

# UNIT – 2

## Solar Energy:

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### - Important Repeated Questions

- 2.1 Solar water heater
- 2.2 Collectors used in modern domestic solar water heater
- 2.3 Solar heating and cooling of buildings
- 2.4 Solar Pumping
- 2.5 Solar cooker
- 2.6 Solar Still
- 2.7 Solar Dryers
- 2.8 Solar Refrigeration and air conditioning
- 2.9 Solar power Plants
- 2.10 Solar Furnace
- 2.11 Solar Chimney Power Plant
- 2.12 Photovoltaic System or Solar cells

### Repeated Questions:

1. **Explain solar radiation geometry terms: Air mass, solar constant, hour angle, declination, altitude, azimuth, etc.**
  - Appeared in: W24 (Q1b, 04 marks), W23 (Q1b, 04 marks), S25 (Q1c, 07 marks), S22 (Q2a, 03 marks), W22 (Q1b, 04 marks)
2. **Explain construction and working of Pyranometer / Pyrheliometer.**
  - Appeared in: W23 (Q1c, 07 marks), W24 (Q2b, 04 marks), S24 (Q1c, 07 marks), S25 (Q2b, 04 marks), W22 (Q2c, 07 marks)
3. **Explain types of solar collectors / flat plate collector / concentrating collectors.**
  - Appeared in: W25 (Q1c, 07 marks), W23 (Q2c, 07 marks), S24 (Q2c, 07 marks OR), S23 (Q2c, 07 marks OR)

### Solar Radiation & Instruments

1. **Define: Direct radiation, Diffuse radiation, Global radiation.**
  - Appeared in: W24 (Q1b, 04 marks)
2. **Calculate day length for given date and latitude.**
  - Appeared in: W23 (Q2c, 07 marks), S22 (Q2c, 07 marks)

### Solar Collectors & Heaters

1. **What is solar air heater? Explain types.**
  - Appeared in: W24 (Q1c, 07 marks)
2. **Explain evacuated tube solar air heater.**
  - Appeared in: S25 (Q2c, 07 marks)
3. **Explain parabolic cylinder / paraboloidal dish collector.**
  - Appeared in: S23 (Q2c, 07 marks), S23 (Q3c, 07 marks)

### Solar Applications

1. **Explain solar dryer.**
  - Appeared in: W25 (Q3a, 03 marks), S22 (Q2b, 04 marks)
2. **Explain solar cooker and methods to improve performance.**
  - Appeared in: W25 (Q2a, 03 marks), S25 (Q2c, 07 marks), W22 (Q5b, 04 marks)
3. **Explain solar still with sketch.**
  - Appeared in: W25 (Q2b, 04 marks), W24 (Q3b, 04 marks), S23 (Q1c, 07 marks)
4. **Explain solar refrigeration and air conditioning.**
  - Appeared in: W25 (Q2c, 07 marks), W24 (Q2c, 07 marks)
5. **Explain solar pond / heliostat / solar furnace.**
  - Appeared in: W24 (Q5a, 03 marks), S23 (Q5c, 07 marks)
6. **Explain photovoltaic system / solar cell working / types.**
  - Appeared in: W25 (Q3c, 07 marks), W23 (Q2a, 03 marks), S24 (Q1b, 04 marks), S25 (Q2a, 03 marks), S22 (Q3a, 03 marks)

Legends: W- Winter, S- Summer, Q- Question and 03/04/07- Marks of Question

### **3.1 SOLAR WATER HEATER:**

- It is a solar system that uses thermal energy of sun to heat water.
- The basic idea behind the solar water heater is piece of black piping filled with water and laid in the sun for the water to heat up. To heat up more water you increase the number of pipes to make a collector and add tank to store the heated water in. The whole system is insulated to minimize heat-loss. Water is cycled through the collector several times to raise the temperature. Some system uses electric pumps to pump water through the system but this increases the cost.
- Alternatively, water can be made to pass through the pipes without a pump using the thermo-syphon effect.
- Basic elements of solar water heater:
  1. Flat plate collector
  2. Storage tank
  3. Circulation system
  4. Control of system

#### **Types of solar water heater:**

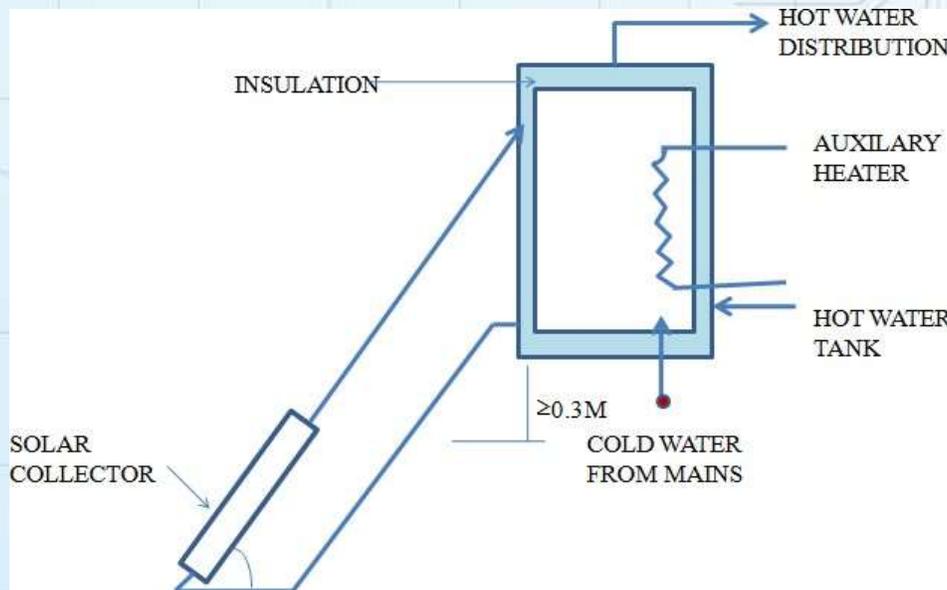
1. Natural circulation/ Passive solar water heater
  - When hot water is taken out from the hot water outlet, the same is replaced b cold water make-up tank fixed above the hot water tank ,water is circulated in the loop naturally due to thermo-syphon action is known as Passive or Natural circulation solar water heater.
  - Natural circulation solar water heater may be pressurized or non-pressurized.
2. Force circulation / Active solar water heater
  - When the collector is fixed above the level of hot water tank. A pump is required to make circulation of water in the loop ,is known as Active or Force circulation solar water heater
  - It can also be classified as :
    - 1 Direct /open loop system
      - An open loop system circulates household water through collector
    - 2 Indirect /closed loop system
      - A closed loop system uses a heat transfer fluid to collect heat and a heat exchanger to transfer the heat to household water.

#### **3.1.1 Natural circulation solar water heater or Passive heating system**

- It is also known as THERMO-SYPHON WATER HEATING SYSTEM.
- THERMO-SYPHON uses the fact that hot water rises above cold water due to density difference.
- It consist of



1. A tilted solar collector facing south with transparent cover glasses
  2. A highly insulated storage tank
  3. Well insulate pipes -connecting collector & tank.
- The storage tank is located above level of collector at least 0.3m above the top edge of collector.
  - As the water in the collector pipes heats up, its density decreases and hence it rises up into the top of the tank, colder water from the bottom of the tank has higher density and so tends to sink and enters into the collector through the lower header.



*Fig 3.1. Natural circulation solar water heater*

- The flow continues until the water in the pipes and the tank is at the same temperature. As long as the sunshine the water will quietly circulate, getting hotter.
- After sunset, the thermo-syphon system can reverse its flow direction and loss heat to surroundings during the night.
- To provide heat during long, cloudy periods an electrical heater is provided in the storage tank.

### **3.1.2 Forced circulation solar water heater or Active heating system**

- The natural circulation solar water heater is normally used for domestic purpose where less amount of hot water is required.
- When a large amount of hot water is required for supplying process heat in an industry or in commercial utilization, a natural circulation solar water heater is not suitable.
- Large arrays of flat plate collectors are then used and forced circulation is maintained with a water pump.
- As shown in Fig, forced circulation solar water heater in which pump is provided in cold water line. Water from a storage tank is pumped through a collector array

- where it is heated and then flow back into the storage tank, colder water takes its place.
- The pump for maintaining the forced circulation is operated by an ON-OFF controller which senses the difference between this temperature of the water at exit of collector and suitable location inside the storage tank.
  - The pump is switched ON whenever this difference exceeds a certain value and OFF when it falls below a certain value.

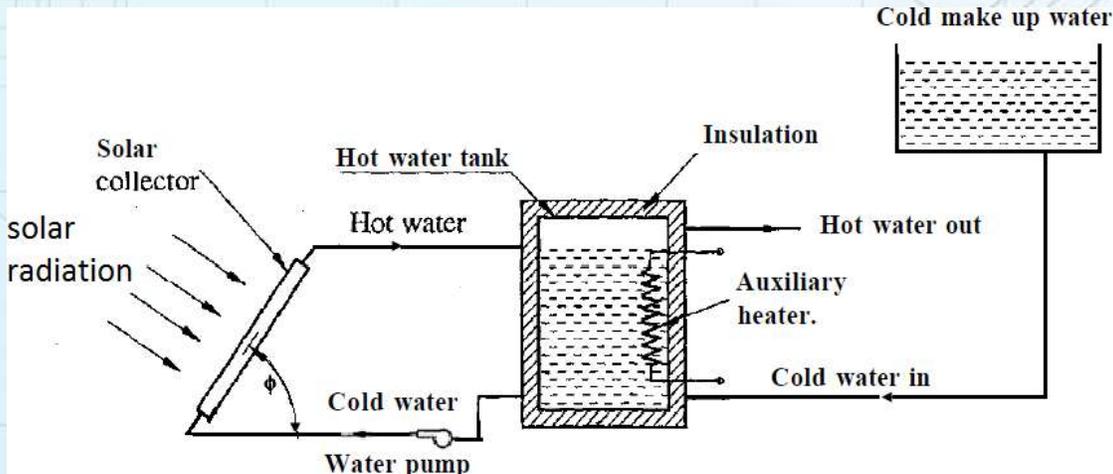


Fig 3.2. Forced circulation solar water heater

### 3.2 COLLECTORS USED IN MODERN DOMESTIC SOLAR WATER HEATER

#### 1. Unglazed liquid flat-plate collector

- Made of a black polymer.
- They do not normally have a selective coating and do not include a frame and insulation at the back
- Low cost
- Thermal losses to environment – high at windy places
- Used for low temperature application

#### 2. Glazed liquid flat-plate collector

- Absorber with selective coating is fixed in a frame between a single or double layer of glass & insulated at back
- Used for moderate temp application

#### 3. Evacuated tube solar collector

- Absorber with selective coating enclosed in sealed glass vacuum tube.
- Thermal losses –low
- Used for moderate to high temperature application

### 3.3 SOLAR HEATING AND COOLING OF BUILDINGS

- It can be broadly classified as
  - 1 Passive space heating / cooling systems
  - 2 Active space heating / cooling system

#### Comparison

Passive space heating / cooling systems	Active space heating / cooling system
1. This system operates without pumps, blowers, or other mechanical devices.	1. In this system, pumps, blowers, or other mechanical devices are required to circulate the working fluid for transportation of heat.
2. A special building design is necessary	2. A special building design is not necessary
3. In this system, the solar radiations are collected by an element of the structure itself. The various elements of the buildings like walls, roof, windows, partitions etc., are so selected and so architecturally integrated that they participate in the collection, storage, transportation and distribution of thermal energy.	3. In this heating system, the solar radiations are collected using some kind of separate collectors. Solar energy may be stored in sensible heat storage materials, or in latent heat storage materials and the energy is redistributed in the building space using pumps, blowers, fans etc.,
4. These systems are suitable where there is ample winter sunshine and an unobstructed southern exposure is possible.	4. Active system can be employed to almost any location and types of building.
5. It is less expensive than active system to construct and operate	5. It is more expensive than passive system to construct and operate

#### 3.3.1 Solar heating of buildings

##### a) Passive solar space heating systems

- The passive solar heating are classified as
  - 1 Direct gain,
  - 2 Thermal storage wall (indirect gain),
  - 3 Thermal storage roof (indirect gain),
  - 4 Attached sun space and
  - 5 Convective loop.

## 1. Direct gain:

- This is the simplest passive solar heating method for heating the building during the winter.
- A double glazed windows facing south as shown in the Fig. or the entire south facing wall is double glazed through which direct radiation in winter enters and strikes floor, walls or other objects in the room; is absorbed and stored as heat. The heat loss from the room is reduced by using double glazes window.
- The floor or walls are made massive to increase the thermal mass which helps in storing the heat during day time when sufficient heat is available and releasing the same during night time. An appropriate overhang is provided above the windows or at the roof level for the case where south wall is glazed shaded the window or the wall during summer when the elevation of the sun is high.
- Adequate movable insulation may be used to reduce heat losses during night.

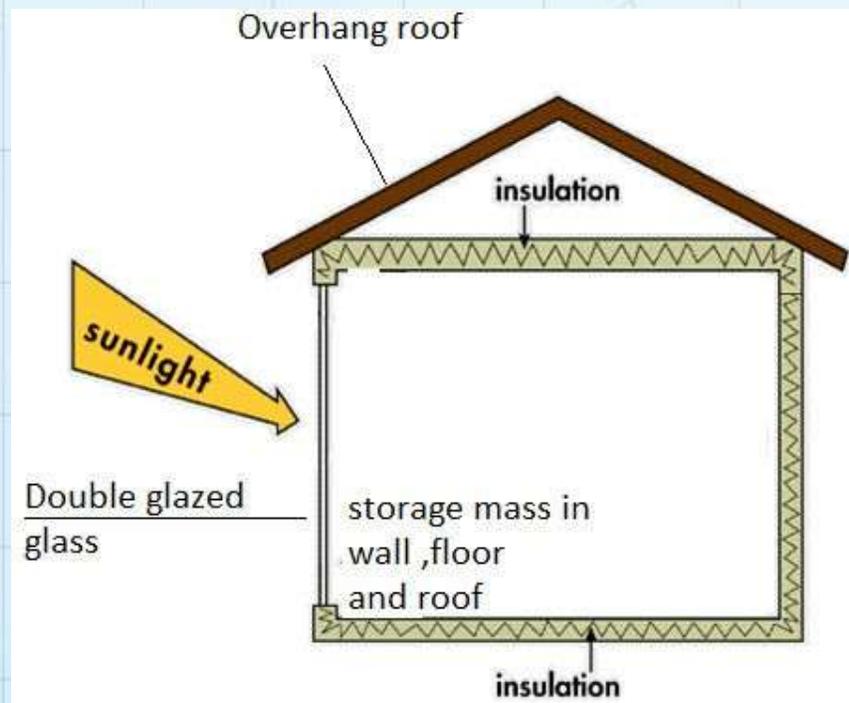
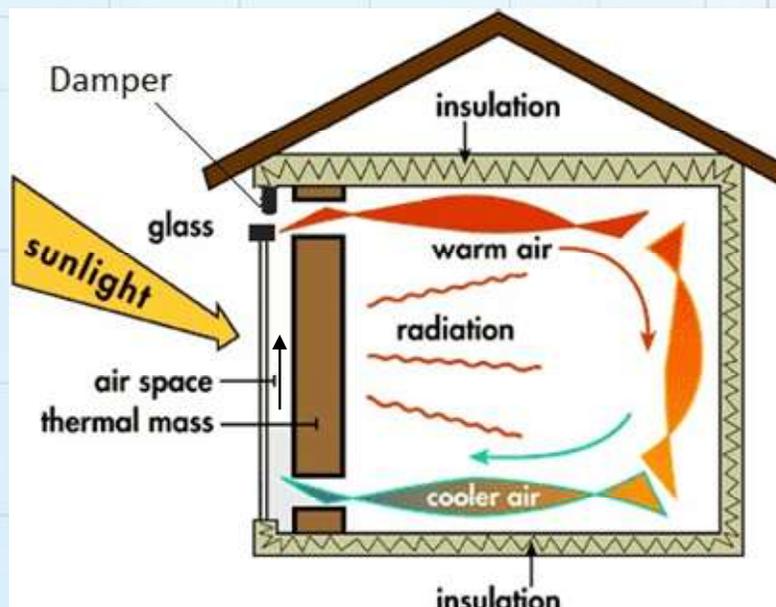


Fig 3.3. Direct gain

## 2. Thermal storage wall:

- In this method, the thermal storage wall is provided between the double glazed facing south and room living space as shown in Fig.3.4.
- Thus this thermal storage wall collects stores and transfers the heat to the room. This wall also known as Trombe wall.
- This is the more effective way of heating the rooms and reducing the large variation in the room air temperature. Also it allows reducing storage mass in floor, roof and walls.

- A south facing thermal storage wall made of masonry or concrete with an outer side facing the sun is blacked.
- The solar radiation after passing through glazing is absorbed by Trombe wall thereby heating it. Hence, air in the gap between the glazing and thermal wall get heated, rises and enters room through the upper vent while the cooled air from the room enters in the gap through bottom vent. This circulation continues till the wall goes on heating the air.
- The dampers are provided at top and bottom vents to control the mass flow rate of air. Room also heated by convection and radiation from thermal wall.
- One additional damper also provided on the top of the glazing to remove the excess heat from the air space.



*Fig 3.4. Thermal storage wall*

### 3. Thermal storage roof:

- This method of heating is similar to thermal storage wall except that the interposed thermal storage mass is on building roof instead of a wall as shown in the Fig.
- The building is provided with metal roof which conducts heat more effectively. Water bags made of transparent or black plastic sheet and filled with water or any other massive material are put over the metal roof.
- In the winters, during daytime when sun is shining, the water in the bags gets heated, stores the heat and heats the room below during day time as well as night time when sun is not shining.
- Movable insulating shutter are used over the water bags. During off sunshine hours or during the night, the insulating shutter are slid over the bags, reducing heat loss from the water bags to the outside.

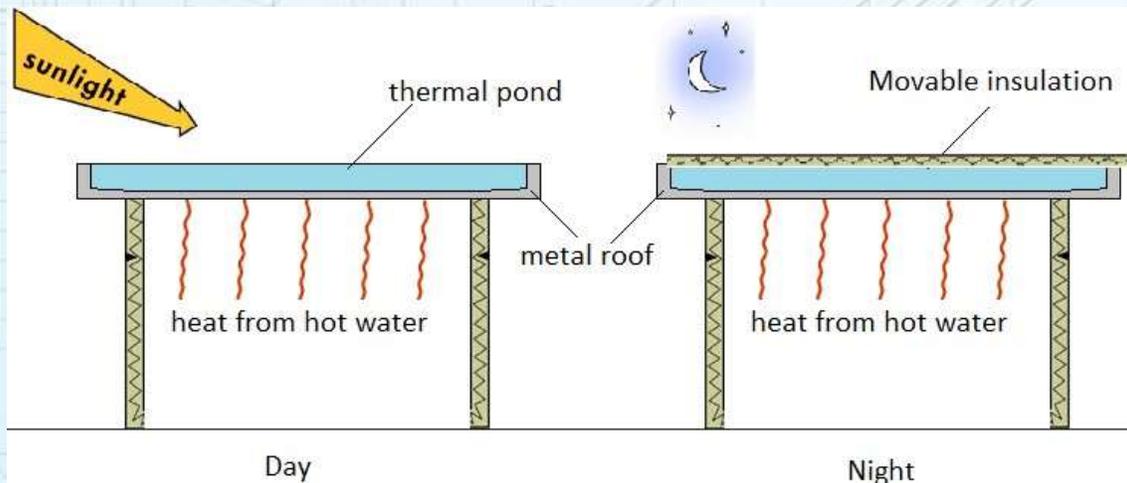


Fig 3.5. Thermal storage roof

#### 4. Attached sun space (green house):

- This method of heating combines features of direct gain and indirect gain (thermal storage).
- A sunspace is an enclosed space on extreme south facing side of the house covered with single or double layers of glass or plastic sheets which function like green house. Andean be used either for growing vegetables or flowers or as sunny space for living.
- The system also consists of thermal storage wall facing south in between the room and sun space. The thermal storage wall gets heated by direct absorption of solar radiation coming through the green house transparent cover.
- The living space is heated through convection and radiation heat transfer from the thermal wall. Vents near the top and bottom of the wall permit the circulation of living room air in the heated sun space.

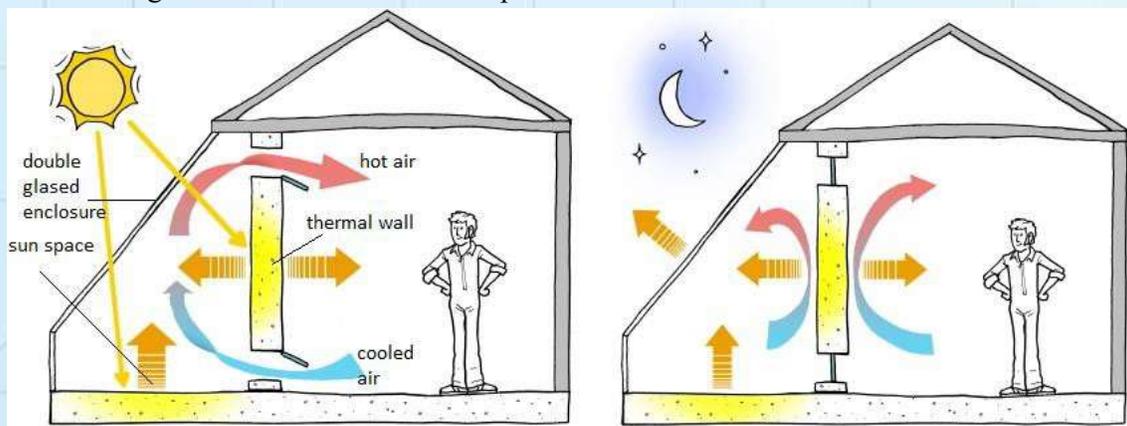
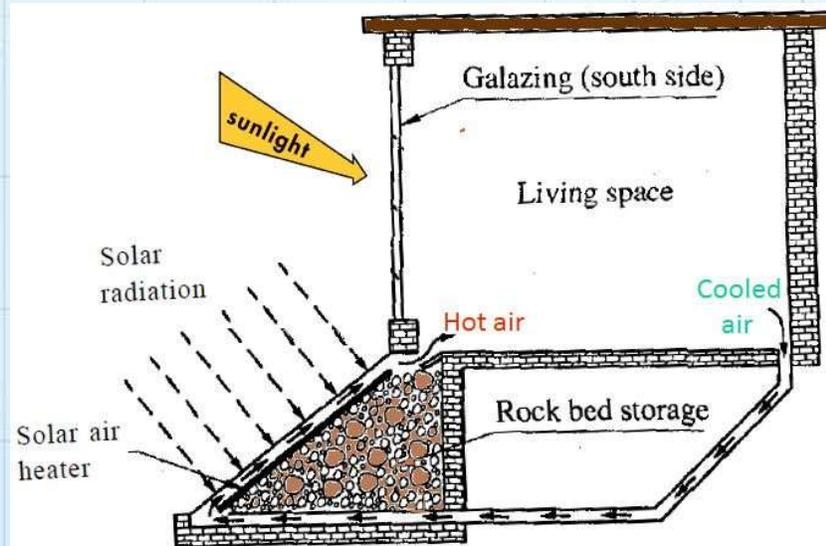


Fig 3.6. Sun space passive solar heating system

#### 5. Convective loop:

- In this heating system the heated air is circulated by means of natural convection (thermo-syphon principle).

- The system consists of
  - solar air heater collector,
  - thermal storage
  - pipes for air circulation
- The bed of rock is located beneath of sunspace, provides thermal storage.
- Air after getting heated in the solar air heater goes either directly into the living room to be heated or through the rock bed thermal storage unit.
- The cool air from the room or from bottom of storage unit enters through the bottom of solar air heater automatically by natural convection and again gets heated, rises and enters the room.
- If more solar heat is available than is required for space heating , the floor vents may be closed.

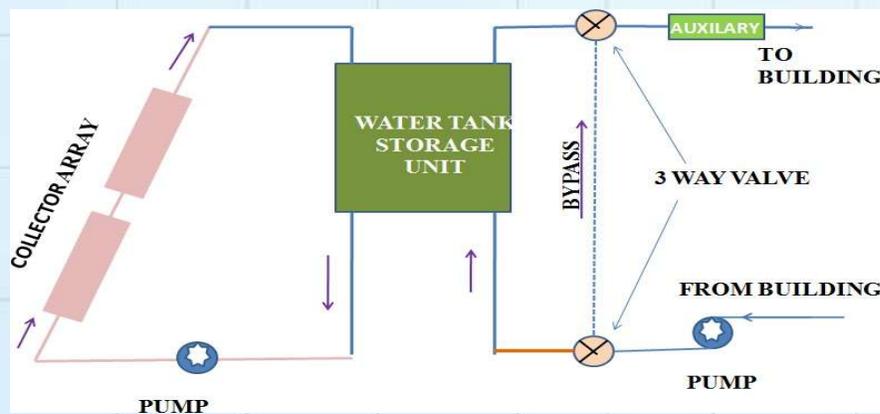


*Fig 3.7. Convective loop passive solar heating system*

### **b) Active solar space heating system**

- In the active system of solar heating, separate solar collectors are used to heat the fluid; storage devices to store heat for use at night and during off sunshine hours; auxiliary heating system to supply heat when required and distribution system along with controls to supply heat to required space.
- If active system is installed in the existing buildings, such a system is called retrofit system.
- However if the buildings are designed which receives more solar energy in winter and less energy in summer, such buildings are called solar house.
- Main components:
  - Solar water collector
  - Heat storage device
  - Pumping device or distribution system
  - Auxiliary heating system

- Control system
- Generally hot water and air as working fluid are used for active space heating system. An active space heating system using water as working fluid is shown schematically in fig.
- In this system, water is heated in solar flat plate collectors and stored in the storage tank.
- Heat is transferred to the air circulating in the space to be heated by mean of the water to air heat exchanger.
- An auxiliary heater is provided in the hot water line which heats water when water temperature falls below the predefined temperature.
- During the normal operation, the three way valves are set to permit solar heated water to flow from the storage tank and auxiliary heater to the distribution system and back to the tank.
- During the long of sunshine hours, the three way valves will adjust automatically to bypass the storage tank and auxiliary heater directly heat exchanger, otherwise large amount to heat is wasted to heat water in the tank.

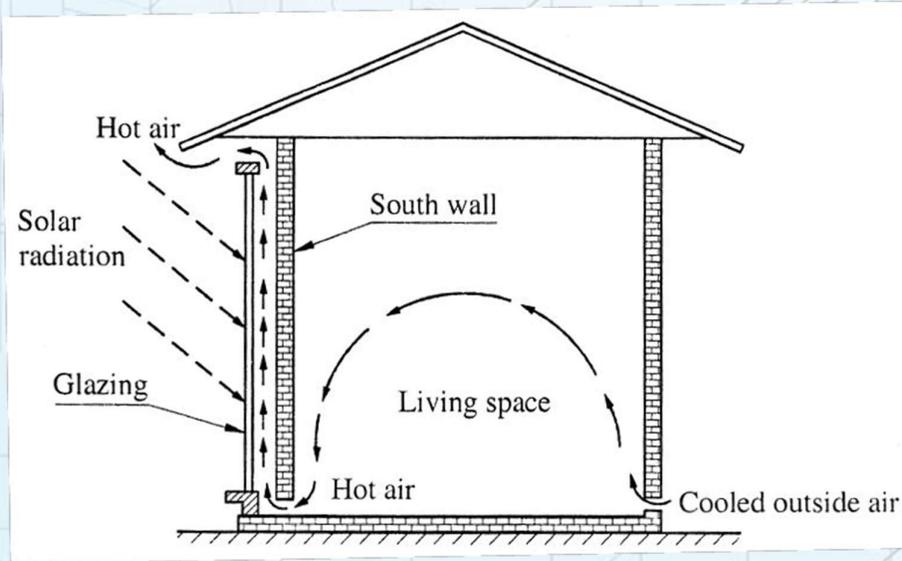


*Fig 3.8. Active solar space heating system*

### **3.3.2 Solar cooling of buildings**

#### **Solar passive cooling through ventilation**

- Ventilation is the process of moving air into and out of an interior space by natural or mechanical means.
- In this method flow of air takes place using chimney effect and is effective where outside temperature is moderate.
- The air between the glazing and the interior south wall is heated by solar radiation.
- The heated air rises up, is ducted outside and the warm air from the room is drawn into this space due to the natural draught thus produced.
- Hence, cooled outside air enters the room from the bottom air vent on the other side of the room.



*Fig 3.9. Solar passive cooling through ventilation*

### 3.4 SOLAR PUMPING

- A solar water pump is a socially and environmentally attractive technology to supply water. Especially if the need for water is in remote locations which are beyond the reach of power lines, solar power is often the economically preferred technology.
- Solar energy can be used for pumping of water in two ways as:
  1. Direct conversion method
  2. Thermodynamic conversion method

#### 1. Direct conversion method:

- In this method, solar energy is directly converted into electricity using Photovoltaic (PV) panels.
- This electricity either stored or used directly in D.C. motor or converted into A.C. using inverter and then used in conventional water pump.
- A typical solar powered pumping system consists of a solar panel array (solar collectors) that powers an electric motor, which in turn powers a bore or surface pump as shown in Fig.
- The water is often pumped from the ground or stream into a storage tank that provides a gravity feed, so energy storage is not needed for these systems.
- The basic system consist of:
  1. Solar panel
  2. Electronic pump enhancer
  3. Pump
  4. Water tank
  5. Supporting pole

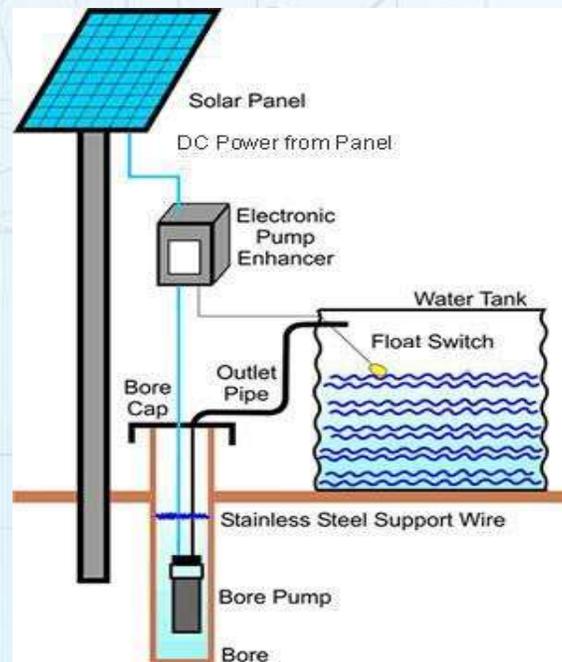
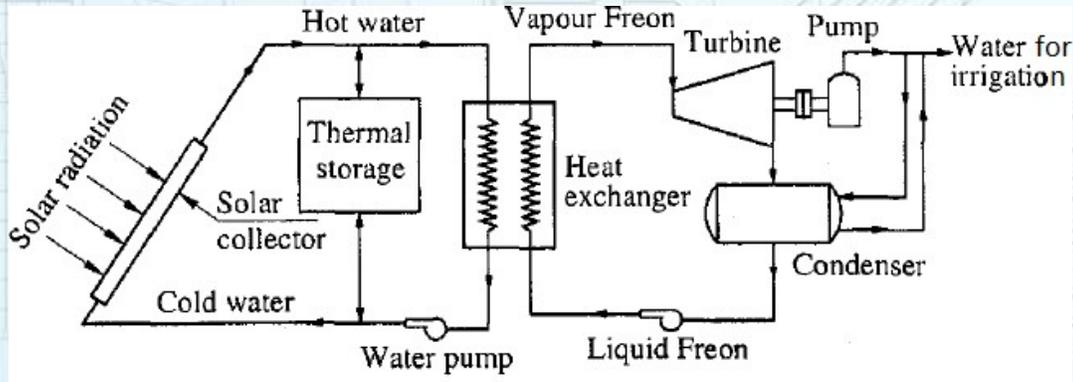


Fig 3.10 Photovoltaic water pumping system

## 2. Thermodynamic conversion method

- In this method, solar energy is first converted mechanical energy and then mechanical energy is used for pumping water.
- In this system some kind of solar energy collectors like flat plate or concentrating type are used for heating a of a working fluid which is then used for operating a Rankine, Brayton or Stirling engine producing mechanical power.
- Rankine cycle is preferred in solar energy conversion over the other two cycles because of its superiority in terms of overall efficiency, components size and high work ratio.
- The system consist of:
  1. Solar collector
    - Flat plate collectors
    - Stationary concentrator
    - Sun tracking concentrators
  2. The heat transport system
  3. Heat exchanger/ boiler
  4. Rankine engine
  5. Condenser
  6. Pump
    - Reciprocating pump
    - Centrifugal pump
    - Diaphragm pump
    - Rotary pump



*Fig 3.11 Solar thermal water pumping system*

- Water is used as a heat transport fluid and conveys its heat to a low boiling point organic Rankine cycle working fluid (Freon R12 or R113 or isobutene) in a heat exchanger.
- The solar collector receives solar energy which is absorbed by water. The hot water gives up heat to Rankine cycle working fluid in the heat exchanger. The high pressure vapours of working fluid produced in heat exchanger is expand in turbine; condense in the condenser and liquid fluid return in heat exchanger. Surplus heat is stored in the thermal storage to be used later when the solar energy is not available.

**Advantages of solar pumping:**

- Simple and reliable, Unattended operation, Low maintenance, no fuel costs or spills, Easy to install, System can be made to be mobile.

**Disadvantages of solar pumping:**

- Potentially high initial costs, Lower output in cloudy weather, Must have good sun exposure between 9 AM and 3 PM.

### 3.5 SOLAR COOKER

- A solar cooker, or solar oven is a device which uses the energy of sunlight to heat food /drink to cook it or sterilize (to make free from micro-organisms) it.
- Thermal energy requirement for cooking purpose forms a major share of total energy consumed, especially in rural area. Using solar energy for cooking purposes is an attractive and relevant option.
- Basically there are three design of solar cooker:
  - 1 Flat plate box type
    - With reflector
    - Without reflector
  - 2 Multi reflector box type
  - 3 Parabolic disc concentrator type solar cooker

Simple solar cooker uses the following basic principles

**Concentrating sunlight:**

- Increasing its heating power

**Converting light to heat**

- Light absorption converts the sun's visible light into heat, substantially improving the effectiveness of the cooker.

**Trapping heat**

- The convection heat transfer from inside the cooker to atmosphere can be reduced by isolating the air inside the cooker from the air outside the cooker. A plastic bag or tightly sealed glass cover will trap the hot air inside.
- This makes it possible to reach similar temperatures on cold and windy days as on hot days.

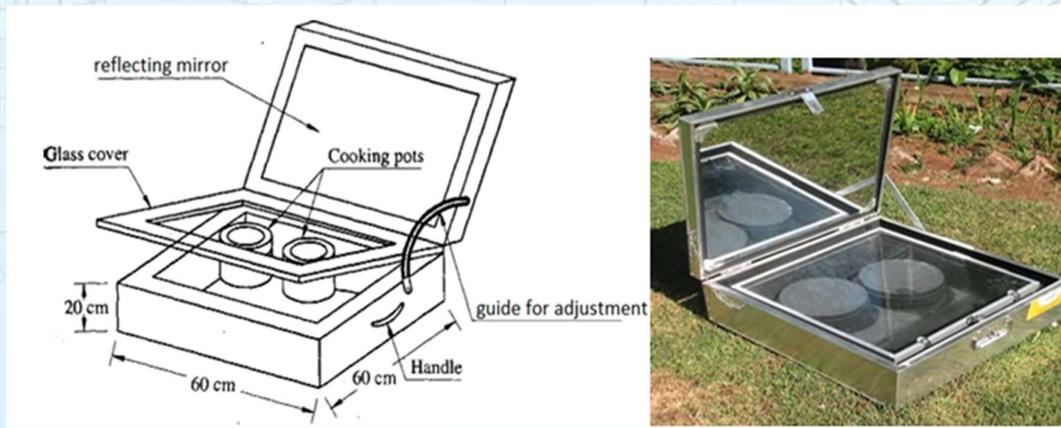
**Greenhouse effect**

- Glass transmits visible light but blocks infrared thermal radiation from escaping. This amplifies the heat trapping effect.

**3.5.1 Box type solar cooker**

- A box cooker consists of
  1. Rectangular enclosure made up of inner and outer metal or wooden box with double glass sheet on it and insulated on bottom and sides,
  2. Top transparent glass covers of each 3 mm thick plain glass,
  3. Reflector mirror,
  4. Cooking pots made from aluminum with blackened coating on outer surface,
  5. Mechanism for adjusting reflector mirror, and
  6. Handle to carry the cooker
- The external dimensions of a typical model are 60cm x 60cm x 20cm height.
- The temperature inside the solar cooker is maintained from 70° to 110°c.
- This temperature is sufficient to cook food slowly steadily and surely with delicious taste and preservation of nutrients.
- Maximum temperature obtained is
  1. 140°C in winter
  2. 160°C in summer
- Solar direct radiation and also reflected radiation (from a reflector mirror) enters through the top transparent glass cover and absorbed by aluminum blackened tray kept inside the solar box. The solar radiation entering the cooker is short wavelength.
- The glass cover reduces re-radiation losses from absorber surface to outside solar cooker. The solar re-radiation (solar energy leaving from absorber surface) has higher wavelength which is not able to pass through the top glass cover. The blackened surface starts absorbing sun rays and temperature inside the box starts rising.

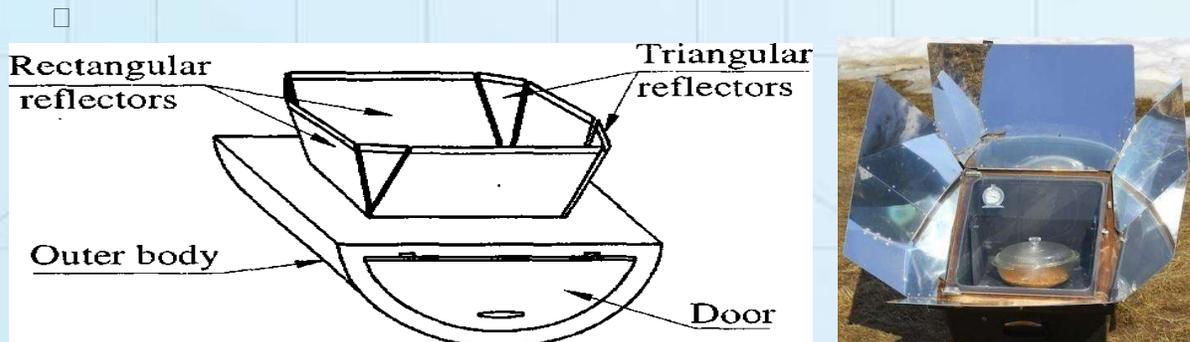
- The cooking pots gets heat energy and food will be cooked in a certain period of time depending upon actual temperature attained inside. The temperature attained depends upon the intensity of solar radiation.
- Depending on the latitude and weather, time of cooking with this cooker ranges from 1 hr to 4 hrs.



*Fig 3.12 Box type solar cooker*

### 3.5.2 Box type solar oven - Multi reflector type

- A box type solar oven was designed by Central Arid Zone Research Institute Jodhpur.
- The solar box type solar oven typically reaches a temperature of 250°C in winter and 350°C in summer.
- In this oven, practically all types of food preparation like cooking, roasting, baking and boiling can be done within 25 to 75 minutes under clear sky conditions.
- This solar oven is ideal for baking purposes.
- A box type solar oven consists of a well-insulated semi-cylindrical box made of sheet aluminum and wood as shown in Fig.



*Fig 3.13 Multi reflector type*

- Two shells are made and the space between them, 7.5cm, is filled with fiber glass insulation. The interior sheet is painted black. A door of a same insulating material is also made for keeping and taking out food.
- The window of the oven consists of two transparent glass sheets. Eight reflectors are provided on the oven, four of square shape and four of triangular shape. The reflectors are made from silver glass mirrors. The oven can be manually tilted and oriented toward sun.
- A cradle like cooking platform is made in the oven which helps in keeping the vessel containing food horizontally irrespective of the sun.
- The main advantage of this solar cooker is that its efficiency is high because its performance is not affected by wind and there are no chances of dust falling in the cooking spots which is problem in the arid zone of India. Moreover, the food remains warm if kept inside the oven for hours together even after sunset.

### 3.5.3 Parabolic disc concentrator type solar cooker

- Parabolic disc concentrator type solar cooker consists of paraboloid reflecting surface as shown in Fig, through which the radiation is concentrated.
- In this cooker cooking pot is placed at focus of paraboloid mirror and is thus directly heated.
- Maximum temperature obtained 450°C
- It can be used for cooking food items requiring roasting, frying or boiling. It can save on fuel for up to 10 LPG cylinders per year for family having 10-15 persons.
- Cooking time 20-30 minutes
- Approximate cost is about Rs.10, 000.
- They generate high temperatures and cook quickly, but require frequent adjustment and supervision for safe operation. Also it requires manual tracking every 15 or 20 minutes. Used for large scale institutional cooking.

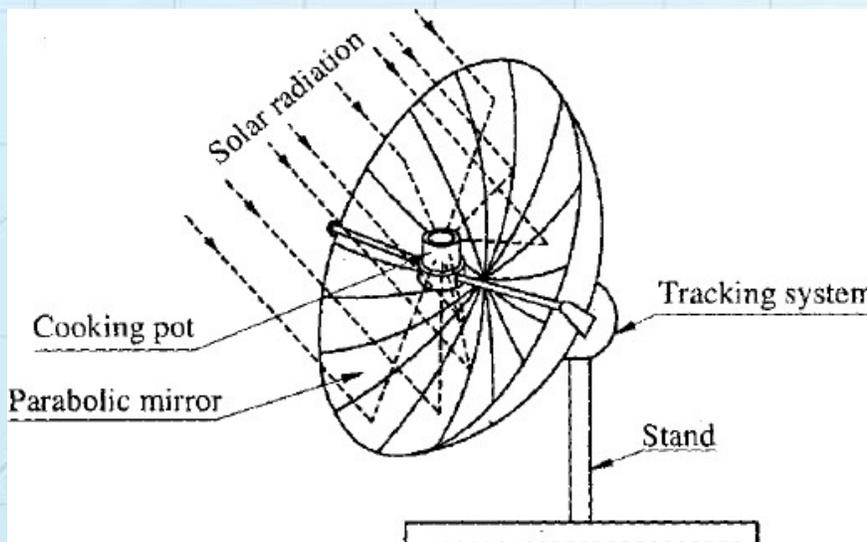


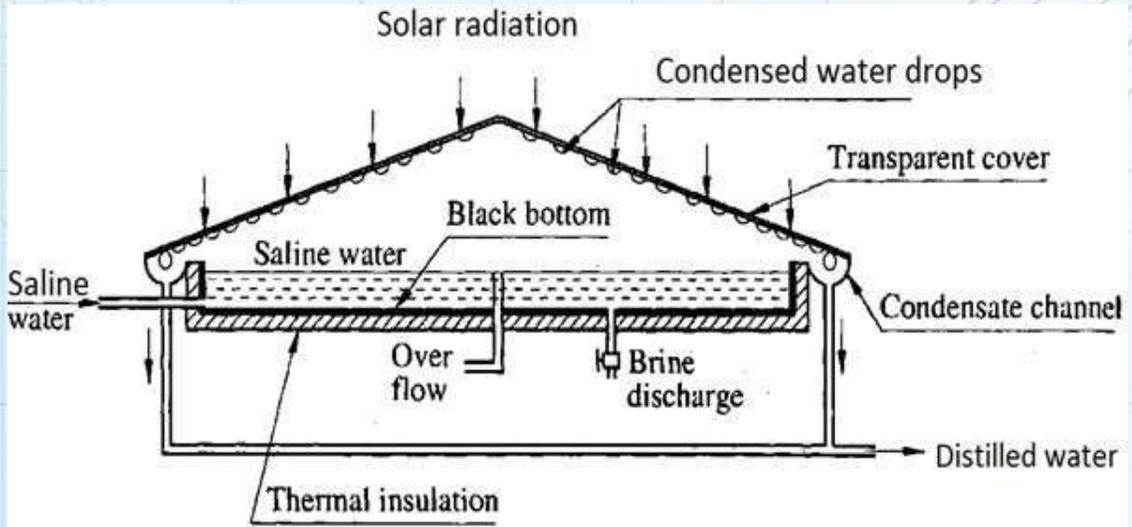
Fig 3.14 Parabolic disc concentrator type solar cooker



### 3.6 SOLAR STILL

- One of the major problems in many parts of world is the scarcity of fresh water (water with less than 500 ppm salt content). Due to climate changes and less rainfall in many parts of the world, fresh water which was available in abundance from rivers, lakes and ponds, is becoming scarce. Also the available resources are getting polluted due to discharge of industrial effluents and sewage in large quantities.
- In this area solar energy is plentiful and can be used for converting saline water into distilled water with help of distillation process.
- Solar distillation process is considered to be one of the simplest and widely adopted techniques for converting sea water into fresh water.
- A solar still is a simple device which converts saline water into fresh water using heat of the sun. Several types of solar stills have evolved. However, only the Basin type solar still has been tried commercially on the large scale.
- The basic principles of solar water distillation are simple yet effective, as distillation replicates the way nature makes rain. The sun's energy heats water to the point of evaporation. As the water evaporates, water vapour rises, condensing on the glass surface for collection. This process removes impurities such as salts and heavy metals as well as eliminates microbiological organisms. The end result is water cleaner than the purest rainwater.
- A simple basin type solar still consists of a shallow blackened basin filled -saline or brackish water to be distilled.
- The depth of water is kept about 5-10cm. It is enclosed with a transparent airtight cover.
- The cover, which usually glass may be plastic, is sloped toward a collection trough(a liquid conveying channel). The transparent roof material transmits nearly all radiation falling on it and absorbs very little, hence it remains cool.

- Solar radiation passed through the cover and is absorbed by bottom blackened surface and converted into heat. Saline water is heated in basin and vapour produce, which is then condensed on the inner surface of glass cover.
- The transparent cover is cool enough to condense water vapour. The condensed water flows down the sloping roof and is collected in troughs at the bottom.
- On a good sunny day, 3 liters/m<sup>2</sup> with efficiency of 30-35 % can be obtained in well designed solar still.



*Fig 3.15 Solar Still*

### 3.7 SOLAR DRYERS

- Drying involves the removal of moisture; this is achieved through the application of heat to the product.
- Due to that water vapour form and it is transferred to surrounding through evaporation.
- Drying process can be possible by two methods:
  1. Sun drying
    - Product directly placed under sunlight
  2. Solar drying
    - Product is placed in solar dryer device & then under sunlight
    - Hence it gives faster drying rates.

#### Types of solar dryers

There are mainly three types of solar dryers:

- 1 Direct type solar dryer
  - with
    1. natural convection type
    2. forced convection type
- 2 Indirect type with forced circulation type solar dryer
- 3 Mixed mode type solar dryer

### 3.7.1 Direct type with natural convection type solar dryer

- Direct drying uses incident radiation only or incident radiation plus reflected radiation.
- Most solar drying techniques that use only direct solar energy also use some means to reflect additional radiation onto the product to further increase its temperature.
- An example of direct absorption dryer is the Cabinet dryer.
- The aim of this type of a dryer is mainly to improve product quality by reducing contamination by dust, insect infestation, and animal or human interference.
- It consists of an enclosure with a transparent top and blackened interior surfaces. Ventilation holes in the base and upper parts of side walls maintained a natural air circulation. The material to be dried is placed on perforated trays.
- Solar radiation entering the enclosure is absorbed in the product itself and the surrounding blackened interior surfaces of enclosure. Therefore, moisture is removed from the product and air inside is heated
- Temperatures ranging from 50 °C to 80 °C are normally attained by this type of solar dryer and the drying time ranges from 2 to 4 days.
- It can be used for drying such as grapes, dates, apricots, chilies etc.

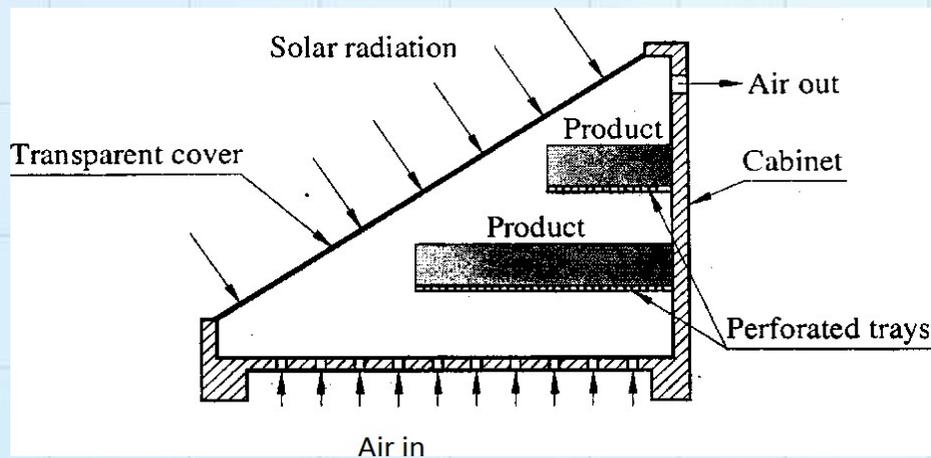
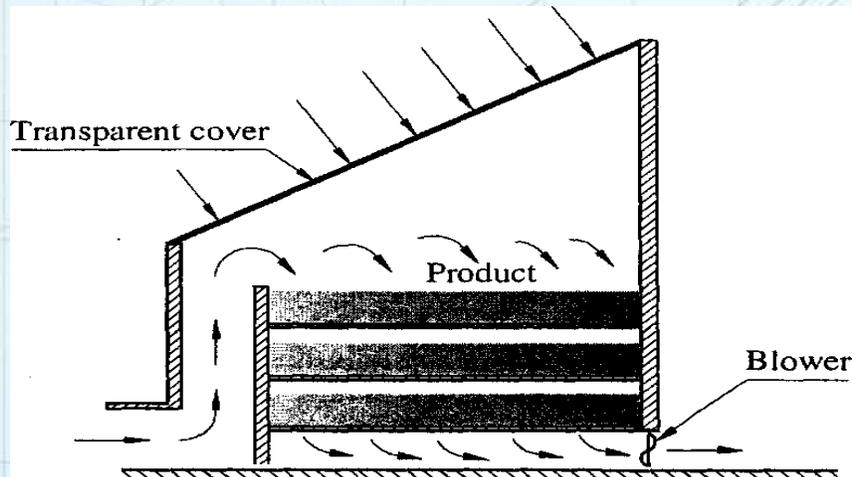


Fig 3.16 Direct type with natural convection type solar dryer

### 3.7.2 Direct type with forced convection type solar dryer

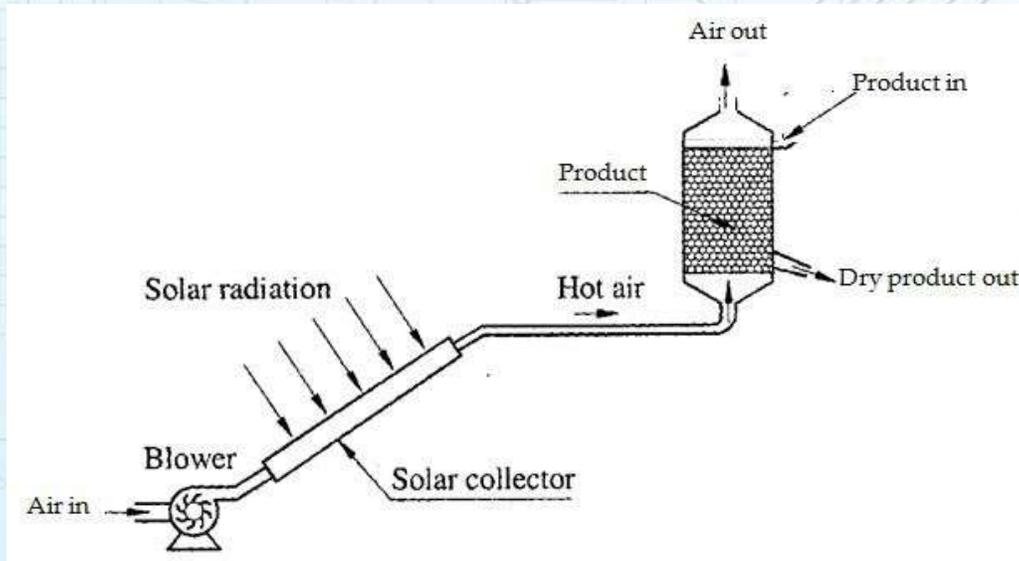
- In this type of dryer, some kind of blower is used for the circulation of air which is either operated electrically or mechanically.
- Such dryers are more efficient, faster, and can be used for drying large quantities of agricultural products.
- The forced circulation type dryer may be direct or indirect types. The direct mode type forced circulation drier is similar to direct type natural circulation except that here natural circulation of air is replaced by forced circulation.
- Used for drying timber.



*Fig 3.17 Direct type with forced convection type solar dryer*

### **3.7.3 Indirect type with forced convection type solar dryer**

- Indirect mode type forced circulation dryers are very efficient, can be used at low as well as high temperatures, and for large quantities of agricultural products.
- Normally, the indirect mode type forced circulation dryers are used when the solar radiation falling directly is not adequate and temperature of product need to be controlled.
- The main idea behind this type of a dryer is to obtain a low cost multi-product system. Also, it leads to choose a drying chamber able to accommodate different kinds of trays.
- Indirect mode with force convection type drier consists of chamber in which the product to be dried is stored and a separate solar air heater which receives solar radiation and convey the heated air to the chamber.
- This type of dryer is suitable for food grains, tea, spices etc. and for the products like leather and ceramics.



*Fig 3.18 Indirect type with forced convection type solar dryer*

### **3.7.4 Mixed mode type solar dryer**

- This utilizes both direct and indirect solar radiation.
- In these types of systems, radiant energy from the sun falls directly onto the product being dried; however, in addition, a preheater also is used to raise the air temperature, which in turn, accelerates the drying rate.
- Acceleration of drying rate can occur in two ways: hot air can transfer some of its heat to the product being dried, thus raising its vapour pressure causing a faster moisture loss; or as temperature of air mass increases, the water-holding capacity also increases.

## **3.8 SOLAR REFRIGERATION AND AIR CONDITIONING**

- There is major environmental concern regarding conventional refrigeration technologies including contribution to ozone layer depletion and global warming.
- The use of solar energy to power refrigeration strives to minimize the negative impacts refrigerators have on the environment.

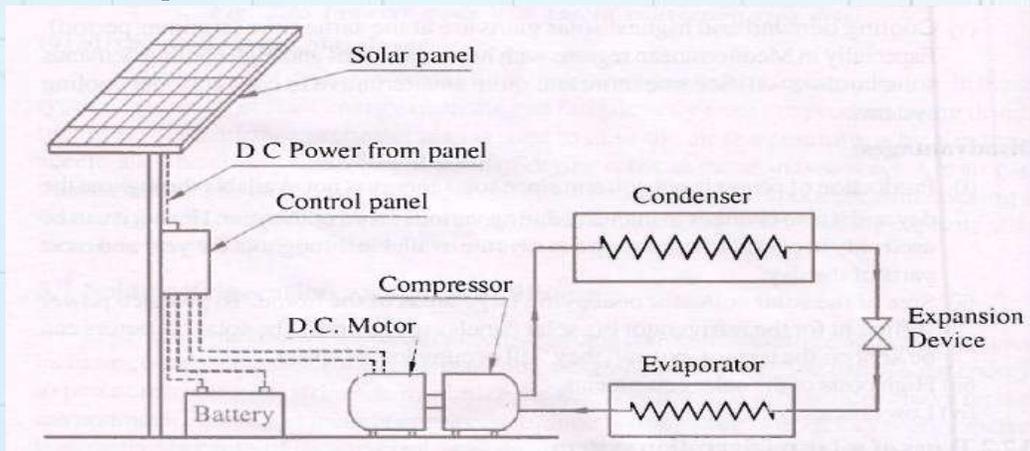
### **Types of Solar refrigeration system**

- 1 Photovoltaic operated refrigeration system
- 2 refrigeration system with thermal collectors
  - Vapour compression refrigeration system
  - Vapour absorption refrigeration system

### **3.8.1 Photovoltaic operated refrigeration system**

- Photovoltaic involve the direct conversion of solar radiation to D.C. using semi conducting materials.

- Solar photovoltaic panel produce D.C. electrical power that can be used to operate D.C. motor, which is coupled to the compressor of a vapour compression refrigeration system.
- The system consist of
  1. Compression
  2. condenser
  3. Expansion valve
  4. Evaporator
- The power is supplied not by the domestic electrical supply system, but from the solar PV panel.



*Fig 3.19 Photovoltaic operated refrigeration system*

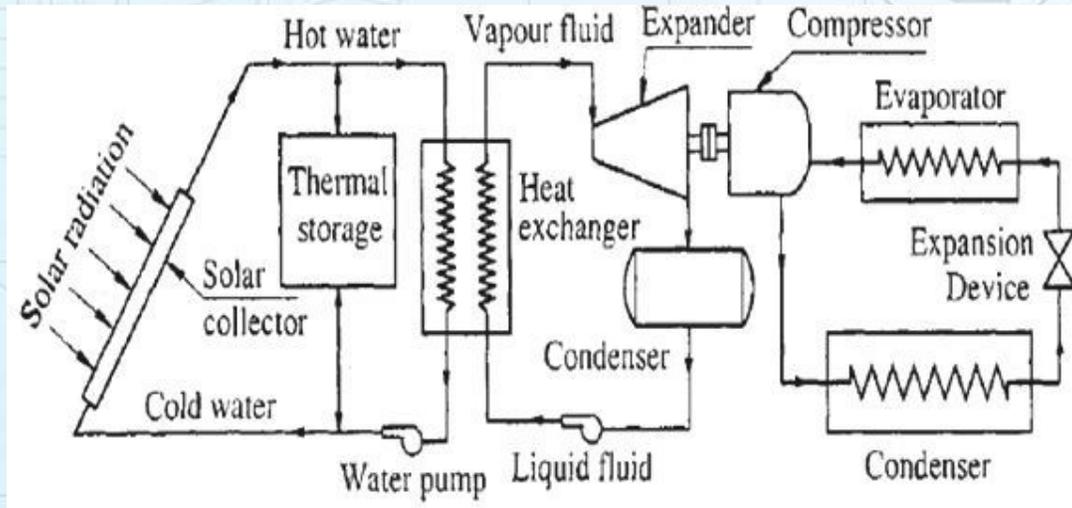
- The solar system of the solar refrigerator consists of the solar panel as shown in Fig. that collects the solar energy. The solar panels are fitted with photovoltaic cells that convert the solar energy into electrical energy and store it in the battery.
- During the normal running of the solar refrigerator the power is supplied directly by the solar panel, but when the output power of solar panels is less, the additional power is supplied by the battery. The battery is recharged when excess amount of power is produced by the solar panels.

### **3.8.2 Refrigeration system with thermal collectors**

#### **1. Vapour compression refrigeration system/solar mechanical refrigeration**

- Solar mechanical refrigeration uses a conventional vapour compression system driven by mechanical power that is produced with a solar-driven heat power cycle.
- The heat power cycle usually considered for this application is a Rankine cycle.
- The overall efficiency of solar mechanical refrigeration, defined as the ratio of mechanical energy produced to the incident solar radiation, is the product of the efficiencies of the solar collector and the power cycle.

- Solar mechanical systems are competitive only at higher temperatures for which tracking solar collectors are required.
- Because of its economy-of-scale, this option would only be applicable for large refrigeration systems e.g., 1,000 tons



*Fig 3.20 Vapour compression refrigeration system/solar mechanical refrigeration*

## 2. Vapour absorption refrigeration system

- Absorption refrigeration is the least intuitive of the solar refrigeration alternatives. Unlike the PV and solar mechanical refrigeration options, the absorption refrigeration system is considered a "heat driven" system that requires minimal mechanical power for the compression process. It replaces the energy-intensive compression in a vapor compression system with a heat activated "thermal compression system."
- A single-stage absorption system using ammonia as the refrigerant and ammonia-water as the absorbent is shown in Fig.
- Absorption cooling systems that use lithium bromide-water absorption-refrigerant working fluid cannot be used at temperatures below 0°C. The condenser, throttle and evaporator operate in the exactly the same manner as for the vapor compression system.
- In place of the compressor, however, the absorption system uses a series of three heat exchangers :
  1. absorber
  2. regenerating intermediate heat exchanger and
  3. a generator
  4. Small solution pump.
- Ammonia vapor exiting the evaporator is absorbed in a liquid solution of water ammonia in the absorber. The absorption of ammonia vapor into the water- ammonia solution is analogous to a condensation process. The process is exothermic

and so cooling water is required to carry away the heat of absorption. The principle governing this phase of the operation is that a vapor is more readily absorbed into a liquid solution as the temperature of the liquid solution is reduced. The ammonia-rich liquid solution leaving the absorber is pumped to a higher pressure, passed through a heat exchanger and delivered to the generator.

- In this system the power requirement for the pump is much smaller than that for the compressor in case of vapour compression system.

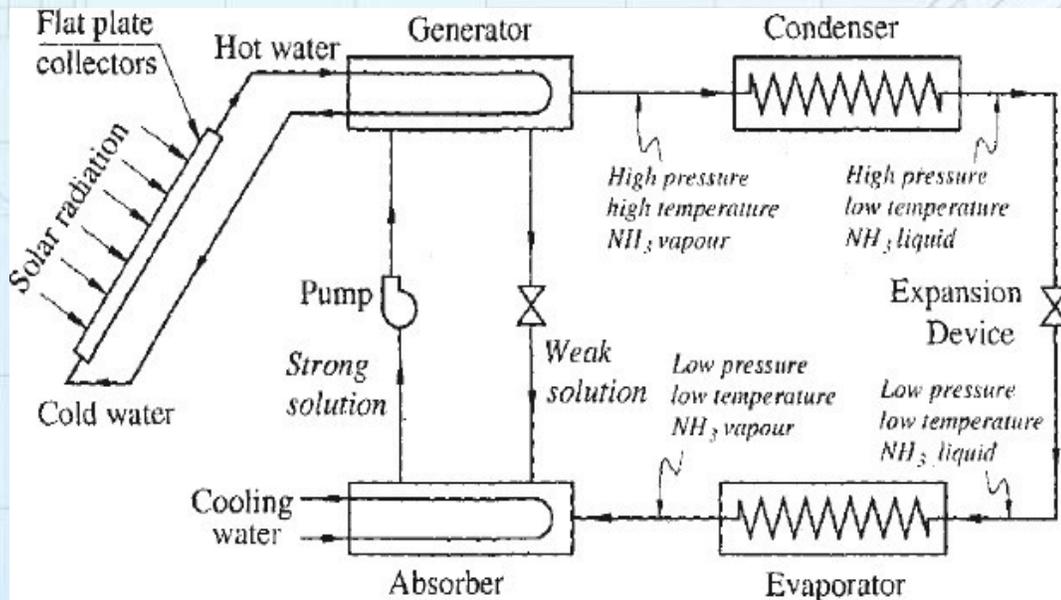


Fig 3.21 Vapour absorption refrigeration system

- In the generator, the liquid solution is heated, which promotes desorption of the refrigerant (ammonia) from the solution. Unfortunately, some water also is desorbed with the ammonia, and it must be separated from the ammonia using the rectifier. Without the use of a rectifier, water exits with the ammonia and travels to the evaporator, where it increases the temperature at which refrigeration can be provided. This solution temperature needed to drive the desorption process with ammonia-water is in the range between 120°C to 130°C.
- Temperatures in this range can be obtained using low cost non-tracking solar collectors. At these temperatures, evacuated tubular collectors may be more suitable than flat plate collectors as their efficiency is less sensitive to operating temperature.
- The advantage of solar refrigeration systems is that they displace some or all of the conventional fuel use.
- The operating costs of a solar refrigeration system should be lower than that of conventional systems, but at current and projected fuel costs, this operating cost savings would not likely compensate for their additional capital costs, even in a long

term life-cycle analysis. The major advantage of solar refrigeration is that it can be designed to operate independent of a utility grid.

- Of the three solar refrigeration concepts presented here, the photovoltaic system is the most appropriate for small capacity portable systems located in areas not near conventional energy sources (electricity or gas).
- Absorption and solar mechanical systems are necessarily larger and bulkier and require extensive plumbing as well as electrical connections.

### **3.9 SOLAR POND**

- In the continuous or discontinuous energy supply system, the energy storage is required to balance the energy of mismatches between the demand and the supply of energy.
- Especially in solar energy system the energy available only particular duration and only day time, hence thermal energy storage is required to improve performance and reducing total cost.
- Solar pond is a device to collect and store the solar thermal energy in the form of sensible heat.
- It consists of an expanse of water about 2 m deep with a thick durable plastic liner laid at the bottom. Salts like magnesium chloride, sodium chloride or sodium nitrate are dissolved in the water, concentration varying from 20 % to 30 %.

There are 3 distinct layers of water in the pond as:

#### **1. The top layer - Surface convective zone:**

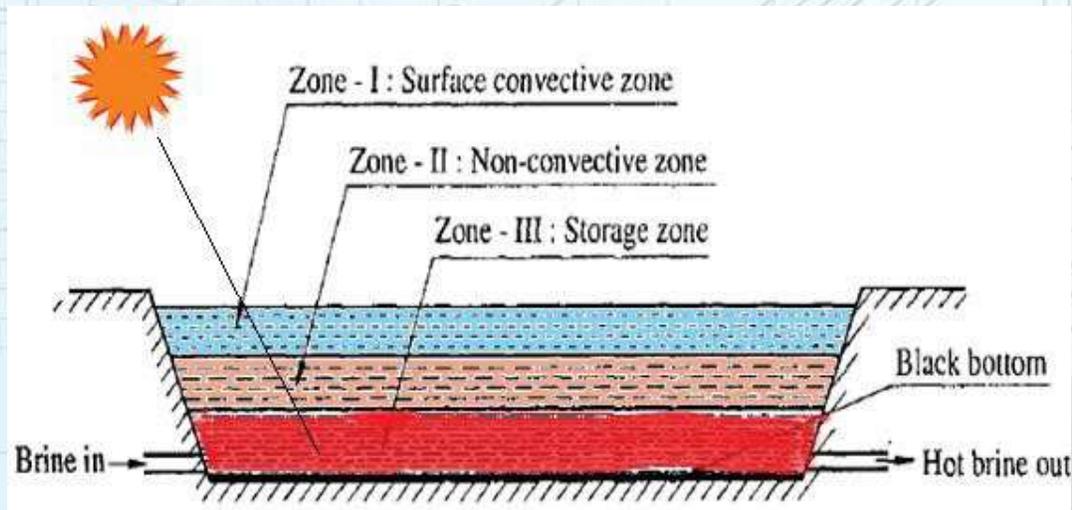
- Normally, it has a small thickness, about 0.3 m to 0.5 m.
- It has a low, uniform concentration (low salt content, salinity  $< 5\%$ ) as well as a fairly uniform temperature close to atmospheric temperature.

#### **2. An intermediate insulating layer with a salt gradient - Non-convective zone:**

- It is much thicker, about 1.0 m to 1.5 m and occupies more than half the depth of the pond.
- Both concentration and temperature increases with depth in this zone.
- This layer establishes a density gradient that prevents heat exchange by natural convection.

#### **3. The bottom layer - Lower convective or storage zone:**

- Normally, it has a thickness about 0.5 m to 1 m and high salt content (salinity about 20 %).
- Both concentration and temperature are nearly constant in this zone.
- This zone serves as the main heat collection as well as thermal storage medium.



*Fig 3.22 Solar pond*

- If the water is relatively translucent, and the pond's bottom has high optical absorption, then nearly all of the incident solar radiation (sunlight) will go into heating the bottom layer. When solar energy is absorbed in the water, its temperature increases which causes thermal expansion and reduced density.
- If the water were fresh (without salts) the low-density hot water would float to the surface, causing circulation of water by convection. The temperature gradient alone causes a density gradient that decreases with depth.
- The situation is changed if the pond contains salt water at bottom with layer of fresh water above it. In this case, the salinity gradient forms a density gradient that increases with depth and this counteracts the temperature gradient, thus preventing heat in the lower layers from moving upwards by convection and leaving the pond.
- Because of its salt content, the solar pond bottom is denser than the cooler fresh water at the top, and hence it does not tend to rise.
- A relatively stable layer of heated salt water is thus produced at the bottom of the pond with a lighter layer of cooler fresh water, which acts as a heat insulator, above it.
- Normally, the temperature at the bottom of the pond will rise to over 90 °C while the temperature at the top of the pond is usually around 30 °C.
- A solar pond can be used for various applications, such as heating and cooling of buildings, industrial process heating, desalination, refrigeration, heating animal housing, drying crops on farms, heat for biomass conversion and solar power generation.
- The heat trapped in the salty bottom layer can be used for many different purposes, such as the heating of buildings or industrial hot water or to drive an organic Rankine cycle turbine or Stirling engine for generating electricity.

***Temperature and concentration profile for a typical solar pond***

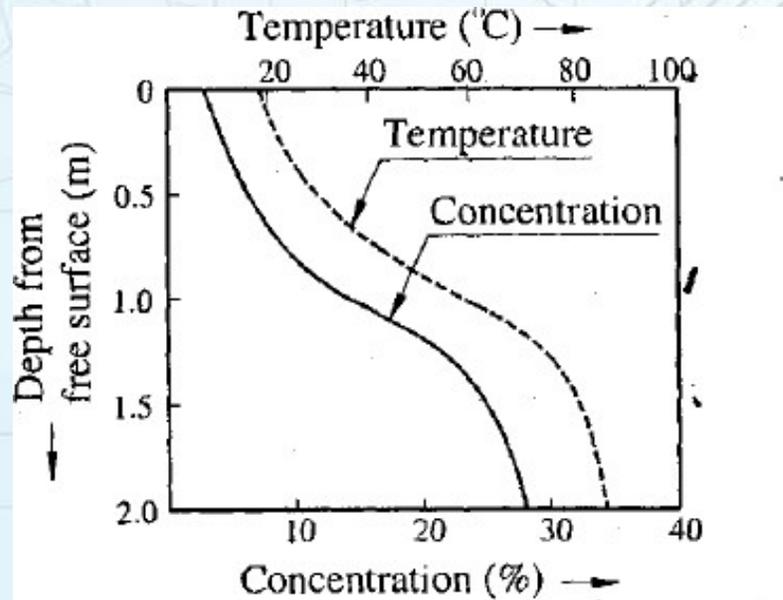


Fig 3.23 Temperature and concentration profile

### 3.10 SOLAR POWER PLANTS

- Solar power generation technologies can be broadly classified into two broad categories:
- Solar Photovoltaic technologies: Photovoltaic converters are semiconductor devices that convert part of the incident solar radiation directly into electrical energy.
- Solar thermal power plants: Solar thermal power plants produce electricity by converting the solar radiation into high temperature heat using mirrors and reflectors.

#### Classification solar thermal power plants

##### 1. Classification based on temperatures

- a. Low temperature cycles:
  - Maximum temperature is limited to 100°C.
  - For low temperature cycle, the thermodynamic cycle preferred is Rankine cycle.
- b. Medium temperature cycles:
  - Maximum temperatures ranging from 150°C to 300 °C.
  - For medium temperature cycle, the thermodynamic cycle also preferred is Rankine cycle.
- c. High temperature cycles:
  - Work at temperatures above 300 °C.
  - For high temperature cycle, the thermodynamic cycle preferred is the Rankine cycle, the Brayton cycle and the Stirling cycle.

##### 2. Classification based on types of collectors

- a. Solar pond power plant

- b. Solar distributed collector thermal power plant
- c. Central receiver system or Power tower -Heliostat
- d. Solar chimney power plant

### 3.10.1 LOW TEMPERATURE SOLAR THERMAL POWER PLANT

#### i. Low temperature power generation cycle using liquid flat plate collectors:

- Array of flat plate collectors are used to receive the solar radiation.
- The booster mirrors are used with collector to get maximum solar energy.
- The hot water at temperature close to  $100^{\circ}\text{C}$  is stored in a well insulated thermal storage tank.
- Hot water from storage tank is circulated through the heat exchanger (vapour generator), and give up heat to the working fluid (low boiling temperature fluid) of Rankine cycle.
- Low boiling temperature fluid evaporates at about  $90^{\circ}\text{C}$  and pressure of a few atmospheres. Vapour generated in generator is then passes through turbine. After expansion in the turbine, low pressure vapour is condensed in the condenser and then liquid again supply to the vapour generator with help of liquid pump.
- Normally, the working fluids used are methyl chloride, toluene or refrigerants like R11, R113, and R114.
- This power plant is very simple, but it required large investment cost per kW because of large collector area involved.
- Overall efficiency of power plant is very low about 2%.

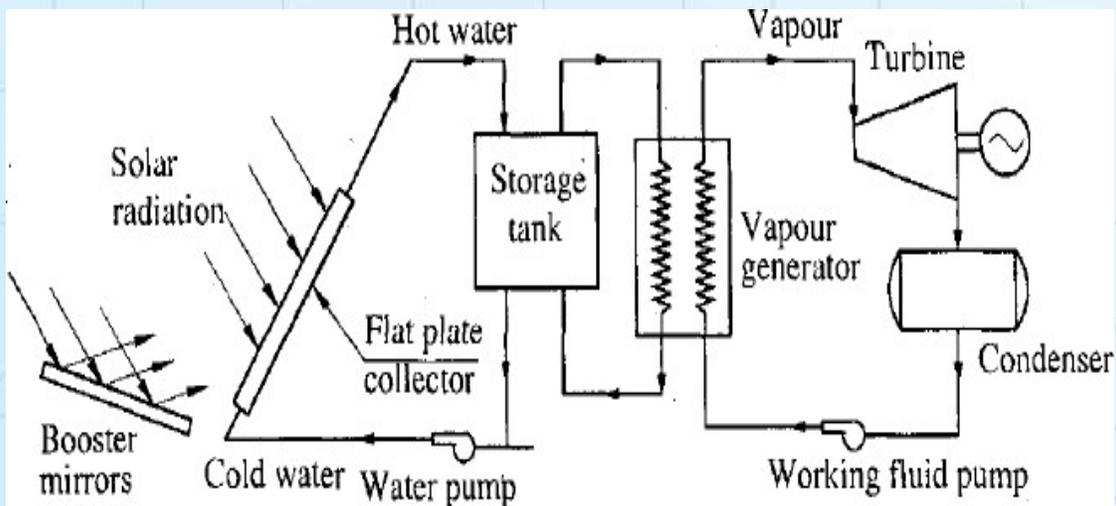
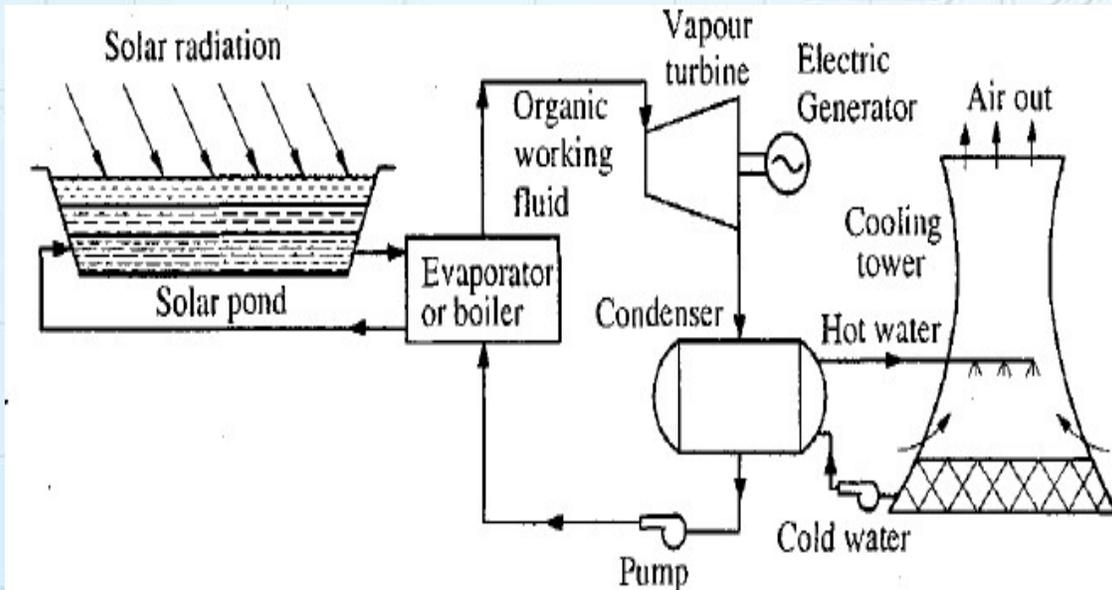


Fig 3.24 Low temperature power generation cycle using liquid flat plate collectors

#### ii. Low temperature power generation cycle using solar pond

- solar pond is used to receive and to store the solar radiation.

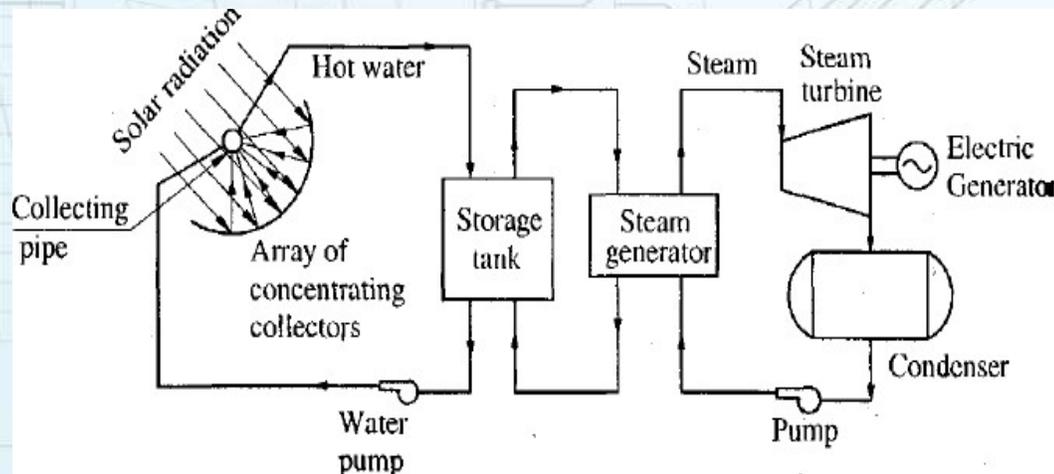
- The system works on Rankine cycle using low boiling temperature working fluid.
- The bottom layers of brine reach 70 to 85 °C while the top remains 25 °C.
- The hot brine from bottom is slowly withdrawn in the laminar flow pattern from the pond and used to evaporate low boiling temperature working fluid of Rankine cycle in the vapour generator.
- The vapours of working fluid flows under high pressure to the turbine and thereby, expanding through the turbine and electrical generator coupled to it. expansion in the turbine, low pressure vapour is condensed in the condenser and then liqn again supply to the vapour generator with help of liquid pump.



*Fig 3.25 Low temperature power generation cycle using solar pond*

### **3.10.2 MEDIUM TEMPERATURE SOLAR THERMAL POWER PLANT**

- In this system, an array of parabolic line focusing type concentrating collectors is used to receive the solar energy because of low cost and require sun tracking in one plane only as compared to paraboloidal concentrating collectors.
- It is work at maximum temperatures ranging from 150 to 300 °C.
- This power plant consists of a parabolic cylindrical reflector to concentrate sunlight on to a collecting pipe within a pyrex or glass envelop, a storage tank, steam generator, steam turbine, condenser, pump and electrical generator.



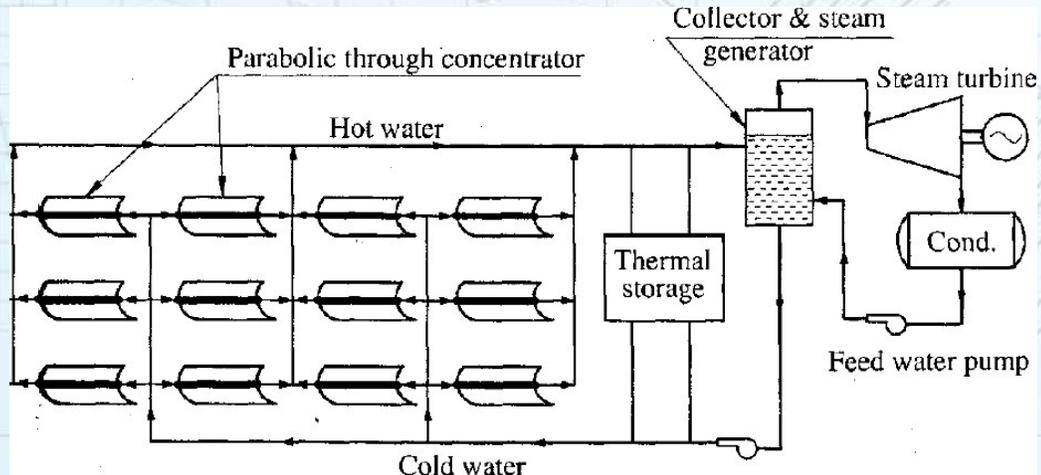
*Fig 3.26 Medium temperature solar power plant*

- Incoming solar energy is absorbed by water, and this heat is transferred to storage tank and finally to steam generator where steam is generated. This steam is utilized to run a turbine. After expansion in the turbine, low pressure steam is condensed in the condenser and then water again supply to steam generator with help of liquid pump.

### **3.10.3 HIGH TEMPERATURE SOLAR THERMAL POWER PLANT**

#### **i. Solar distributed collector thermal power plant**

- In this power plant, solar energy is collected by several individual collectors located in solar field. A very large area of few km<sup>2</sup> is covered by the field
- The Parabolic through collectors with line focus are used
- The main components of plant are:
  - 1 Parabolic through collectors distributed in the solar field
  - 2 Piping system for primary heat transport (water) circuit
  - 3 At transport fluid pump
  - 4 Storage tank
  - 5 Steam generator
  - 6 Secondary fluid (steam)circuit
  - 7 Steam turbine
  - 8 Condenser and condensate pump



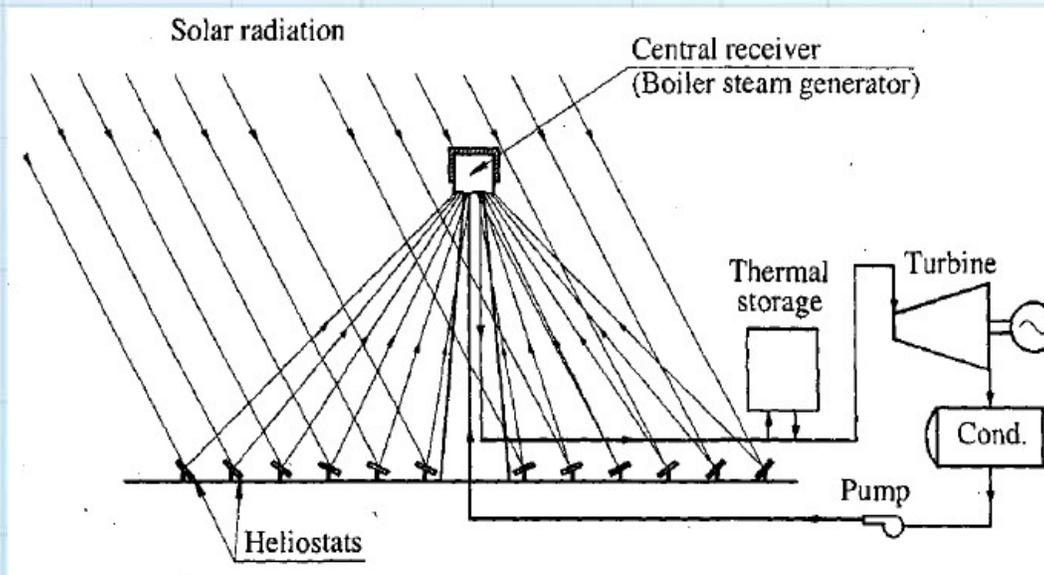
*Fig 3.27 Solar distributed collector thermal power plant*

- Incoming solar energy is collected in the collector which absorbed by water, and this heat is transferred to storage tank and then to steam generator where steam is generated. This steam is utilized to run a turbine.
- After expansion in the turbine, low pressure steam is condensed in the condenser and then water again supply to the steam generator with help of feed water pump after feed water heating in the feed water heater.
- The operating temperature of parabolic through collectors with line focus with sun tracking in one plane is in the range of 200 °C to 300 °C.
- In the solar distributed collector thermal power plant, parabolic through collectors with line focus are generally recommended for medium size electrical power plant (typically size 50 MW) used for applications such as standalone power plant for farm or community centre, captive power plant for small industry.
- The small solar distributed collector thermal power plant (typically size 2 MW) may be preferred for cogeneration plant (to deliver steam, hot water and electric power) and irrigation water pumping.

## ii. **Solar Central Receiver or Solar Tower thermal power plant:**

- In this solar-thermal power plant, a wide field of heliostats focuses the sun's power onto a single collector to heat a medium such as water or molten salt.
- The system consists of
  - 1 The field of oriented flat mirrors or array of heliostats
  - 2 Tower with the central receiver on top of it
  - 3 heat conversion sub system
  - 4 Heat storage device

- The fields of heliostats comprise many mirrors. The movement of most modern heliostats employs a two-axis motorized system, controlled by computer based on the latitude and longitude and the time and date.
- In the central receiver at the top of the tower on which solar radiation reflected from fields of heliostats is concentrated. The central receiver has a heat absorbing surface by which the heat transport fluid is heated.
- In most of case water is a heat transport medium and working fluid of Rankine cycle. Another possibility is to use a gas as heat transport medium and also working fluid of Brayton cycle of a gas turbine.
- Thermal buffer storage is provided so that the plant can continue to operate for a maximum period of 30 minute in case of cloud cover. Short term storage of heat can be provided by fire bricks, ceramic oxides, rocks, eutectic salts, fused salts, sulphur or lithium metal, sodium metals etc.
- Heliostat costs represent 30-50% of the initial capital investment for solar power plant depending on the energy policy and economic framework in the location country.



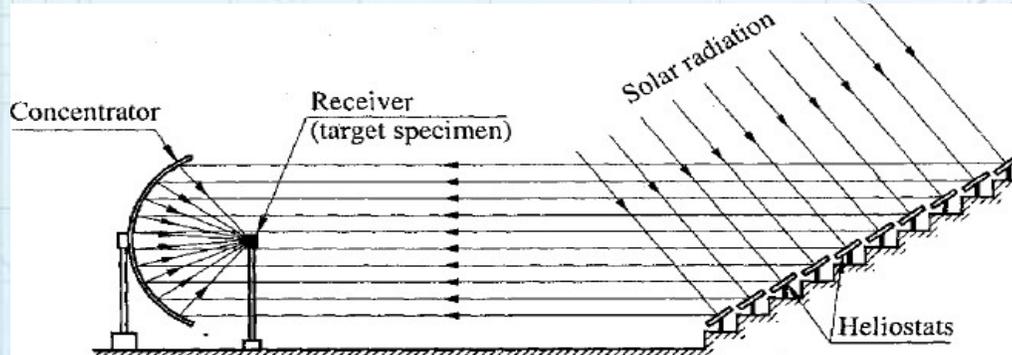
*Fig 3.28 Solar Central Receiver thermal power plant*



### **3.11 SOLAR FURNACE**

- A solar furnace is an optical system used to produce high temperatures by concentrating solar radiation onto specimen.
- Solar furnace consists of
  - 1 A concentrator (paraboloidal reflector surface),
  - 2 Small size receiver
  - 3 Heliostats

- The large number of heliostats directs solar radiation on to a concentrator (paraboloidal reflector surface). The heliostats are adjusted such that they direct the radiation parallel to the optical axis of the paraboloidal reflector. The paraboloidal reflector then brings the radiation to a focal point where the receiver is fitted.
- The temperature at the focal point may reach 3,500 °C and this heat can be used to generate electricity, melt steel, and make hydrogen fuel or nano-materials.



*Fig 3.29 Solar furnace*

### **Applications of solar furnace:**

- The rays are focused onto an area the size of a cooking pot and can reach 3,500 °C depending on the process installed, for example: (i) about 1,000 °C for metallic receivers producing hot air, (ii) about 1,400 °C to produce hydrogen by cracking methane molecules, (iii) up to 2,500 °C to test materials for extreme environment such as nuclear reactors or space vehicle, (iv) up to 3,500 °C to produce nano-materials by solar induced sublimation and controlled cooling, such as carbon nanotubes or zinc nano-particles.
- The solar furnace is an excellent means for studying properties of ceramics at high temperatures above the range ordinarily measured in the laboratory with flames and electric currents.
- Physical measurements such as melting points, phase changes, specific heat, thermal expansion, thermal conductance, magnetic susceptibility and thermionic emission.
- Solar furnaces can be used in space to provide energy for manufacturing purposes.
- The solar furnace can be utilized to produce high temperature for metallurgical and chemical operations.

### **Advantages of a solar furnace:**

- In the solar furnace, heating is possible without any contamination and easy to control the temperature.
- Solar furnace provides high temperature and rapid heating & cooling.
- Using solar furnace it is possible to measure various properties on an open specimen and continuous observation is possible.

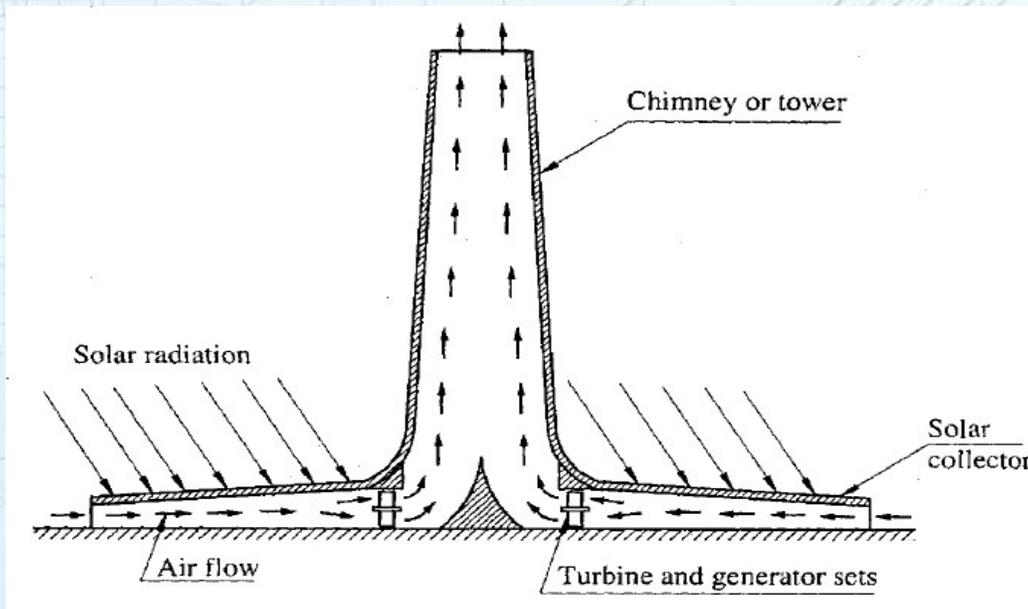
### **Disadvantages of a solar furnace:**

- Their use is limited to sunny days and that too for 4-5 hours only.
- Very high temperature is obtained only over a very small area.
- Initial cost of solar furnace is very high.



### **3.12 SOLAR CHIMNEY POWER PLANT**

- The solar chimney power plant is a renewable-energy power plant for generating electricity from solar power.
- Sunshine falling on a greenhouse-like collector structure around the base of a tall chimney heats the air within it.
- The resulting convection causes air to rise up the tower by the chimney effect.
- This airflow drives wind turbines to produce electricity.
- It is also called solar updraft tower power plant.
- Sunlight passing through the transparent cover causes the air trapped in the greenhouse to heat up by 10°C to 20°C.



*Fig 3.30 Solar chimney power plant*

- A typical 50 kW solar chimney power plant requires chimney height of 195 metres and a diameter of 10 metres with a collection area (greenhouse) of 46000 m<sup>2</sup> and a diameter of 244 metres.
- Solar thermal collectors or photovoltaics can be arranged inside the collector greenhouse to increase output.
- Initial cost –high
- Operating cost –low



### 3.13 PHOTOVOLTAIC SYSTEM OR SOLAR CELLS

- Solar cells are devices which convert solar energy directly into electricity via the photovoltaic effect.
- Solar cell principles:
- It is based on the photovoltaic effect.
- In general, the photovoltaic effect means the generation of a potential difference at the junction of two different materials in response to visible or other radiation.

The solar cell works in three steps:

1. Photons in sunlight hit the solar panel and are absorbed by semiconducting materials, such as silicon.
  2. Electrons (negatively charged) are knocked loose from their atoms, causing an electric potential difference. Current starts flowing through the material to cancel the potential and this electricity is captured. Due to the special composition of solar cells, the electrons are only allowed to move in a single direction.
  3. An array of solar cells converts solar energy into a usable amount of direct current (DC) electricity.
- Semi-conductors like silicon, cadmium telluride, gallium arsenide etc. are a suitable material for absorbing the energy of photon of sunlight.

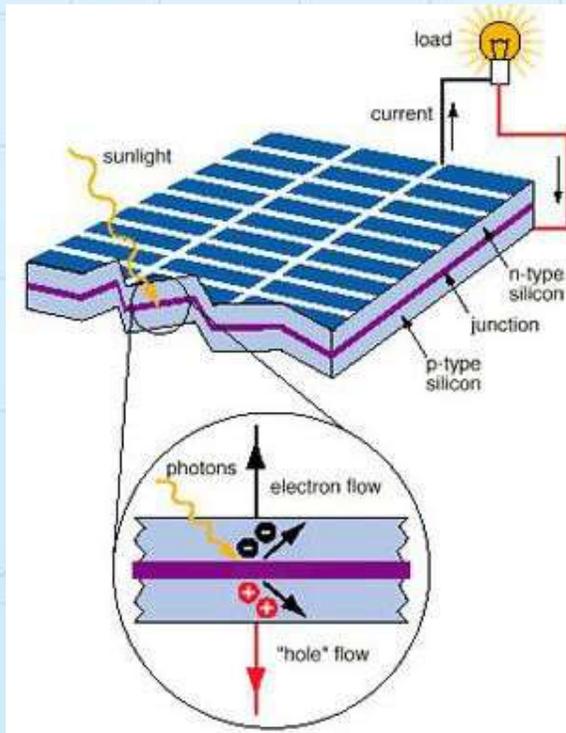


Fig 3.31 Principle of working of solar cell

## Photovoltaic cells, modules, panels and arrays

- Photovoltaic array is the device which generates electricity when exposed to light.
- A typical single PV cells can produce about 0.5 V and 6 Amp, which gives 3W power.
- A number of cells are combined to form a module.
- When modules are combined we get a panel.
- Panels are combined to get an array.

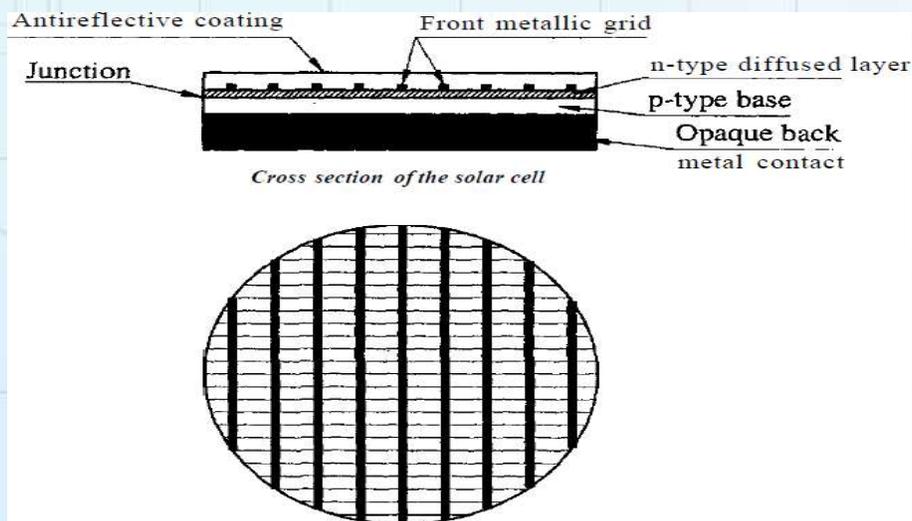


Fig 3.32 Structure of solar cell

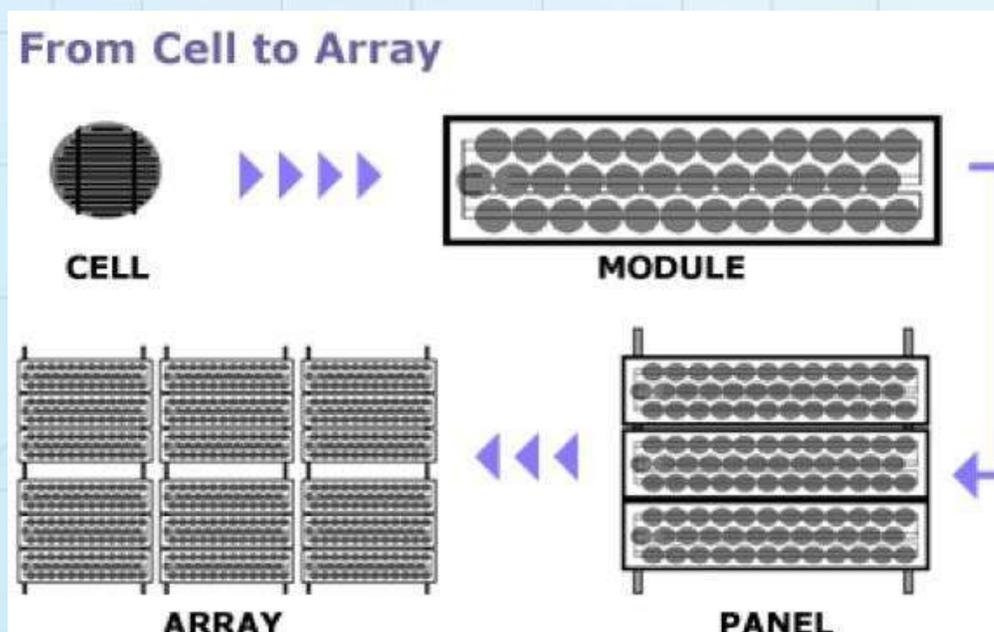


Fig 3.33 Photovoltaic cell, module, panel and array

## A basic solar photovoltaic system for power generation

- It consist of :
  1. A PV panel array, ranging from two to many hundreds of panels;
  2. A control panel, to regulate the power from the panels;
  3. A power storage system, generally comprising of a number of specially designed batteries;
  4. An inverter, for converting the DC to AC power e.g. 240 V AC.
  5. A backup power supplies such as diesel start-up generators (optional)
    - Framework and housing for the system
    - Trackers and sensors (optional)
- Arrays of panels are being increasingly used in building construction where they serve the dual purpose of providing a wall or roof as well as providing electric power for the building.
- Eventually as the prices of solar cells fall, building integrated solar cells may become a major new source of electric power.
- The daily energy output from PV panels will vary depending on the orientation, location, daily weather and season. On average, in summer, a panel will produce about five times its rated power output in watt hours per day and in winter about two times that amount.
- For example, in summer a 50 watt panel will produce an average of 250 watt-hours of energy, and in winter about 100 watt-hours.

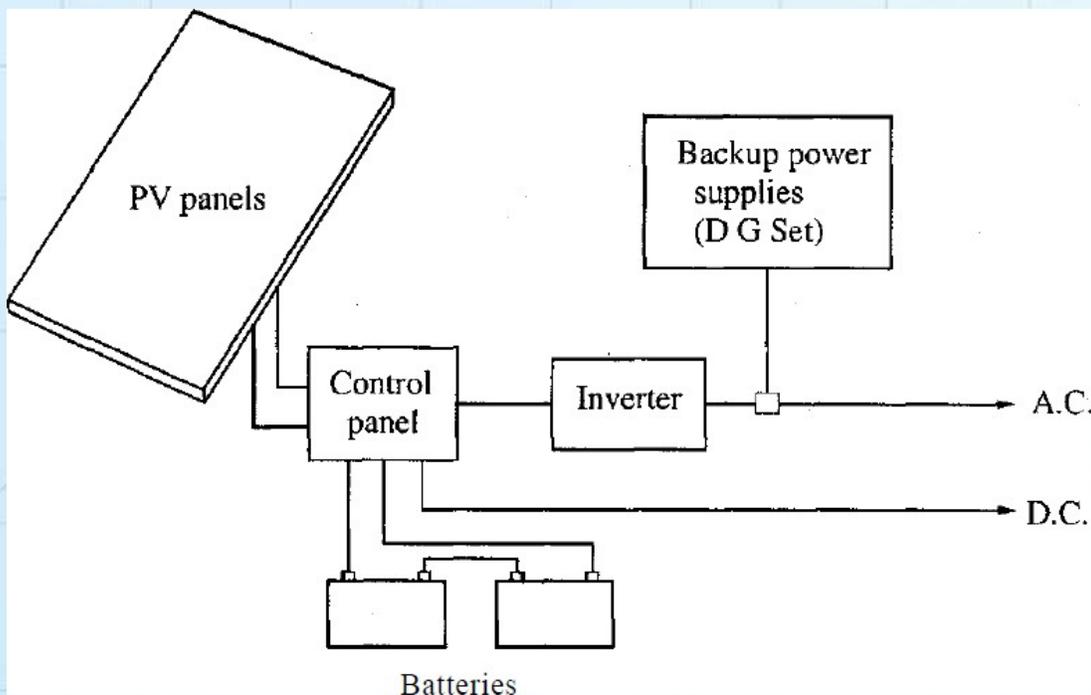


Fig 3.34 Element of PV system

- Trackers are used to keep PV panels directly facing the sun, thereby increasing the output from the panels.
- Energy storage is often necessary when power is required when the sun is not shining - either at night or in cloudy periods - or in quantities greater than can be supplied directly from the array. Specially designed "deep-cycle" lead acid batteries are generally used. Unlike normal batteries, they can discharge about half of their stored energy several thousand times before they deteriorate.
- Inverters are necessary if mains-voltage appliances are to be used. In assessing the cost of the total system, it may be more economical to purchase an inverter and mass produced consumer appliances than to use low voltage DC appliances which may be more expensive.
- Sometimes wind generators are used in conjunction with PV systems, if the combination of sun and wind is viable. Small petrol or diesel generators are often used as the backup. These systems are relatively cheap to purchase but expensive to run.
- The performance of PV modules and arrays are generally rated according to their maximum DC power output (watts) under Standard Test Conditions (STC).
- Standard Test Conditions are defined by a module (cell) operating temperature of 25° C, and incident solar irradiance level of 1000 W/m<sup>2</sup> and under Air Mass 1.5 spectral distribution.
- Today's photovoltaic modules are extremely safe and reliable products, with minimal failure rates and projected service lifetimes of 20 to 30 years.

### **Types of solar cell**

- Solar cells can be classified in the three ways as followed:

#### **A. Classification on basis of type of active materials used in its fabrication**

1. Single crystal silicon solar cell
2. Multicrystalline silicon solar cell
3. Amorphous silicon solar cell
4. Cadmium telluride solar cell
5. Copper indium gallium diselenide
6. Gallium arsenide multi-junction
7. Dye-sensitized solar cell
8. Quantum dot solar cell
9. Organic/polymer solar cell

#### **B. Classification on basis of thickness of active material**

1. Bulk material solar cell
2. Thin film solar cell

#### **C. Classification on basis of junction structure**

1. p-n homo-junction solar cell
2. p-n hetero-junction solar cell
3. p-n metal semiconductor-junction solar cell
4. p-i-n semiconductor-junction solar cell

## **Wafer-based crystalline silicon / Bulk material solar cell**

### **1. Mono crystalline silicon solar cells**

- A mono crystalline silicon solar cell is made from a wafer of one big silicon mono crystal.
- These cells belong to the most efficient class in the photovoltaic technology. For the moment the efficiency factor is about 15 %. The required production process for this type of solar cell is complex and rather expensive. The surface of the cell is smooth and equally colored blue. They are not flexible and must be mounted in a firm frame and protected against an aggressive environment.

### **2. Polycrystalline silicon solar cells**

- A polycrystalline silicon solar cells wafer is sawed out of a cast “ingot” of molten silicon which is re crystallized. The wafer forms the basic of a polycrystalline solar cell. This solar cell is cheaper because the production process is less complex. The efficiency factor is lower as compared with mono crystalline cells.
- For the moment the efficiency factor is about 12 %.
- The surface of a poly solar cell looks a little bit smudged with various blue patches. They are not flexible and must be mounted in a firm frame and protected against an aggressive environment.

## **Thin film solar cell**

### **1. Amorphous silicon solar cells**

- An amorphous silicon solar cell consists of a thin homogenous layer of silicon atoms instead of a crystal structure. The light absorption in amorphous silicon is more effective compared to the former silicon types. So the cells can be thinner, hence the name “thin film” cells.
- Amorphous cells can be used on various carriers both on solid and flexible materials. Bend or folded surfaces are no problem. The cell surface is dark grey colored. These cells are cheap but the efficiency factor is a low 6 % for the moment.
- A property of amorphous solar cells is the power decrease in the first month after first introduction. After this period the power output remain rather steady. In the specification of the cell the steady power state is mentioned.

### **2. Cadmium telluride solar cell**

- A cadmium telluride solar cell uses a cadmium telluride (CdTe) thin film, a semiconductor layer to absorb and convert sunlight into electricity. The cadmium present in the cells would be toxic if released. However, release is impossible during normal operation of the cells.

### **3. Copper indium gallium diselenide**

- Copper indium gallium diselenide (CIGS) is a direct band gap material. Incorporation of Ga in to the CIGS mixture increases the band gap beyond 1.1 eV. It has the highest

efficiency (~20%) among thin film materials and more stable as compared to a-Si cell in outdoor applications.

- However, exposure to elevated temperature results in loss of efficiency, but light soaking restores it to original efficiency level. The main attraction of this solar cell is inexpensive preparation.

### **Applications of solar cells**

1. Cathodic protection systems
2. Electric fences
3. Remote lighting systems
4. Telecommunications and remote monitoring systems
5. Solar powered water pumping
6. Rural electrification
7. Water treatment Systems
8. Miscellaneous applications of solar cells
  - Watches, toys, calculators, emergency power systems, refrigerators for remote areas, portable power supplies for camping and fishing etc.

### **Advantages of solar cell**

1. Photovoltaic systems can be designed for a variety of applications and operational requirements.
2. It can be used for either centralized or distributed power generation.
3. Photovoltaic systems have no moving parts, are modular, easily expandable and even transportable in some cases.
4. Energy independence and environmental compatibility
5. The fuel (sunlight) is free, and no noise or pollution is created from operating photovoltaic systems.
6. Minimal maintenance and have long service lifetimes.

### **Disadvantages of solar cell**

1. High initial cost.
2. Surface area required is high.
3. Solar energy is intermittent. Hence requires large storage. This increase the cost and make the system bulky.
4. Conversion efficiency - low - about 30%