Module-2
Solar Radiation Geometry

6.1.2.4 Solar Radiation Geometry

For the analysis of solar radiation, it is essential to understand the radiation geome and the related solar angles. The various solar angles are illustrated in **Fig. 6-7**.

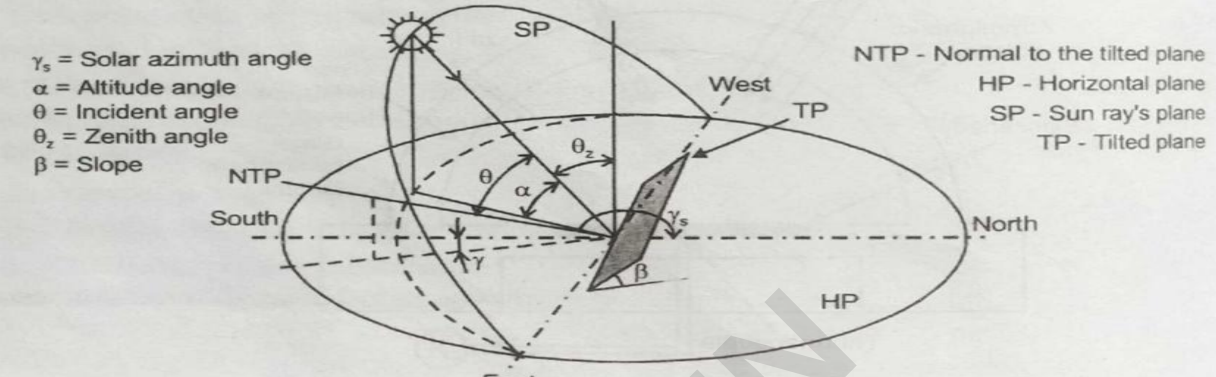
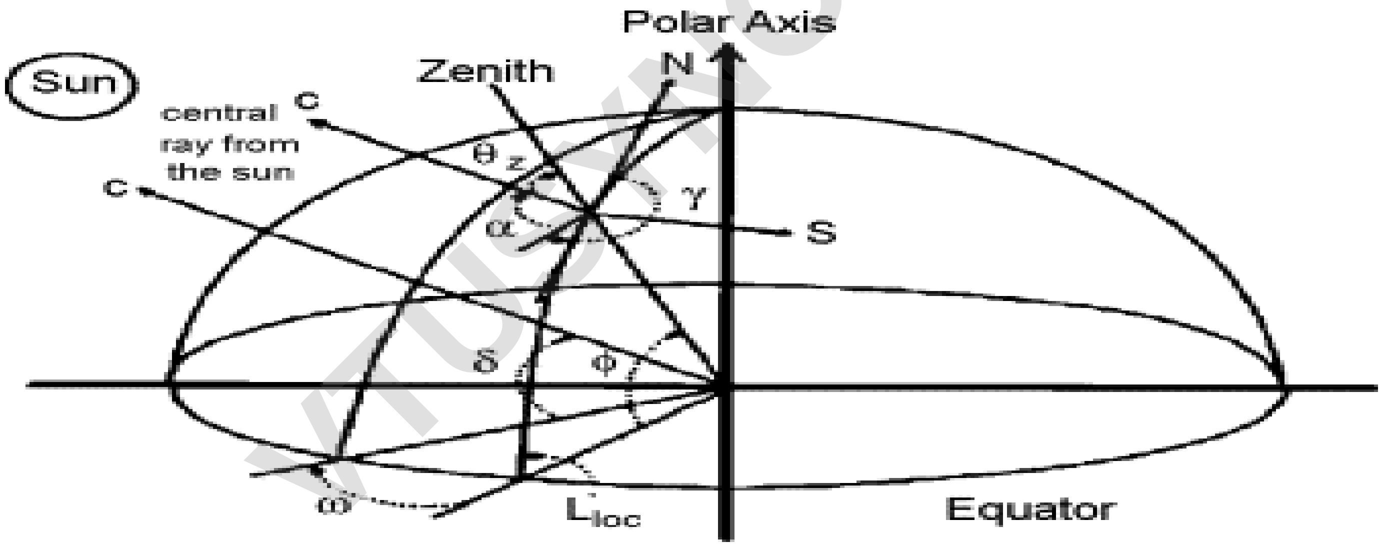
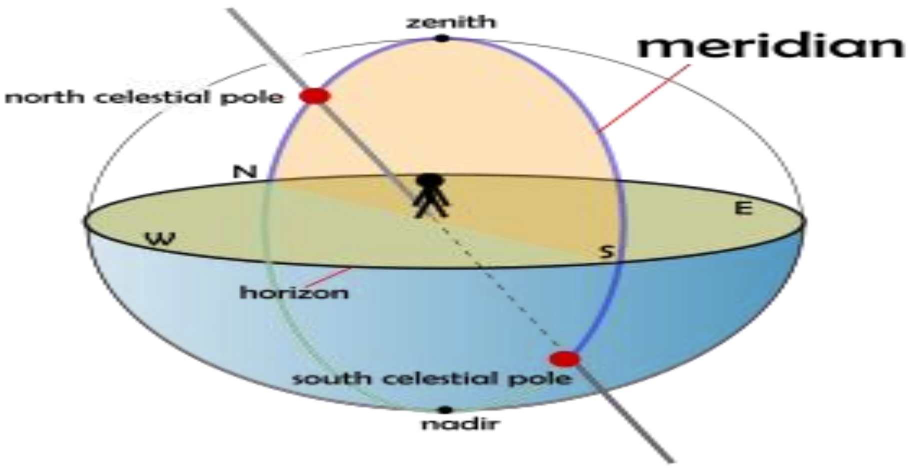


Fig. 6-7. Solar angles





- **Solar Altitude angle(α):**

- Altitude Angle is the angle between the Sun 's rays and projection of the Sun's rays on the horizontal plane.

- **Zenith angle (θ_Z):**

- It is Complementary angle of Sun's Altitude angle.
- It is a vertical angle between Sun's rays and line perpendicular to the horizontal plane through the point i.e. angle between the beam and the vertical.

$$\Theta_Z = \pi/2 - \alpha$$

- **Solar Azimath angle (γ_S):**

- It is the horizontal angle measured from north to the horizontal projection of sun 's rays.

- **Solar Declination angle (δ):**

- The angle between the line joining the centers of the sun and the earth and its projection on the equatorial plane is called the solar declination angle (δ).

- **Meridian:**

- Meridian is the imaginary line passing through a point or place on earth and north and south poles of the earth.

- **Hour angle (ω):**

- Hour angle is the angle through which the earth must turn to bring meridian of the point directly in line with the sun 's rays. Hour angle is equal to 15^o per hour.

- **Surface Azimuth angle(γ):**

- The angle between the normal to the collector and south direction is called surface azimuth angle

- **Solar Incident angle(θ):**

- It is the angle between an incident beam radiation falling on the collector and normal to the plane surface.

- **Slope(β):**

- Angle between the collector surfaces with the horizontal plane is called slope (β).

- **Latitude Angle (φ):**

- The latitude (φ) of a point or location is the angle made by the radial line joining the location to the center of the earth with the projection of the line on the equatorial plane.
- The earth's axis of rotation intersects the earth's surface at 90° latitude (North Pole) and −90° latitude (South Pole).

❖ Radiation Flux on a Tilted Surface

➢ Beam Radiation:

- **Tilt factor (Rb):** The ratio of the beam radiation falling on the tilted surface to that on a horizontal surface is called as Tilt Factor for Beam Radiation.

- For case of tilted surface facing due south $\gamma=0$

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

while for a horizontal surface

$$\cos\theta_z = \sin\phi\sin\delta + \cos\phi\cos\delta\cos\omega$$

Hence $$r_b = \frac{\cos\theta}{\cos\theta_z} = \frac{\sin\delta\sin(\phi-\beta) + \cos\delta\cos\omega\cos(\phi-\beta)}{\sin\phi\sin\delta + \cos\phi\cos\delta\cos\omega}$$

➢ Diffuse Radiation:

- **Tilt factor (Rd):** The ratio of diffuse radiation flux falling on the tilted surface to that of horizontal surface is called The Tilt Factor for Diffuse Radiation.
- Its value depends on the distribution of diffuse radiation over the sky and the portion of the sky dome seen by the tilted surface.
- Assuming that the sky is an isotropic source of diffuse radiation, for a tilted surface with slope. we have

$$r_d = \frac{1+\cos\beta}{2}$$

$(1+\cos\beta)/2$ is the shape factor for a tilted surface w.r.t. sky

➢ Reflected Radiation:

- It is the radiation shape factor for the surface with respect to surrounding ground.
- It given by the relation,

$$R_r = \rho\,(1- \cos\beta / 2)$$

Where ρ is the reflectivity of the ground.

❖ Solar Thermal Conversion

- Solar thermal conversion is the process of converting sunlight into thermal (heat) energy. This heat can then be used for various applications such as water heating, space heating, industrial processes, or even electricity generation.
- It works on the principle of absorbing solar radiation and converting it into heat using a thermal collector.
- The Main Components:
    - Solar collector (flat plate, evacuated tube, or concentrating types)
    - Heat transfer fluid (like water, oil, or air)
    - Storage system (optional, for saving heat)

❖ Collection and Storage in Solar Thermal Conversion

➢ Collection of Solar Thermal Energy

The collection process involves capturing solar radiation and converting it into heat using Solar Collectors.

- Types of Solar Collectors:

➢ Flat Plate Collectors (FPC):

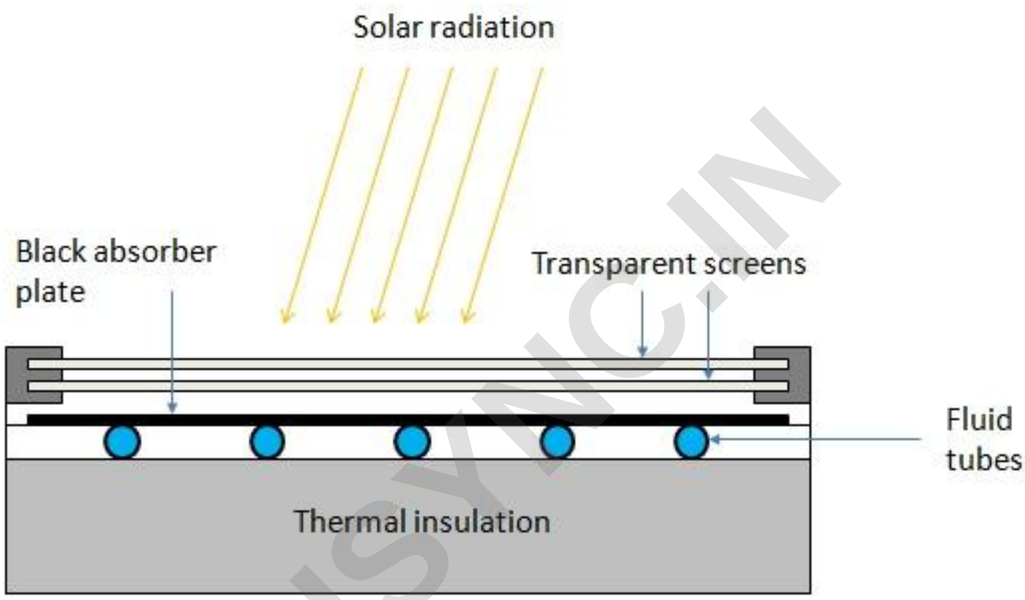
- Common for domestic water heating.
- Consists of a dark absorber plate, transparent cover, insulation, and casing.
- Heats water or air as it passes through tubes on the absorber plate.

➢ Concentrating (Focussing) Collectors:

- Use mirrors/lenses to focus sunlight onto a small area.
- Achieve high temperatures (above 300°C).
- Types: Parabolic trough, Parabolic dish, Heliostat field.

❖ Liquid Flat plate collector (FPC):

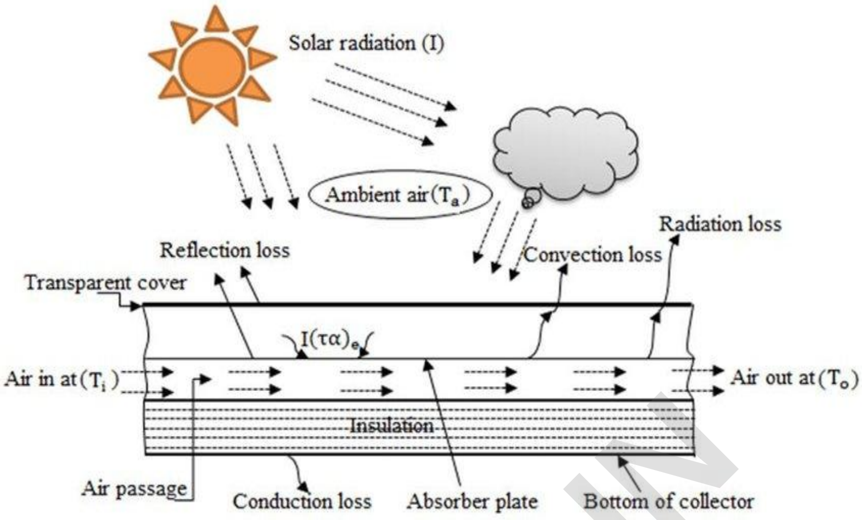
- The constructional details of a simple flat plate collector are shown in Fig. The basic elements in a majority of these collectors are:
- Transparent glass cover (one or two sheets).
- Blackened absorber plate usually made of copper, aluminum or steel,
- Tubes, channels or passages, in thermal contact with the absorber plate.



➢ Construction & Working Principle

- It consists of a insulation made up of wood or plastic provided at the bottom to Prevent conductive heat transfer.
- The absorber plate is made of good conducting material like aluminum or copper which is coated with black to increase its absorption property. i.e., maximum absorption of radiation and minimum amount of emission.
- In operation cold water from the overhead tank is made to flow through water tubes.
- When solar radiation passes through transparent glass cover & falls on the absorber plate it absorbs heat energy.
- This heat energy transferred to the cold water flowing through the tube and gets heated up.
- Heated water being lighter in density than cold water hence it raises up and collects in the solar water heater tank.

❖ Solar Air Heaters



○ Working Principle

- **Solar radiation** passes through the transparent cover (glazing) of the collector.
- The **absorber plate** inside the collector absorbs the solar radiation and heats up.
- Air is passed through the **air duct** (either above, below, or both sides of the absorber plate).
- The **heat from the absorber plate** is transferred to the flowing air.
- As the air gets heated, it becomes lighter and **rises naturally** or is forced to move using a fan.
- The **heated air exits** from the outlet and is used for applications like drying, space heating, etc.
- **Insulation** is provided at the bottom and sides to minimize heat loss.
- The process continues as long as sunlight is available, making it a **renewable and continuous heating system** during daytime.

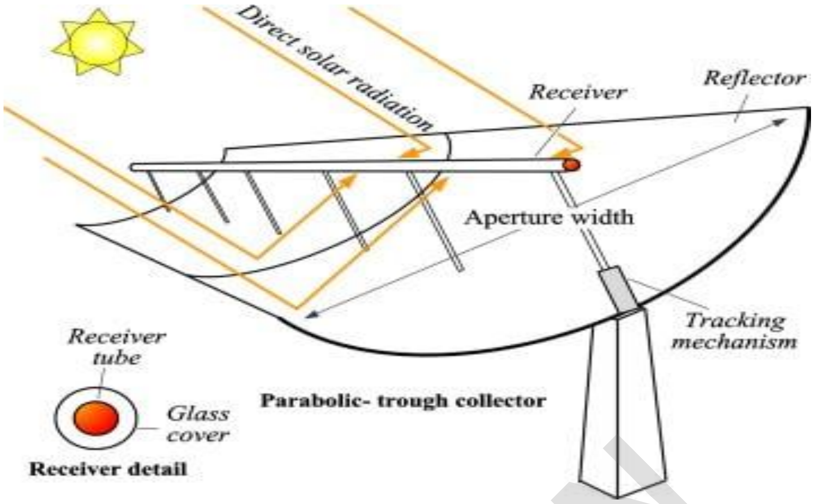
❖ Concentrating Collectors

- These are the solar collectors where the radiation is focused either to a point (focal point of the collector) or along a line (focal axis of the collector).

○ Classification of Concentrating Collectors

- Cylindrical Concentrating Collectors
- Parabolic Concentrating Collectors
- Paraboloidal Concentrating Collector.

❖ Cylindrical Parabolic Concentrator:



- **Working:**

- The curved reflective surface (shaped like a parabola in one direction) is aligned to face the sun.
- Sunlight hits the parabolic surface and is reflected toward the focal line.
- A receiver tube is placed along this focal line, and it carries a working fluid (like oil or water).
- The reflected rays concentrate solar energy onto the receiver tube, heating the fluid.
- The heated fluid can then be used for: Power generation (e.g., by running a turbine), Industrial process heat, Water heating

❖ Compound Parabolic Concentrator (CPC)

- A **Compound Parabolic Concentrator (CPC)** is a type of non-imaging solar concentrator used to collect and focus sunlight onto a small receiver

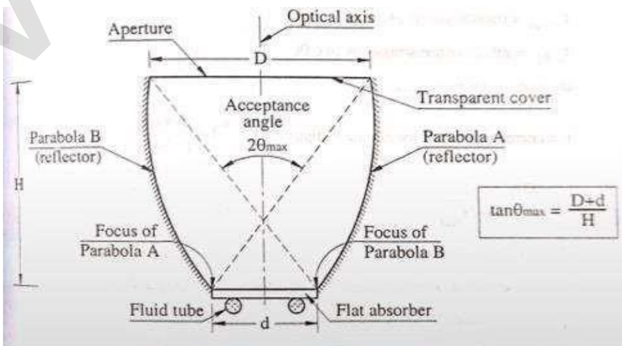


Fig. 2.40 Compound parabolic concentrator (CPC)

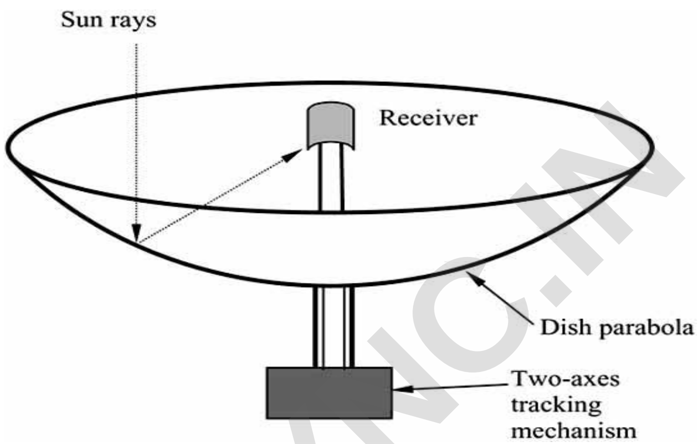
- **Working:**

- Sunlight enters the wide opening of the CPC.
- The inner surfaces of the CPC are curved and reflective (shaped like two joined parabolas).
- Sun rays, even if not directly aligned, are reflected multiple times off the curved surfaces.

- These reflections guide the rays toward the narrow exit at the bottom, where the receiver (absorber) is placed.
- The receiver absorbs the concentrated solar energy, which can be used to heat a fluid (like water or oil) or for thermal applications.

❖ Paraboloidal Dish Collector

- A Paraboloidal Dish Collector (PDC) is a type of solar energy collector that uses a parabolic-shaped dish to concentrate sunlight onto a small receiver. This design allows for the efficient capture and conversion of solar energy into heat or electricity.



▪ Construction

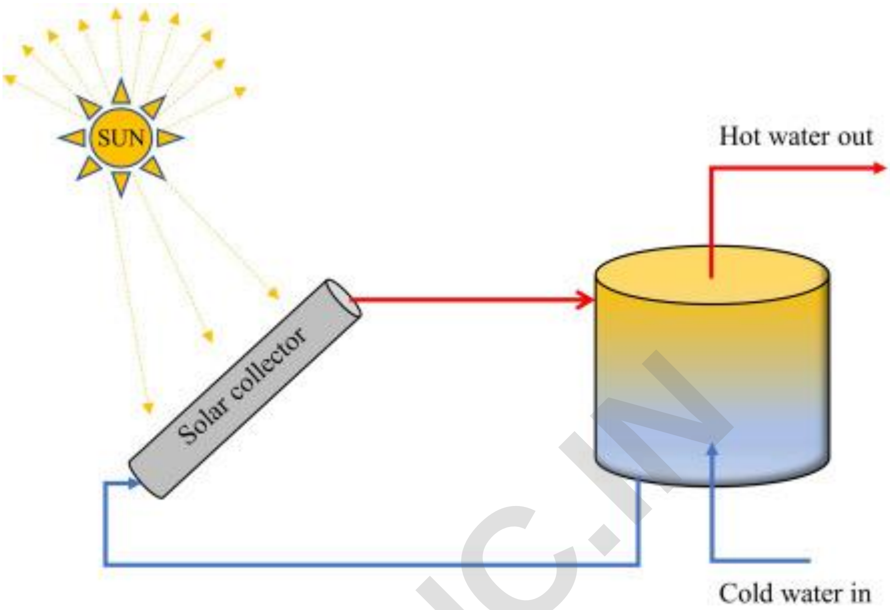
- **Parabolic Reflector (Dish):**
  A large, concave mirror shaped like a paraboloid. It reflects and concentrates sunlight to a single focal point.
- **Receiver (Cavity or Thermal Absorber):**
  Placed at the **focus** of the dish, it absorbs the concentrated solar energy. A heat transfer fluid (like air, oil, or molten salt) flows through the receiver.
- **Support Structure and Tracking System:**
  The dish is mounted on a structure with a **dual-axis solar tracker** to follow the sun throughout the day, ensuring maximum solar capture.

▪ Working:

- A **Paraboloidal Dish Collector** works by using a curved, reflective dish shaped like a paraboloid to focus sunlight onto a small receiver at its focal point. The concentrated solar energy is then absorbed and converted into heat, which can be used to generate electricity or for other thermal applications. The dish follows the sun throughout the day to maximize energy collection.

❖ Applications of Solar Energy

➢ Solar Water Heating



❖ Working Principle

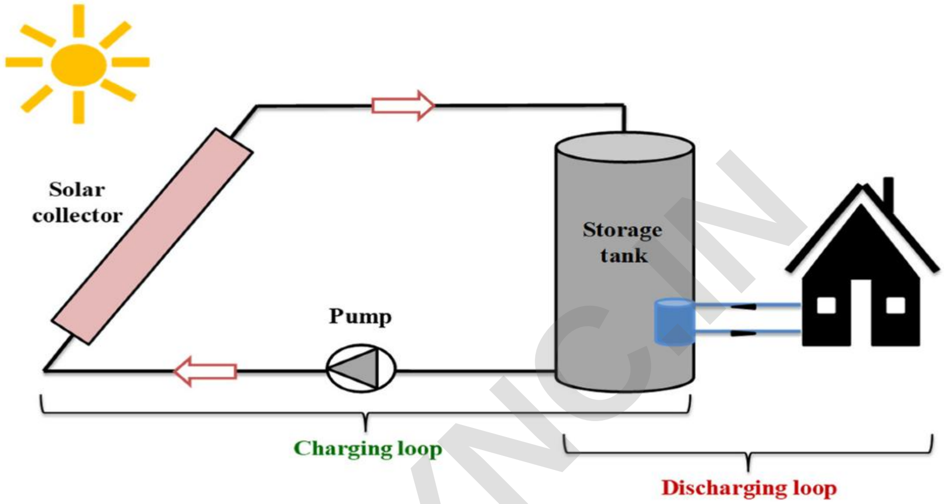
- The Sun rays fall on the Solar Collector. A black absorbing surface (absorber) inside the collector, which absorbs solar radiation and transfers the heat energy to water flowing through it. Heated water is collected in a tank which is insulated to prevent heat loss. Then Circulation of water from the tank through the collector and back to the tank continues automatically.
- A Solar Water Heater consists of a Collector panel to collect solar energy and an Insulated Storage Tank to store hot water.

❖ Applications

- Water heating is one of the major uses of solar energy, it is implemented for providing hot water for showers, dishwashers and clothes washers etc.
- Solar Water Heating System (SWHS) can be used for Homes, Community Centers, Hospitals, Nursing Homes, Hotels, Dairy Plants, Swimming Pools, Canteens, Ashrams, Hostels, Industry etc.
- Use of Solar Water Heater (SWH) can reduce electricity or fuel bills considerably.

❖ Sensible Heat Storage

- **Sensible Heat Storage** is a method of storing thermal energy by increasing or decreasing the temperature of a solid or liquid storage medium without changing its phase.

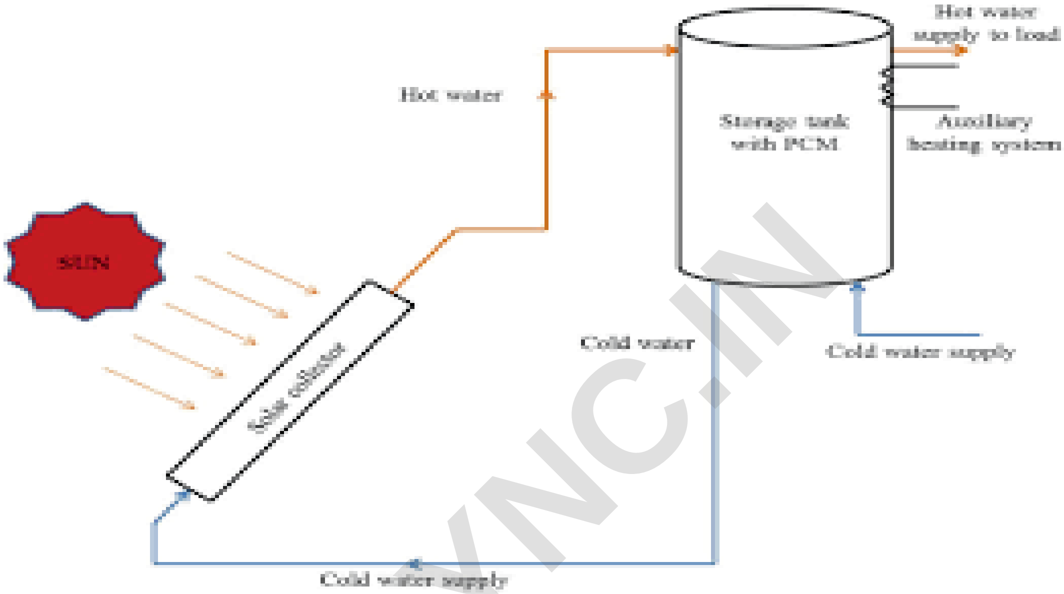


❖ Working Principle

- In this materials like water, oils, molten salts, or solid media such as rocks and concrete are commonly used due to their good heat capacity.
- During the charging process, heat is absorbed, raising the temperature of the medium and storing energy. This stored heat is later released during the discharging phase as the medium cools down.
- The amount of heat stored depends on the material's mass, specific heat capacity, and the temperature difference.
- This system is simple, reliable, and commonly used in solar heating, building temperature control, and industrial heat recovery.

❖ Latent Heat Storage

- Latent Heat Storage is a thermal energy storage method that **stores energy during phase change** (usually solid ⇌ liquid). The stored energy is released when the material returns to its original phase.

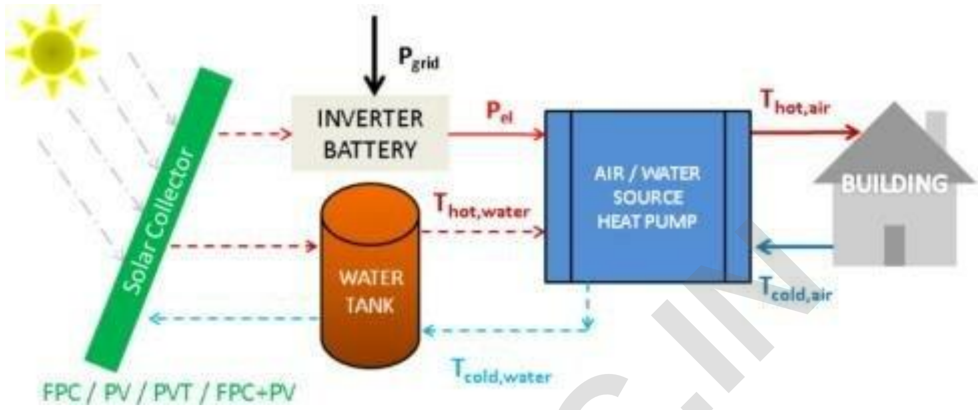


❖ Working Principle

- When heat is supplied, the storage medium—called a phase change material (PCM) absorbs energy and undergoes a phase change (e.g., melting) at a nearly constant temperature, storing a large amount of heat as latent heat.
- During this process, the temperature of the material remains almost constant despite the heat input. When heat is needed, the PCM solidifies, releasing the stored latent heat at the same constant temperature.
- This method allows for **higher energy storage density** compared to sensible heat storage because it uses the energy absorbed or released during the phase transition.

❖ Space Heating

- Space heating systems are used to maintain a comfortable indoor temperature during cold seasons by **adding heat** to a room or building.

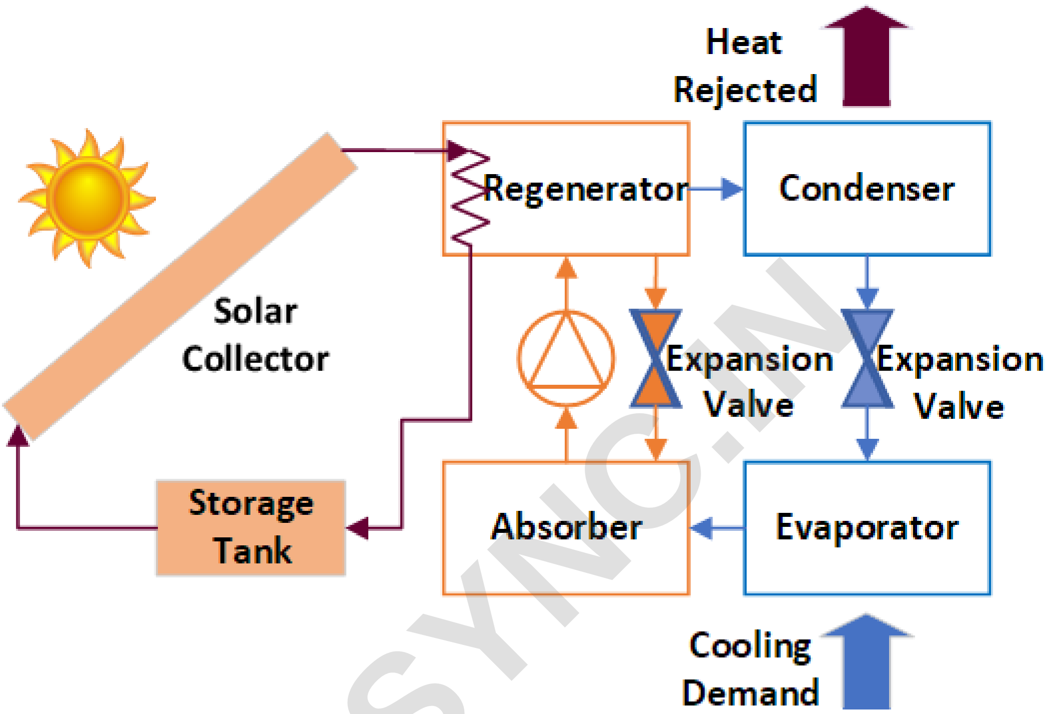


○ Working Principle

- A solar collector absorbs sunlight and converts it into heat energy.
- A heat transfer fluid (either air or liquid) flows through the collector to carry the absorbed heat.
- The heated fluid is sometimes stored in an insulated tank for later use.
- The heat is distributed to the indoor space using radiators, underfloor heating, or air ducts.
- A thermostat controls the room temperature and activates the system as needed.
- A backup heating system may be used when solar energy is not sufficient.
- The fluid then returns to the collector to be reheated, continuing the cycle.

❖ Space Cooling

- Space cooling systems are used to maintain a comfortable temperature during hot seasons by **removing heat** from the space.

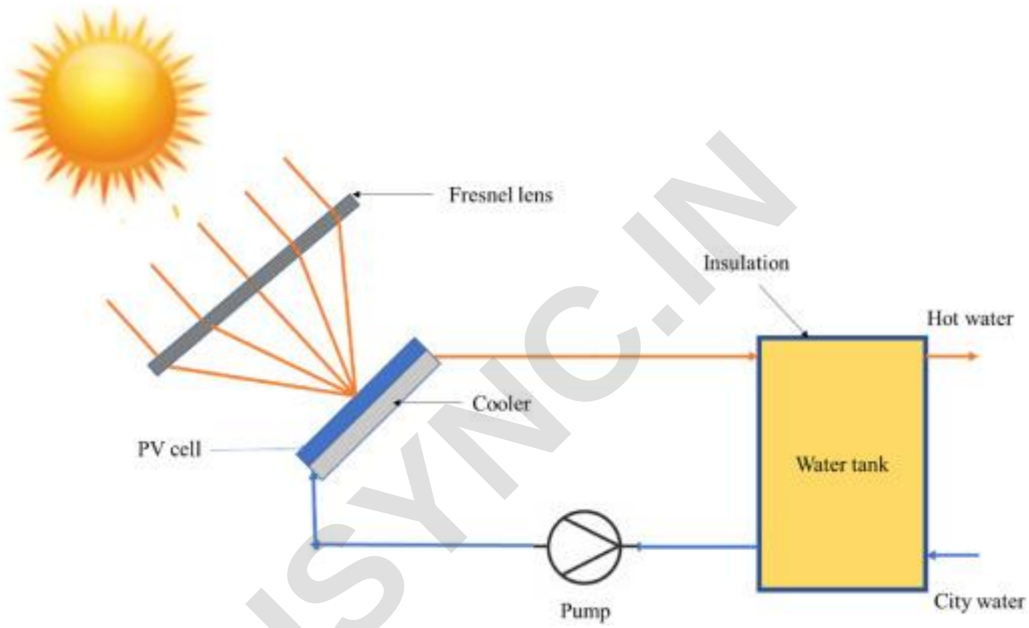


○ Working Principle

- Solar collectors capture sunlight and convert it into heat energy.
- The collected heat is transferred by a fluid to an absorption or adsorption cooling unit.
- The cooling unit uses this heat to drive a refrigeration cycle that produces chilled water or cool air.
- The chilled air or water is circulated inside the building through ducts or fans to cool the indoor space.
- Heat generated during the cooling process is rejected outside via a condenser.
- A thermostat controls the cooling system to maintain desired indoor temperatures.
- Backup cooling systems may operate when solar energy is insufficient.

❖ Active Cooling System

- An **active system** is a solar energy system that uses mechanical devices like pumps or fans to circulate a fluid (water, air, or antifreeze) through solar collectors to collect, store, and distribute heat efficiently.

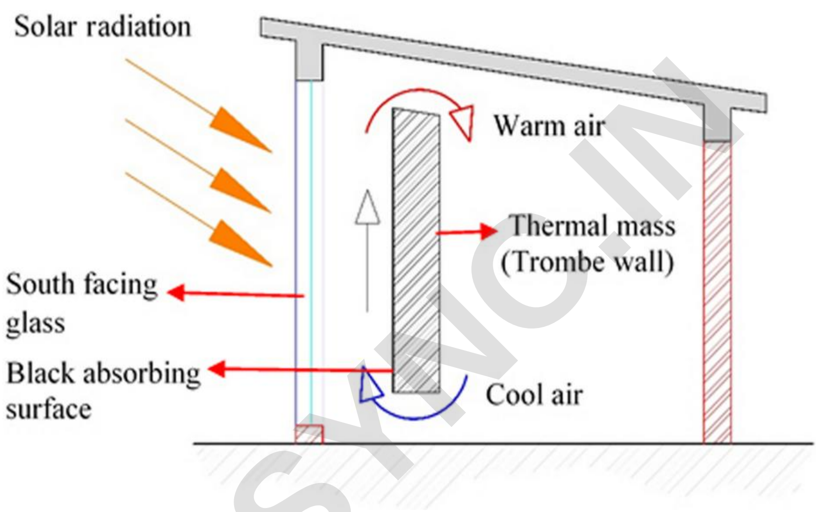


- **Working principle**

- **Solar collectors** capture solar energy and convert it into heat.
- This heat is supplied to a **solar-powered cooling device** (e.g., absorption or adsorption chiller).
- **Pumps or fans** actively circulate the heat transfer fluid (water or air).
- The cooling device uses the heat to generate a **cooling effect** (chilled water or air).
- The cooled air or fluid is distributed to the building for **space cooling**.
- A **controller** manages the system operation based on temperature needs.

❖ Passive Cooling System

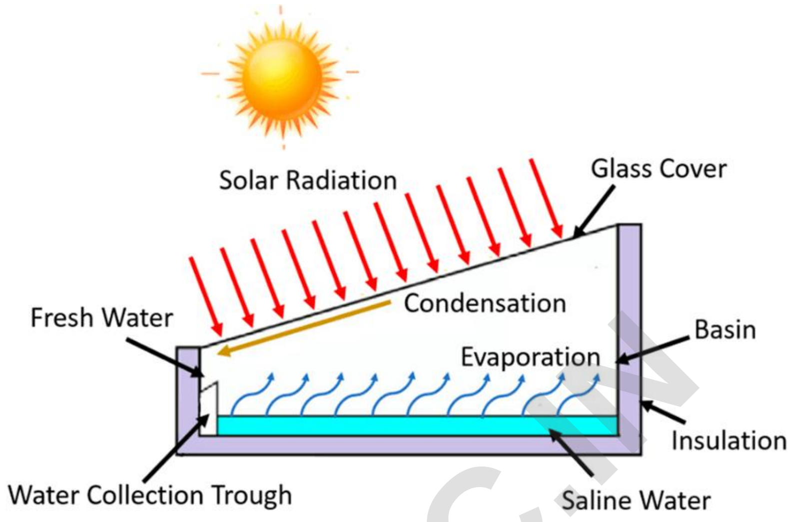
- A **passive system** is a method of utilizing solar energy **without the use of mechanical devices**, relying instead on the **design, materials, and natural heat flow** (like conduction, convection, and radiation) to collect, store, and distribute solar heat for applications such as space heating, cooling, and lighting.



○ Working Principle

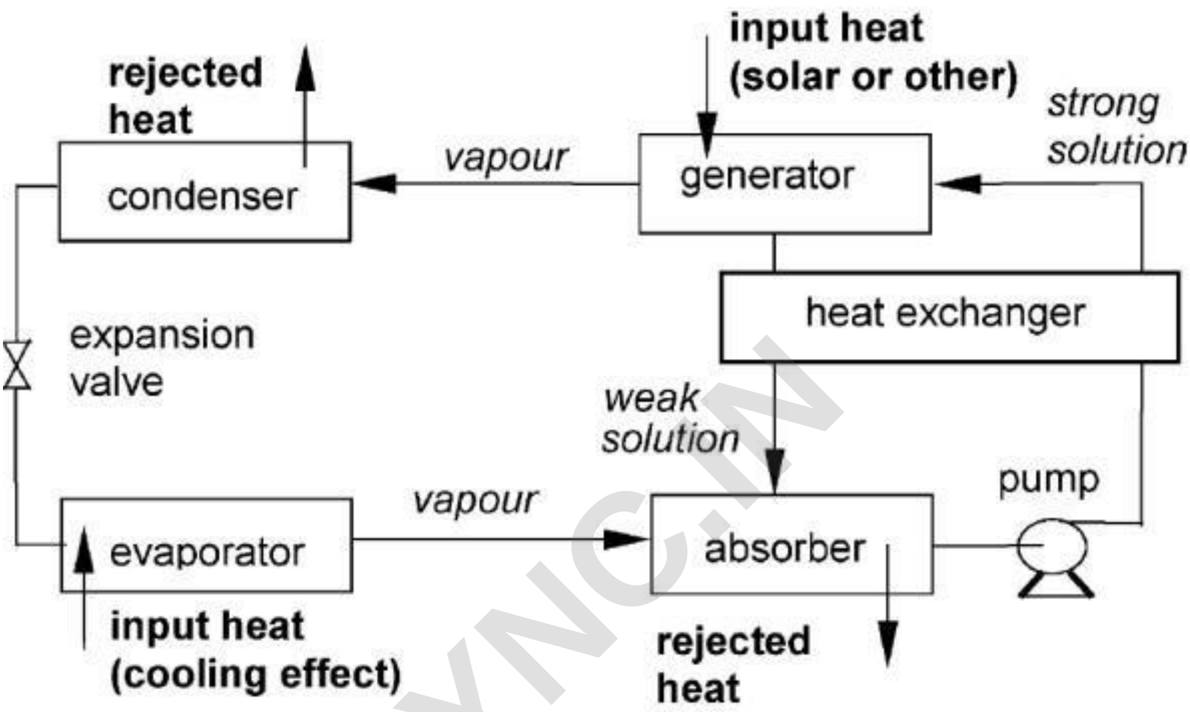
- **Solar radiation** enters the building through properly oriented windows.
- **Thermal mass** (walls, floors) absorbs and stores the heat during the day.
- The stored heat is **gradually released** to warm the building when needed.
- **Natural processes** like conduction, convection, and radiation distribute heat.
- **Ventilation and shading** are used to control temperature and prevent overheating.
- No mechanical devices are used - it works **purely by design and natural heat flow**.

❖ Solar Distillation



- In the solar distillation process, impure or saline water is poured into a black-colored basin inside a solar still. The basin is then covered with a transparent glass or plastic sheet that is slightly sloped.
- When the still is placed under sunlight, the solar energy heats the water inside the basin. As the water heats up, it begins to evaporate, leaving behind impurities, salts, and other contaminants.
- The water vapor rises and comes into contact with the cooler inner surface of the transparent cover. Upon contact, the vapor condenses into water droplets, which then slide down the sloped surface due to gravity. These droplets are collected in a water collection trough or channel, resulting in pure, distilled water.

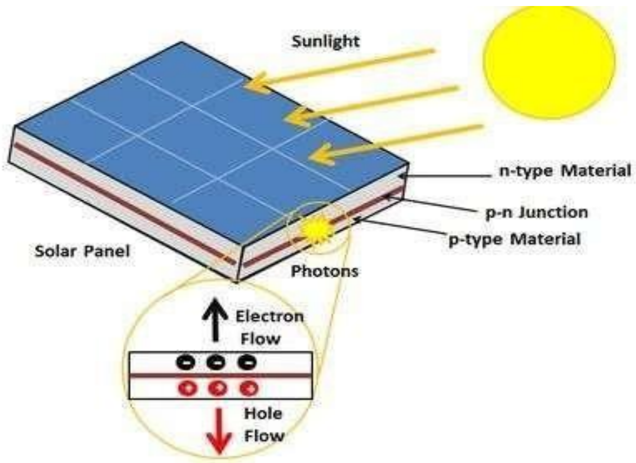
❖ Solar Refrigeration

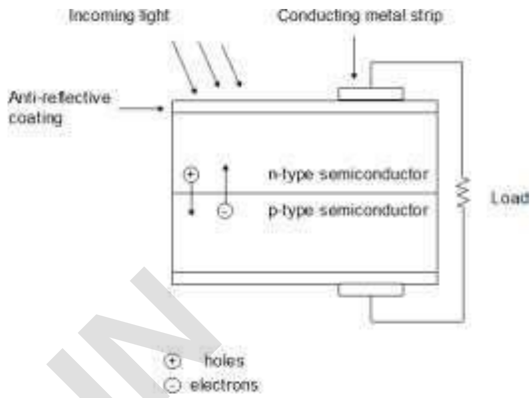


❖ Working Principle

- **Solar collectors** absorb sunlight and convert it into **thermal energy (heat)**.
- The collected heat is used to **heat a regenerator** containing a refrigerant-absorbent mixture (like ammonia-water or lithium bromide-water).
- Due to heating, the **refrigerant (e.g., ammonia)** evaporates and separates from the absorbent.
- The refrigerant vapor moves to the **condenser**, where it **releases heat** and turns into liquid.
- The liquid refrigerant then flows into the **evaporator** through an expansion valve.
- In the evaporator, the refrigerant **evaporates at low pressure**, **absorbing heat** from the refrigeration space (causing cooling).
- The vapor returns to the **absorber**, where it mixes again with the absorbent.
- The cycle repeats using **solar heat** from the collector as the energy source.

❖ Solar Electric Power generation – Solar photovoltaics





- It is a device that converts solar energy into electric current using the photoelectric effect. Photovoltaics are made up of semiconductors & it converts solar radiation into direct current electricity.

❖ Working Principle

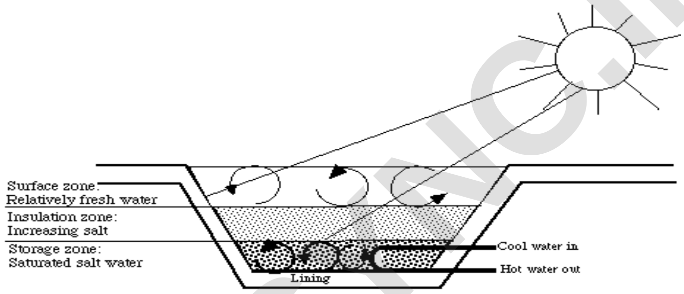
- photo-voltaic cell is made up of semi-conductor materials like silicon one layer has n-type silicon and another layer have P-type silicon and interface between n-type and p-type silicon is called P-n junction.
- In a P-n junction semi-conductor material, electrons from n-side tend to move towards P- side rapidly combine with large number of holes concentration.
- Similarly, holes from P-side tend to move towards n-side rapidly combine with large number of electron concentration, this charge distribution across the junction gives rise to electrical field.
- When a P-n junction semi-conductor material exposed to the sunlight some of the solar photons will have a tendency to dislodge free-electrons from its fixed position in the material.
- Ejected free-electrons tend to move towards p-side and this flow negatively charged electrons constitute an electric current.

❖ Solar pond:

- Solar pond is a pool of salt water used to collect and store solar energy, this heat energy in turn can be used for various such as process heating, water desalination, refrigeration, drying and Solar power generation.

○ **Construction:**

- **Top zone:** It also called as surface zone; it contains less salt content in it and its at atmospheric temperature.
- **Bottom zone:** It also called as storage zone, it high salt content in it and it has a temperature of about 70-85^0 C, which collects and store solar energy in the form of heat.
- **Intermediate zone:** It separates top and bottom zone, layers of water in this zone neither rise nor fall.



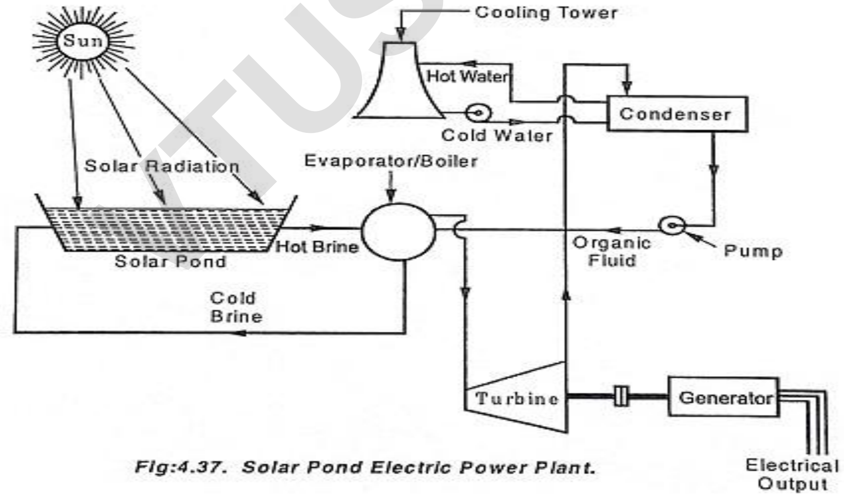


Fig:4.37. Solar Pond Electric Power Plant.

○ **Working principle:**

- In operation pond is filled with salt water, with very high salt content at it's bottom and less salt content at it's top.
- During the sunshine, temperature of water increases by absorbing solar radiation.
- As solar radiation is absorbed, hot water in the storage zone cannot rises up due to high salt content in it.
- Therefore, hot water remains in the bottom layer of the pond from which heat is withdrawn and it can be used for various applications.