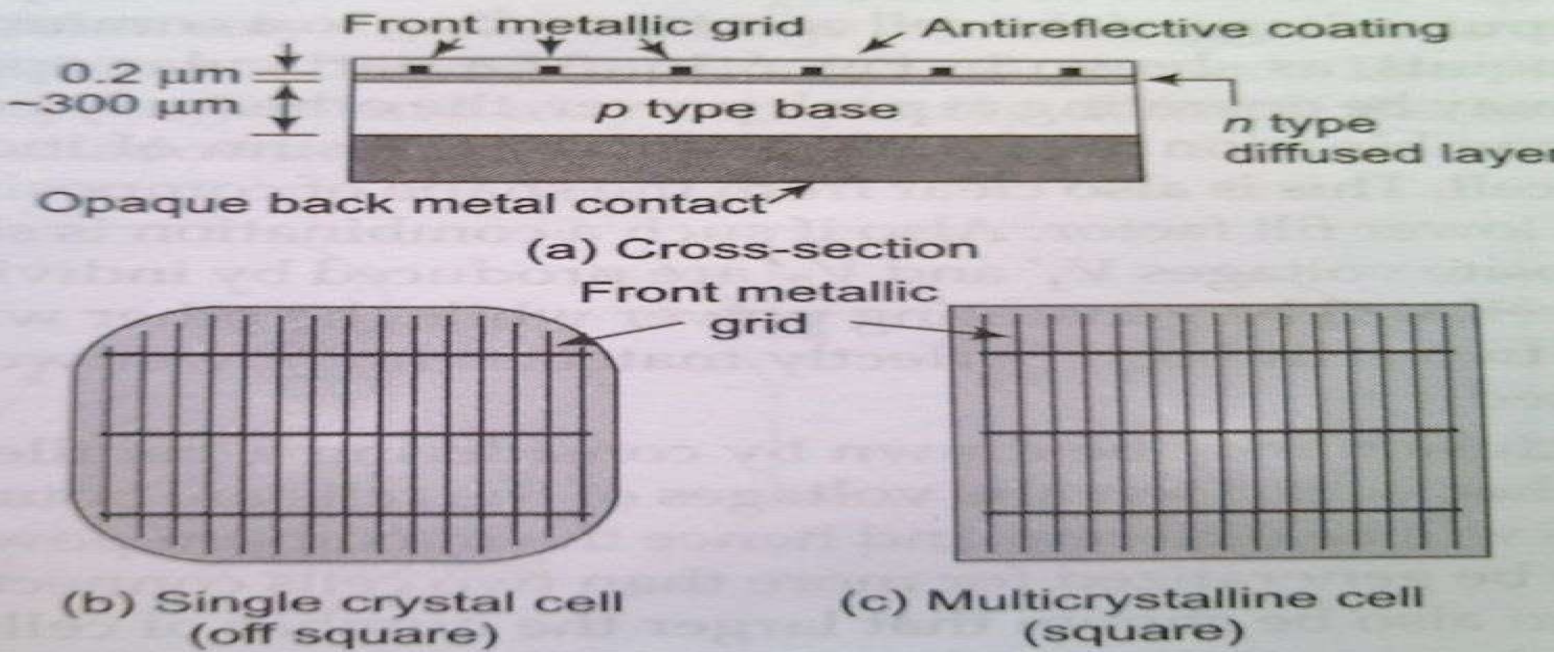
  pn homojunction cell, pn heterojunction cell, pn multijuntion cell, metal semiconductor schottky junction, p-i-n semiconductor junction.

- **On basis of type of active material used in its fabrication**

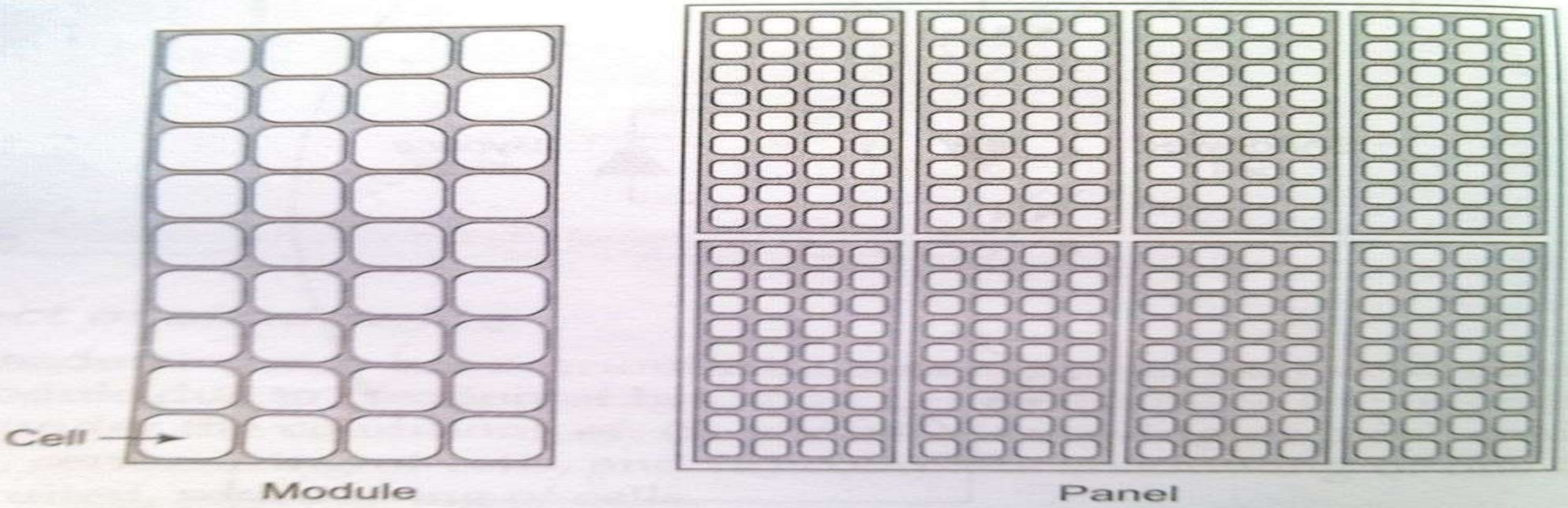
  Single crystal, multicrystalline silicon, amorphous silicon(a-Si) cell, gallium arsenide(GaAS) cell, Copper Indium diselenide cell(CIS), cadmium telluride cell(CdTe) and Organic PV cell.

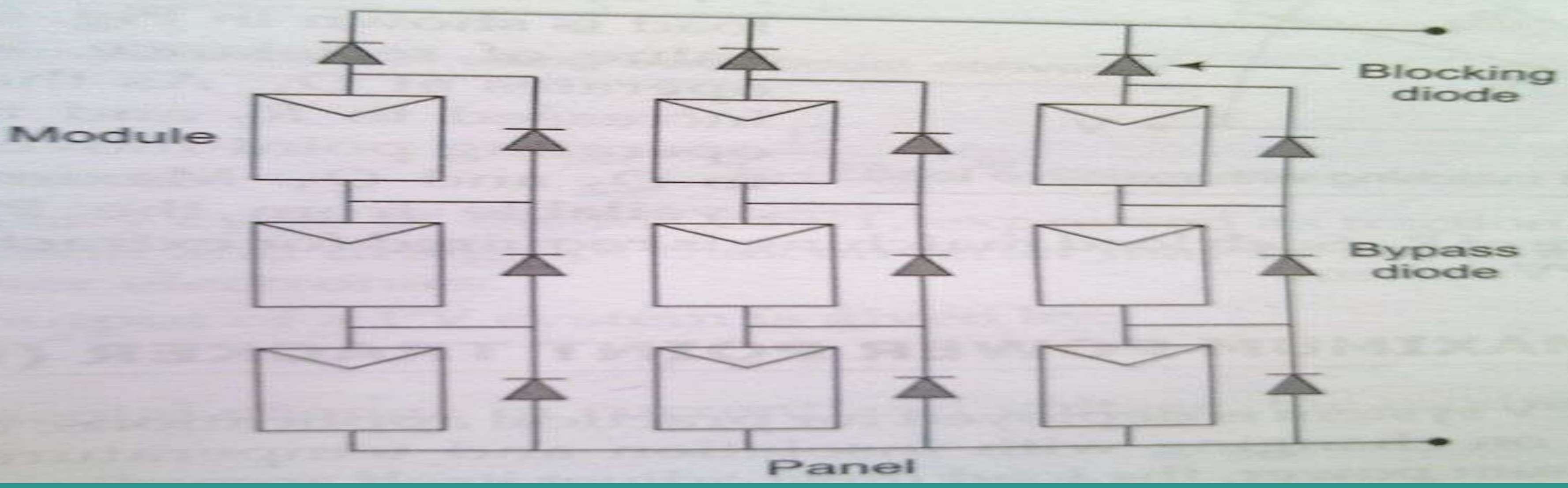


Basic structure of CdTe cell



- **SOLAR CELL:-** It is basically a bulk silicon cell where the bulk material is the p-type silicon. A thin layer of n-type silicon is formed at the top surface. There is anti-reflective coating, textured rear surface.
- **SOLAR PV MODULE**:-It is the basic building block of a PV system. It is the interconnection of a number of cells and all these cells should have the same characteristics. Partial shadowing may damage the module.
- **SOLAR PV PANEL**:-Several solar modules are connected in series/parallel to increase the voltage/current ratings. Solar panel is a group of several modules connected in series parallel combination in a frame that can be mounted on a structure. The combination of such panels are called as an **SOLAR ARRAY**.

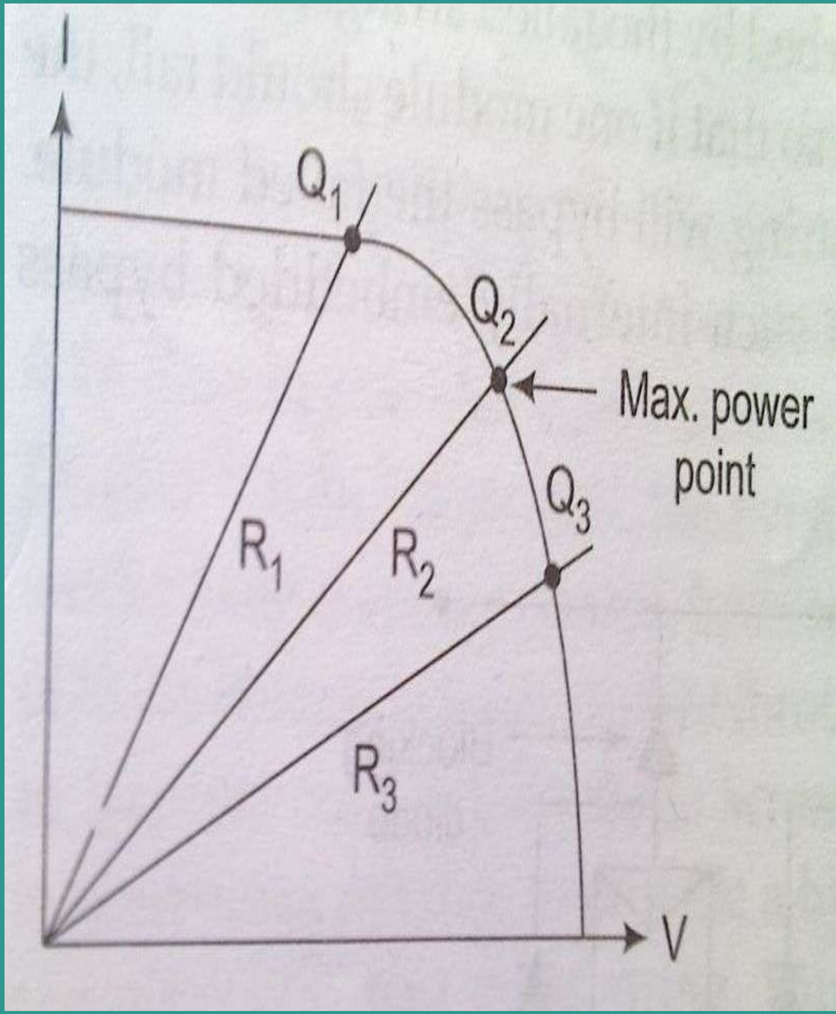




A typical panel: Series-Parallel Connection of modules.

MAXIMIZING THE SOLAR PV OUTPUT AND LOAD MATCHING

- The best use of Solar PV system is made by maximizing the output.
- First by mechanically orienting the Panel for sun tracking to receive maximum solar radiation.
- Secondly by electrically tracking the operating point by manipulating the load.



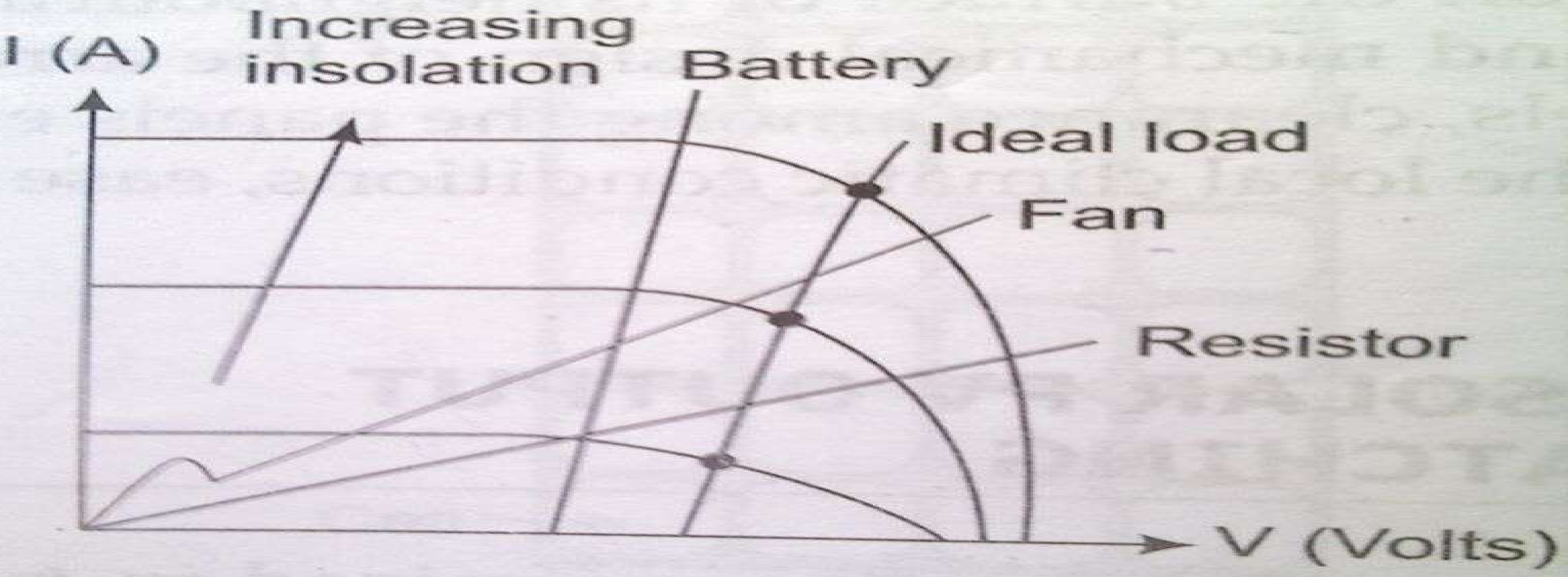
MAXIMUM POWER POINT TRACKER(MPPT)

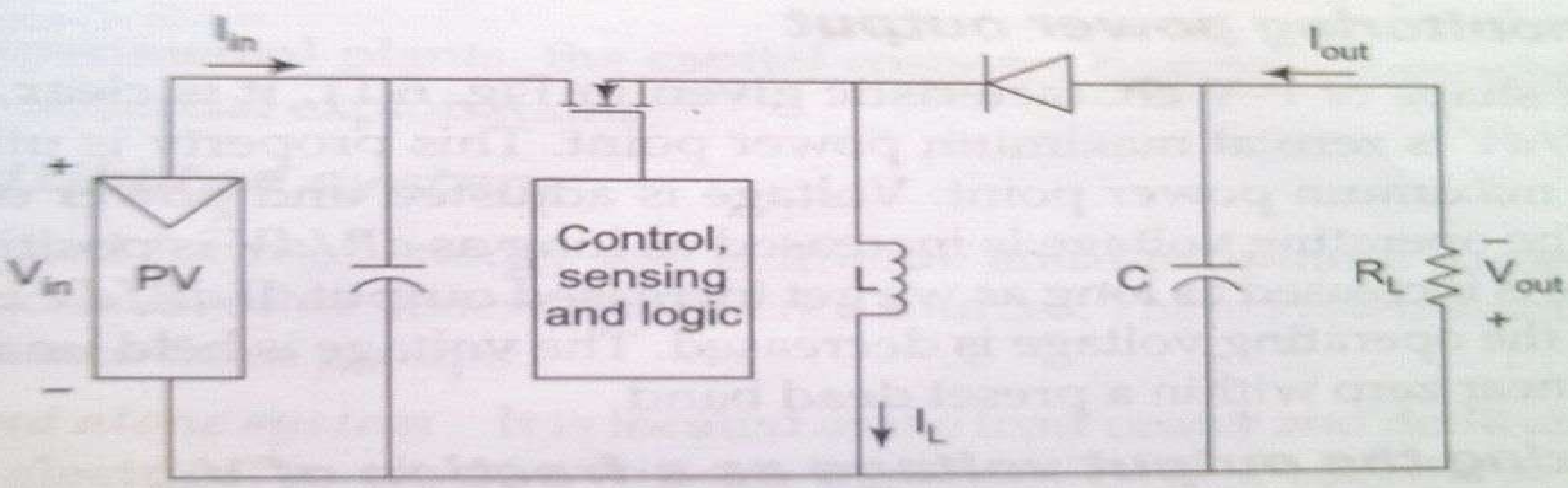
- To receive the maximum power, the load must adjust itself accordingly to track the maximum power point.
- Generally **MPPT** is an adaptation of dc-dc switching voltage regulator.
- A **buck-boost Converter** is normally used.
- Three possible strategies for operation of **MPPT** are:-

  1)By monitoring dynamic and static impedances.

  2)By monitoring the power Output.

  3)By fixing the output voltage.





MPPT using a Buck-Boost Converter

SOLAR PV SYSTEM CLASSIFICATION

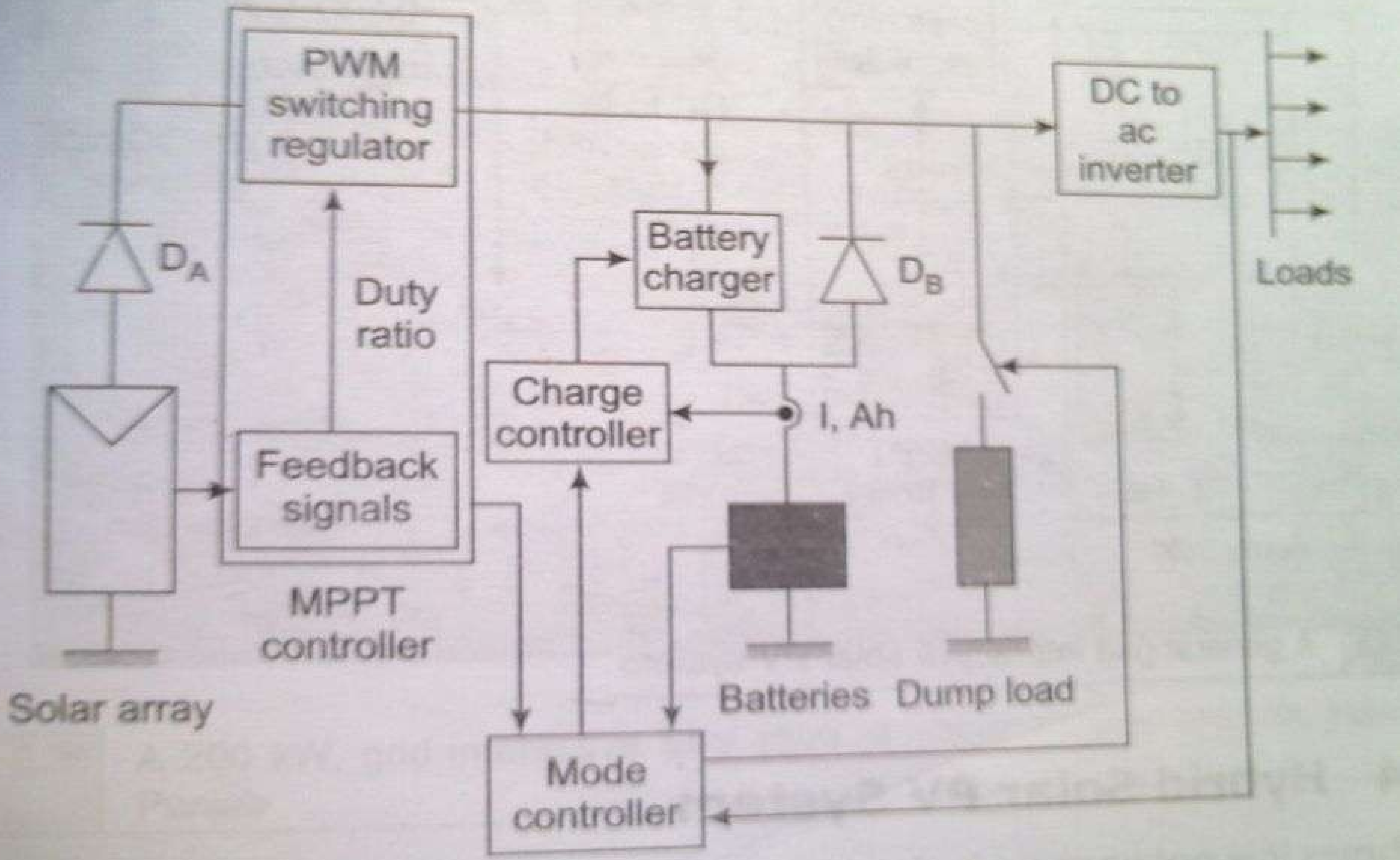
- **Central Power Station System**:- These are conceptually similar to any other conventional power station. They feed power to the grid to meet day time peak loads. The capital costs are high.
- **Distributed System**:- This system is much more successful and unique. It can be further classified into 3 types:

  1)Stand-alone System

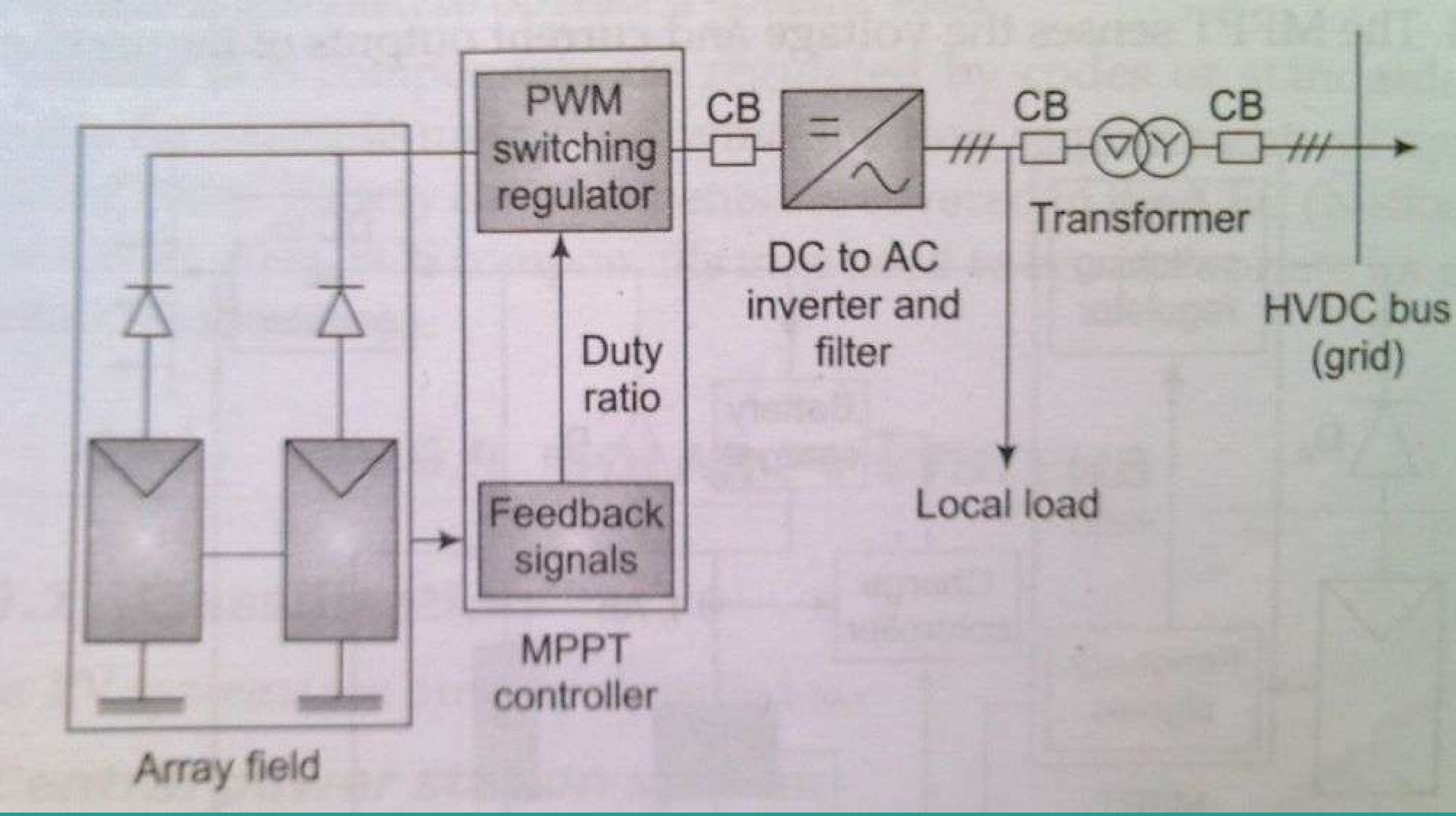
  2)Grid-Interactive System

  3)Hybrid Solar PV System (Consumer applications)

- **Stand-alone Solar PV system:-**Located at the load center and dedicated to meet all the electrical loads of a village/community or a specific set of loads basically in remote or rural areas which have no access to grid supply.
- **Grid-Interactive System:-** It is connected to utility grid with two-way metering system. It is meant for the whole village of community. It is relatively a bigger system.
- **Hybrid Solar PV system:-** These systems are meant for low energy consumer devices. Basically designed for indoor applications.



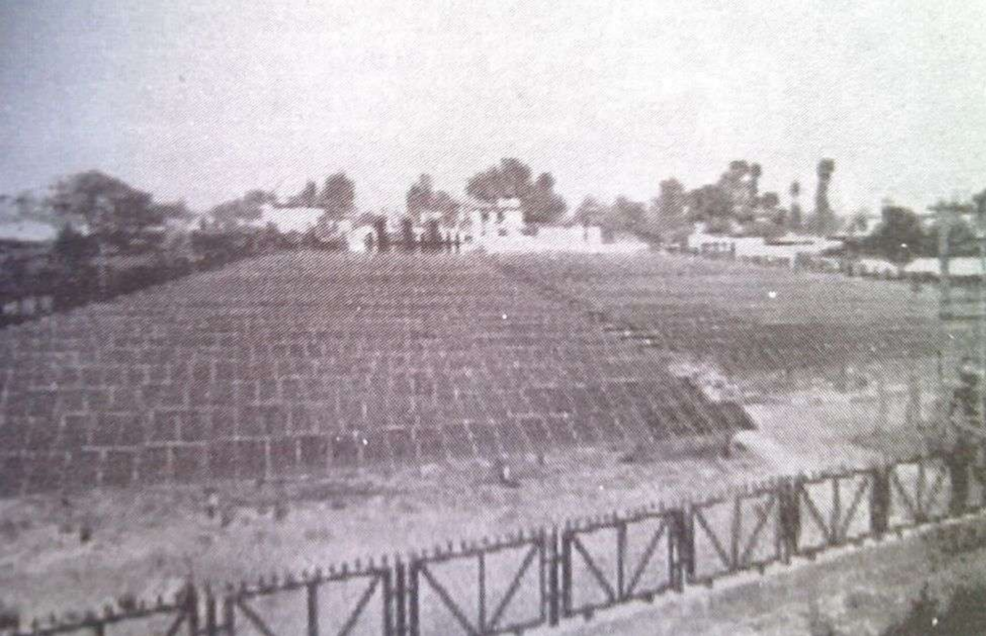
A general stand-alone solar PV system



A general Grid-Interactive solar PV system

SOLAR PV APPLICATIONS

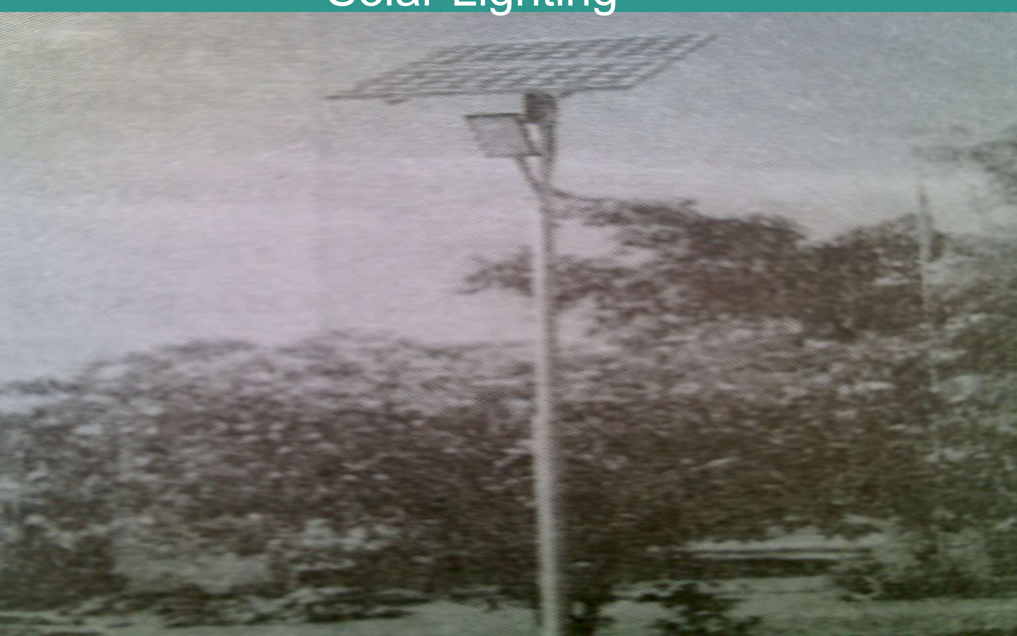
- **Grid-Interactive PV Power generation**
- **Water pumping** for the purpose of drinking or for irrigation during the sunshine hours.
- Besides water pumping, **Lighting** is the second most important application of stand-alone system.
- Used for **Medical Refrigeration** of life saving drugs.
- **Village Power**:- Solar PV power can meet low energy demands of many remote, small, isolated villages.
- Solar PV panel are ideally suited for **Telecommunication and Signaling Applications** such as local telephone exchange, radio and TV broadcasting.



A 200 KW Grid-Interactive plant at punjab

Water Pumping

Solar Lighting



Solar Lantern