Solar radiation geometry

Solar radiation geometry is the determining factor of heat gain, Shading and the potential of day light penetration. Direction of beam radiation is useful in establishing geometric relationship between a plane and incoming beam solar radiation. Direction of beam radiation can be described in terms of several angles.

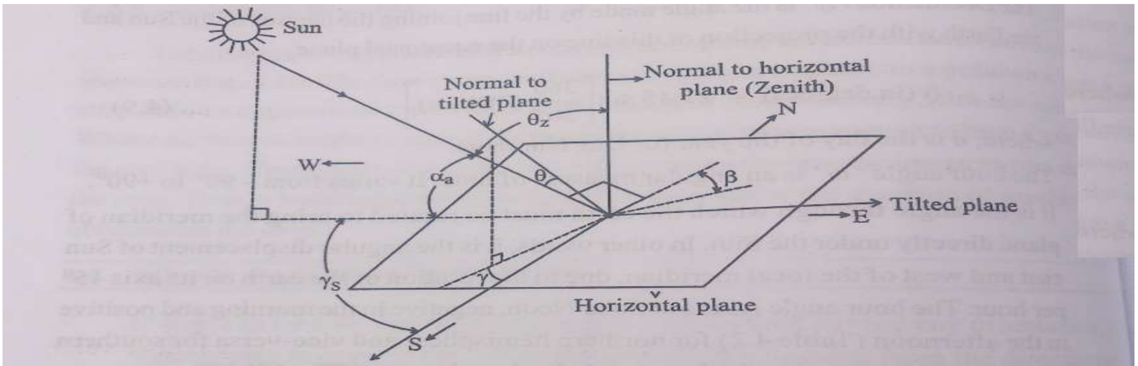


Fig. 4.11 Diagram illustrating the angle of incidance 'θ', the zenith angle 'θ_z', the solar altitude angle 'α_a', the slope 'β', the surface azimuth angle 'γ' and the solar azimuth angle 'γ_s'.

Solar altitude angle(α):

Altitude Angle is the angle between the Sun's rays and projection of th*e Sun's rays* on the horizontal plane

Zenith angle(θz):

It is Complementary angle of Sun's Altitude angle. OR

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.

Solar Azimuth Angle(γs):

It is the solar angle in degrees along the horizon east or west of north. OR

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

Declination(δ):

It is the angle between a line extending from the center of the Sun and center of the earth and projection of this on earth's equatorial plane.

Declination is the direct consequence of earth's tilt and It would vary between 23.5o on June 22 to – 23.5o on December 22. On equinoxes of March21 & Sept22 declination is zero.

The declination is given by the formula

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

Where n is the day of the year

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 15o per hour.

slope(β):

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

surface azimuth angle(γ):

Angle between the normal to the collector and south direction is called surface azimuth angle(γ).

Solar Incident angle(θ):

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

Solar day length

That is called a solar day. On earth a solar day is 24 hrs. however earth's orbit is elliptical, meaning it's not a perfect circle. That means some solar days on earth are a few minutes longer than 24hrs and some are a few minutes shorter.
At the time of sunset or sunrise the zenith angle θz=90 , we obtain sunrise hour angle as

$$Cos\ \omega s = -\frac{Sin\phi Sin\delta}{cos\phi\ Cos\delta} = -tan\phi\ tan\delta \qquad \omega s = Cos^{-1}\{-\tan\phi\ tan\delta\}$$

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

Local apparent time (solar time)

Solar time measured with reference to solar noon which is the time when the sun is crossing observer meridian. At solar noon the sun is at the highest position in the sky. The sun traverse each degree of longitude in 4 min (as the earth takes 24hrs to complete one revolution). The standard time converted in to solar time by incorporating two corrections.

The first correction arises due to the difference in longitude of the location and meridian on which standard time is based. The correction has a magnitude of 4minutes for every degree difference in longitude. Second correction called the equation of time correction is due to the fact that earth's orbit and the rate of rotation are subject to small perturbations. This is based on the experimental observations.

Local Solar Time=Indian Standard time± 4(Standard time Longitude-Longitude of the location) + (Equation of time correction)

Flat plate collector (FPC):

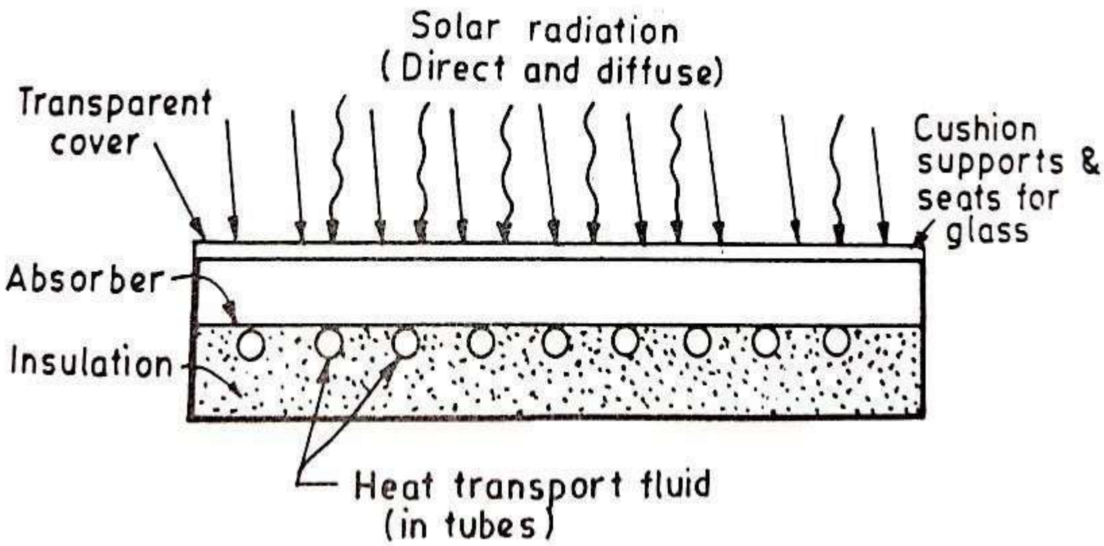


Fig. 3.3.1. Selection through typical flat-plate collector.

- In a flat plate collector, the absorber plate which is a black metal plate absorbs the radiation incident through the glass covers. The temp of the absorber plate increases and it begins to emit radiation of longer wavelength (IR). This long wavelength radiation is blocked from the glass covers which act like the Co2 layer in the atmosphere. This repeated reflection of radiation between the covers and the absorber plate results in the rise of the temp of the absorber plate.
- The schematic diagram of a FPC is as shown in fig. it consists of a casing either made up of wood or plastic having an area of about 2m*1m*15cm. in the casing insulator is provided at the bottom to check conductive heat transfer. Mineral wool, glass wool, fiber glass, asbestos thermocol etc. are used as insulator.
- Above the insulator the absorber plate is fixed. The absorber plate is made of good conducting material like aluminum or copper. It is coated black to increase its absorption property. Usually, the black coating is done by chemical treatment.
- Selective coatings which allow for maximum absorption of radiation and minimum amount of emission are applied on to the absorber plate. The underside of the plate consists of absorber tubes which run along the length of the plate. These plates are also made of the same material as that of the absorber plate.
- Sometimes the plate itself is bent into the form of tubes. Through these tubes the heat absorbing medium (water) is circulated. This medium will absorb the heat from the plates and the tubes and its temp increases. This medium will absorb the heat from the plates and the tubes and its temp increases.

- This way solar energy is collected as heat energy. Above the absorber plate glass covers are provided. These glass covers help to bring out the greenhouse effect, thus increasing the η of the collector. More than one cover is used to prevent the loss of radiation by refraction.

The losses that occur are

- **Conduction loss:** This loss is prevented by introducing an insulating material between the absorber plate and the casing where there is contact between the two and also by using a low conducting material like wood or plastic for the casing. Thus the conduction loss is reduced.
- **Convection loss:** It takes place both from the top and the bottom of the absorber plate. The bottom loss is reduced by providing insulation between the absorber tubes and the base of the casing. The top side loss is prevented by providing glass covers and maintaining the distance between the covers by about 1.25 to 2.5 cm. Also, convection loss is prevented by evacuating the top and the bottom side of the absorber plate.
- **Radiation losses:** It is prevented by applying a selective coating on to the top side of the absorber plate. This coating allows 90% of the radiation to be incident on to the absorber plate while transmissivity of the plate is reduced to only 10%. The usual material used for the coating is “black chromel”. The radiation loss also prevented by treating the underside of the glass covers by coating which are opaque to the reradiated infrared radiations but are transparent to the incident visible radiation. The materials used for this coating are tin oxide or indium oxide.
- **Reflection and refraction losses:** These losses are prevented by providing more than one glass covers so that the reflected and refracted radiation is incident back on the absorber plate.

Solar air Heater

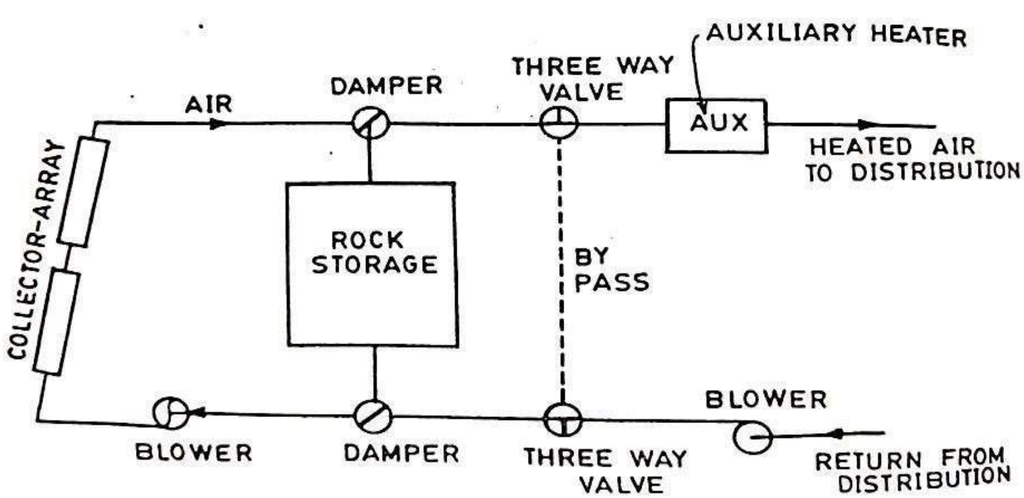


Fig. 5.3.6. Schematic diagram of a basic hot air heating system.

Schematic diagram of a basic hot air heating system is shown in Fig.5.3.6. In this system the storage medium is held in the storage unit, while air is the fluid used to transport energy from collector to the storage and to the building. By adjusting the dampers, the heated air from the collector can be divided between rock storage and the distribution system, as might be required by the conditions.

For example, when the sun shines after several cloudy days it would be desirable to utilize the available heat directly in the distribution system rather than placing it in storage.

Two three-way valves can be used to bypass the storage tank, as explained above. An auxiliary source of heating is also provided. Auxiliary heating can be used to augment the energy supply to the building from the collector or storage if the supply of heat from it is inadequate.

The position of the blower in figure is shown at the upstream of the collector and the storage, and it forces the air through these for heating. In this case slight leakage of heated air will take place. Blower can also be placed on the downstream side of the collector and storage, so that the pressure in the collector is not above ambient pressure, which might be advantageous in controlling leakage.

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). Since the radiation is focused, the η of concentrating collector is always greater than that of non-focusing or FPC. This is because of the following reasons,
In case of focusing collector the area of the absorber is many times smaller than that of the area of the collector. Where as in a non-concentrating type the area of the absorber equals area of the collector. Hence here the loss of absorbed radiation is more compared to the concentrating type.

In a concentrating collector since the radiation is focused, its intensity is always greater than that in the non-focusing type. Because of these reasons the concentrating collectors are always used for high temp applications like power generation and industrial process heating.

Compound Parabolic Concentrator (CPC):

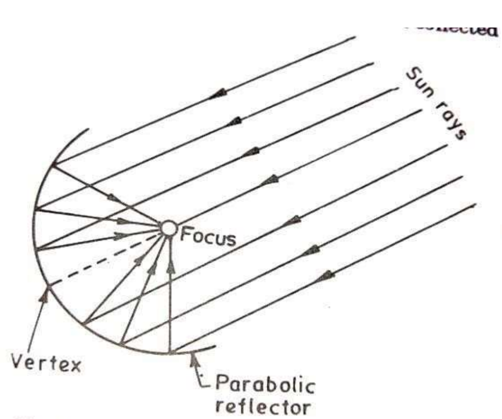


Fig. 3.7.1. Cross-section of parabolic-trough collecto

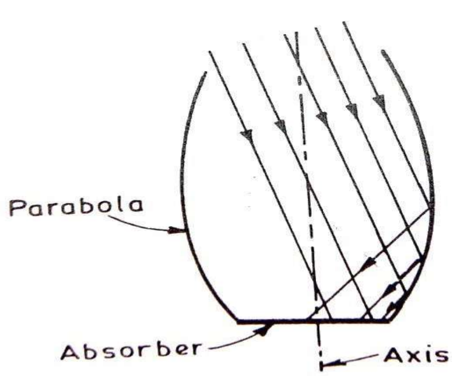


Fig. 3.7.10. Compound parabolic concentrator.

Compound Parabolic Concentrator consists of two parabolic mirror segments, attached to a flat receiver. The segments are oriented such that the focus of one is located at the bottom end point of the other in contact with the receiver. It has a large acceptance angle and needs to be adjusted intermittently. Rays in the central region of the aperture reach the absorber directly whereas, those near the edges undergo one or more reflections before reaching the absorber. The concentration ratio achieved from this collector is in the range of 3-7.

Cylindrical Parabolic Concentrator:

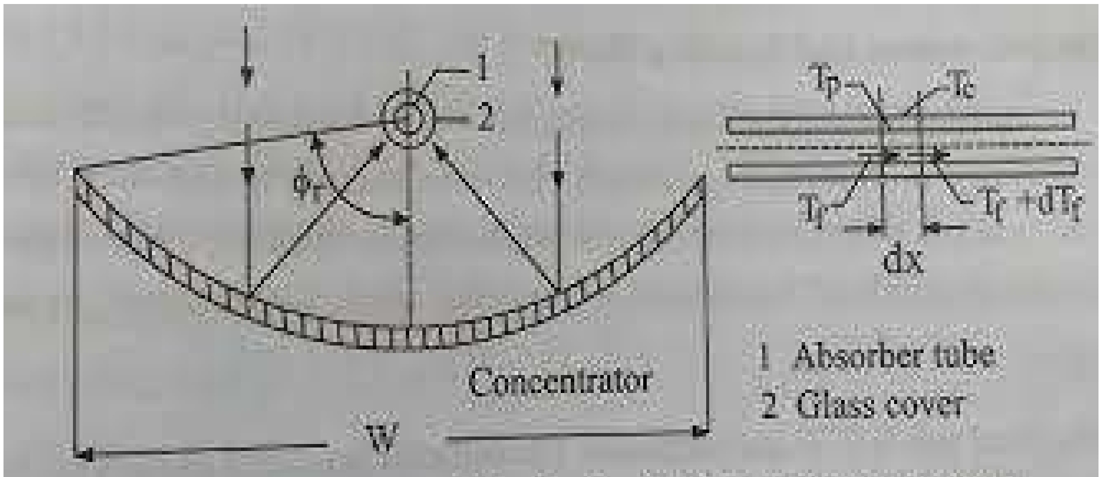


Fig. 4.30 Cylindrical Parabolic Collector Cross-Section

It consists of a cylindrical parabolic through reflector and a metal tube receiver at its focal line as shown in figure above. The receiver tube is blackened at the outside surface to increase absorption. It is rotated about one axis to track the sun. The heat transfer fluid flows through the receiver tube, carrying the thermal energy to the next stage of the system. This type of collector may be oriented in any one of the three directions: East-West, North-South or polar. The polar configuration intercepts more solar radiation per unit area as compared to other modes and thus gives best performance. The concentration ratio in the range of 5-30 may be achieved from these collectors.

Paraboloidal Dish Collector:

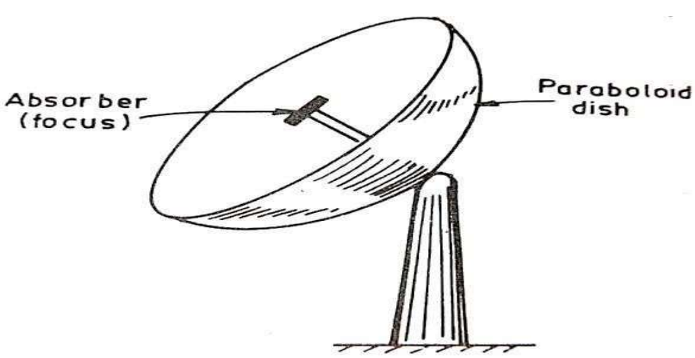
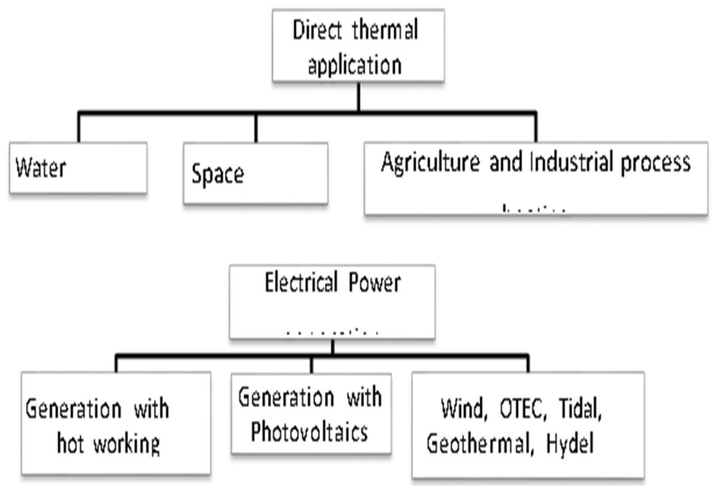


Fig. 3.7.7. Point focus solar collector (Paraboloid).

When a parabola is rotated about its optical axis a paraboloidal surface is produced. Above figure shows the details of this type of collector. Beam radiation is focused at a point in the paraboloid. This requires two axis tracking. It can have concentration ratio ranging from 10 to few thousands and can yield temperature up to 3000oC. Paraboloidal dish collectors of 6-7m in diameter are commercially manufactured.

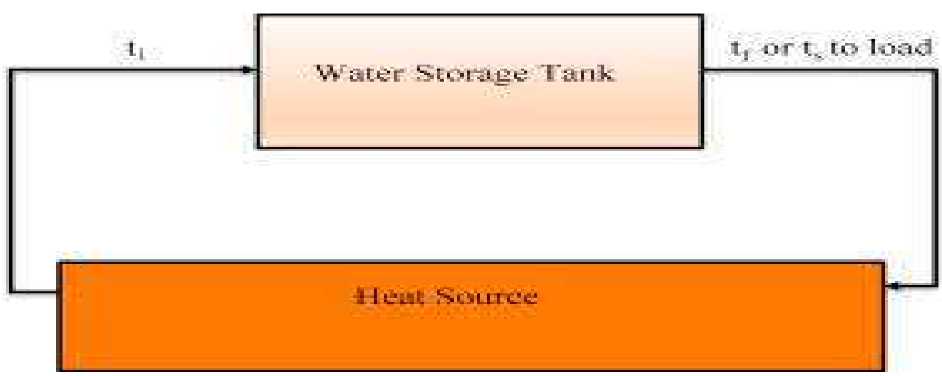
Application of Solar Energy



Thermal applications:

1) Water heating
2) Space heating or cooling
3) Process heating
4) Refrigeration
5) Distillation
6) Furnace heating
7) Electric power generation
8) Cooking

SENSIBLE HEAT STORAGE



Sensible heat storage means **shifting the temperature of a storage medium without phase change**. It is the most common simple, low-cost, and longstanding method. This storage system exchanges the solar energy into sensible heat in a storage medium (usually solid or liquid) and releases it when necessary.

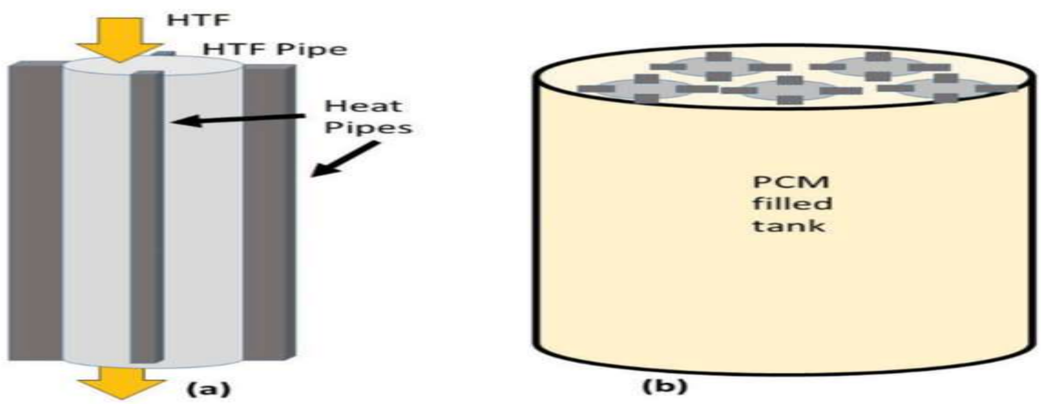
Advantages.

- It is abundant and inexpensive.
- It is easy to handle, nontoxic, noncombustible.
- Its flow can take place by thermosyphon action.
- It has high density, high specific heat, good thermal conductivity and low viscosity.
- Control water system is flexible.

Disadvantages

- Limited temperature range (0 to 100)
- Corrosive medium.
- Low surface tension (leaks easily)

LATENT HEAT STORAGE



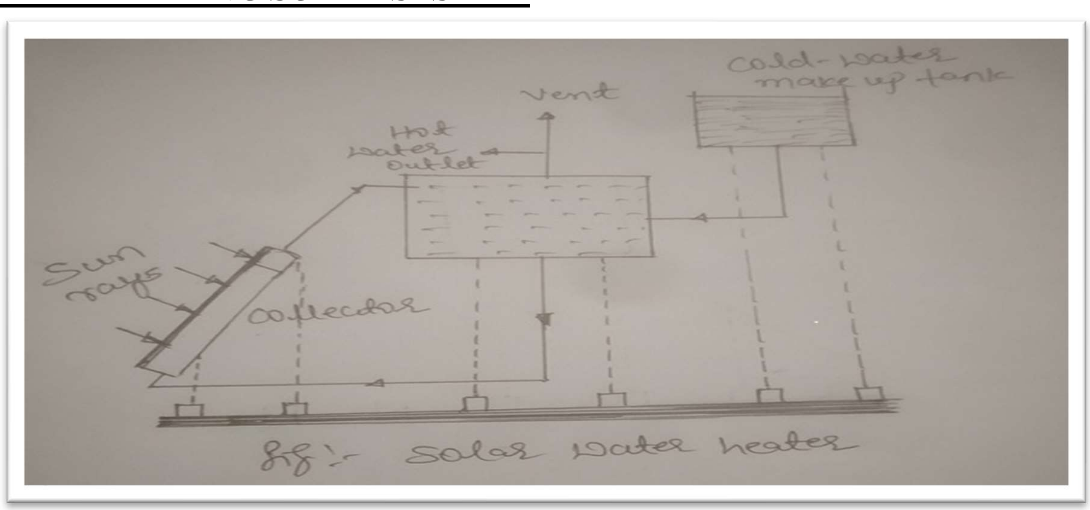
Latent heat storage **stores heat in a storage medium in the form of potential energy between the particles of the substance**. The conversion between the heat and the potential energy within the substance involves a phase change – thus heat storage occurs without significant temperature changes in the storage medium.

In this class of storage energy is stored by virtue of latent heat of change of phase of the storage medium. Phase change materials have considerably higher thermal energy storage densities as compared to sensible heat storage material and are able to absorb or release large quantities of energy at a constant temperature. Therefore, these systems are more compact but more expensive than sensible heat storage system.

Various phase changes that can occur are

Solid-solid   Solid-gas   Solid-liquid   Liquid- gas

WATER HEATING SOLAR SYSTEM



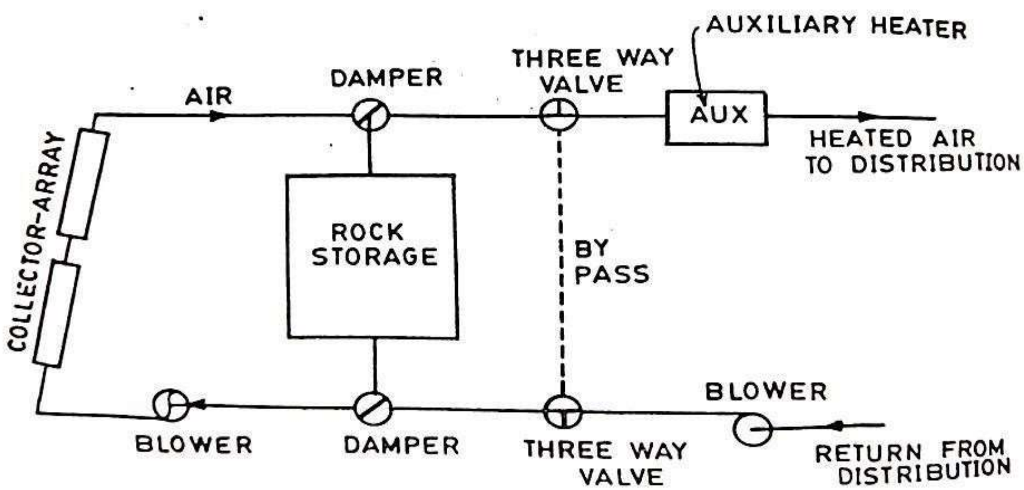
The details of the most common type of solar heater are shown in fig. a tilted flat plate solar collector with water as a heat transfer fluid is used. A thermally insulated hot water storage tank is mounted above the collector.

The heated water of the collector rises up to the hot water tank and replaces an quantity of cold water which enters the collector. The cycle repeats resulting in all the water of the hot water tank getting heated up.

When hot water is taken out from the hot water outlet the same is replaced by cold water from a cold water make up tank fixed above the hot water tank. The scheme is known as passive heating scheme as water circulated in the loop naturally due to thermo-syphon action.

When the collector is fixed above the level of hot water tank a pump is required to induce circulation of water in the loop and scheme will be known active or forced solar thermal system. An auxiliary electrical emersion heater may be used as a back-up for use during cloudy periods. In average Indian climatic conditions, a solar water heater can be used for about 300 days in a year. Solar water heater cost approximately Rs18000-21900 and delivers water at 60 – 80 C. it has a life span of 10-12 years

Solar air Heater



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SPACE HEATING

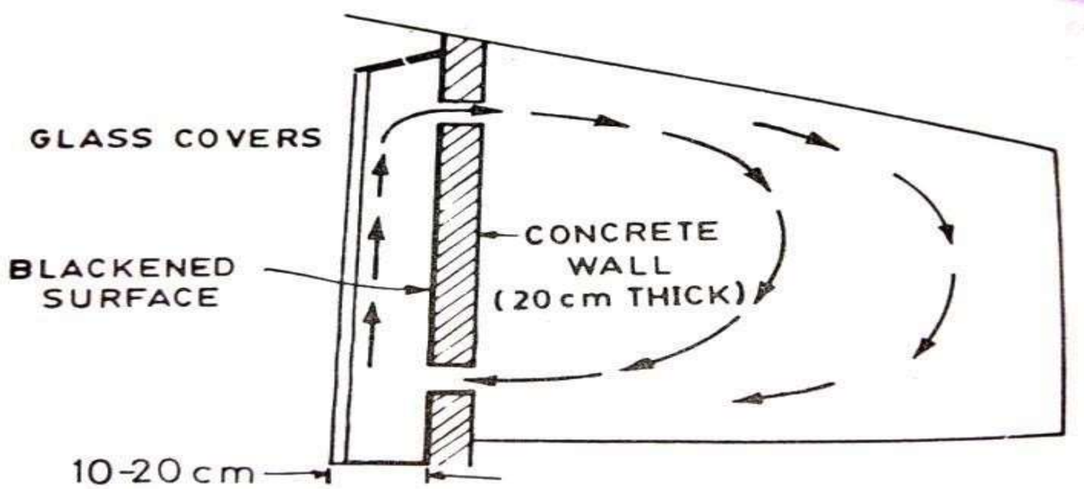

Fig. 5.3.1. A passive solar heating system.

Solar energy is also used for heating or cooling a building to maintain a comfortable temperature inside. Passive system do not require any mechanical devices and make use of natural process of conduction, convection and radiation for transport of heat.

A sunspace is any enclosed space, such as a green house or sun porch, with a glass wall on the south side. A sunspace may be attached (or built on) to a thick south wall of the building to be heated by the sun. Vents near the top and bottom of the wall, as in Fig. 5.3.1, permit circulation through the main building of the heated in the sunspace. Heat storage is provided by the thick wall, a concrete or masonry floor, water containers, and other materials in the sunspace. Thus, an attached sunspace system combines features of direct gain and storage wall concepts.

SOLAR SPACE COOLING OF BUILDINGS

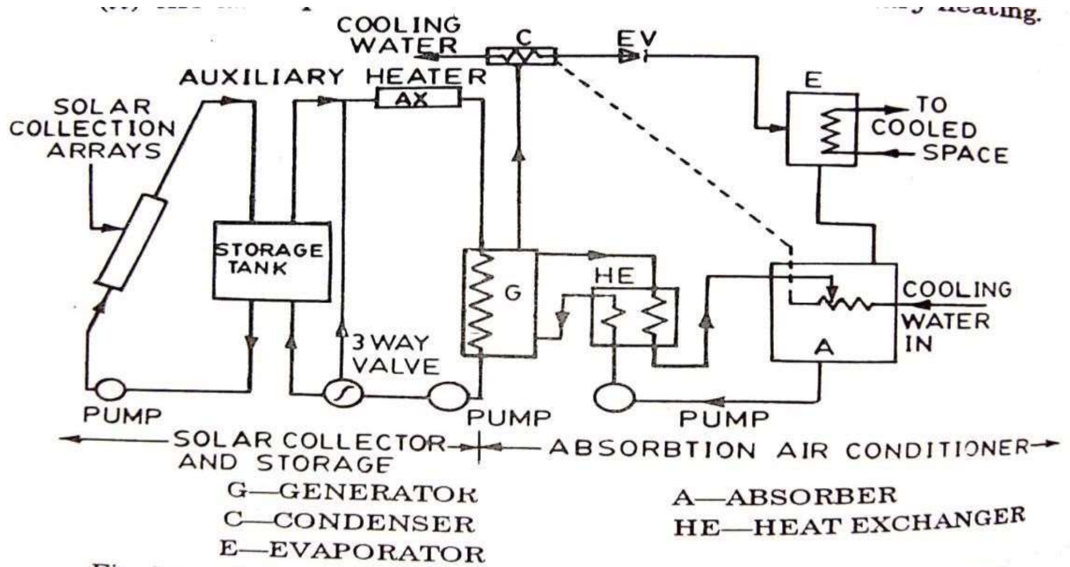

Fig. 5.4.1. Schamatic of Solar Operated Absorption Air Conditioner.

The absorption air conditioning system is shown schematically in Fig.5.4.1.

The system consists of two parts

(i) The solar collector and storage, and

(ii) The absorption air conditioner and the auxiliary heating.

The essential components of the cooler are

(i) generator (G), (ii) condenser (C)Evaporator (E), (iv) Absorber (A), (v) Heat-exchanger (HE).

The operation of air conditioners with energy from flat-plate collector and storage systems is the most common approach to the solar cooling today. In essence cooling is accomplished as the generator of the absorption cooler is supplied with heat by a fluid pumped from the collector storage system or from auxiliary. Heat is supplied to a solution of refrigerant in absorbent in the generator, where refrigerant is distilled out of the absorbent fluid. The refrigerant is condensed and goes through a pressure reducing valve to the evaporator where it operates and cools air or water for the cooling space. The refrigerant vapor goes to the absorber where it comes in contact with the solution which is weak in refrigerant and which flows from the generator. The vapor is absorbed in the solution, which is then returned to the generator. A heat exchanger is used for sensible heat recovery and greatly improves cooler C.O.P.

SOLAR POND

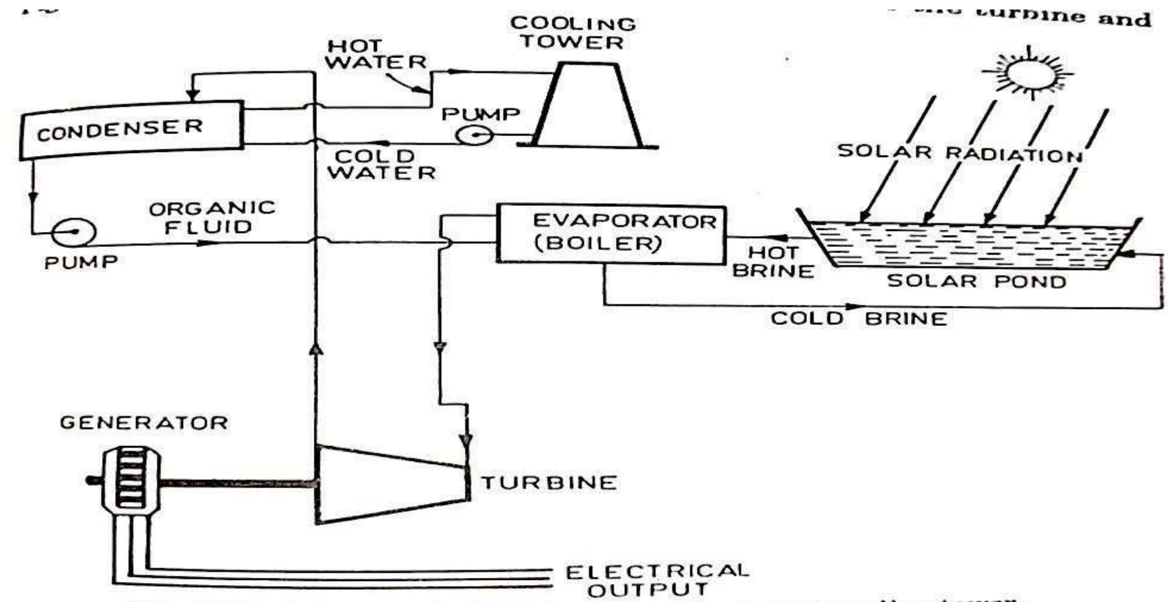

Fig. 4.3.3. Solar pond electric power plant with cooling tower.

- A solar pond is a mass of shallow water about 1 or 2 meters deep with a large collection area, which acts as a heat trap. It contains dissolved salts to generate a stable density gradient.
- Part of the incident solar radiation entering the pond surface is absorbed throughout the depth and the remainder which penetrates the pond is absorbed at the black bottom. If the pond were initially filled with fresh water, the lower layers would heat up, expand and rise to the surface.
- Because of the convective mixing and heat loss at the surface, only a small temperature rise in the pond could be realized. On the other hand, convection can be eliminated by initially creating a sufficiently strong salt concentration gradient.
- In this case, thermal expansion in the hotter lower layers is insufficient to destabilize the pond. With convection suppressed, the heat is lost from the lower layers only by conduction. Because of the relatively low conductivity, the water acts as an insulator and permits high temperature (over 90oC) to develop in the bottom layers. At the bottom of the pond, a thick durable plastic liner is laid.
- Materials used for the liner include butyl rubber, black polyethylene and hypalon reinforced with nylon mesh. Salts like magnesium chloride, sodium chloride or sodium nitrate are dissolved in the water, the concentration varying from 20 to 30 percent at the bottom to almost zero at the top.

SOLAR DISTILLATION:

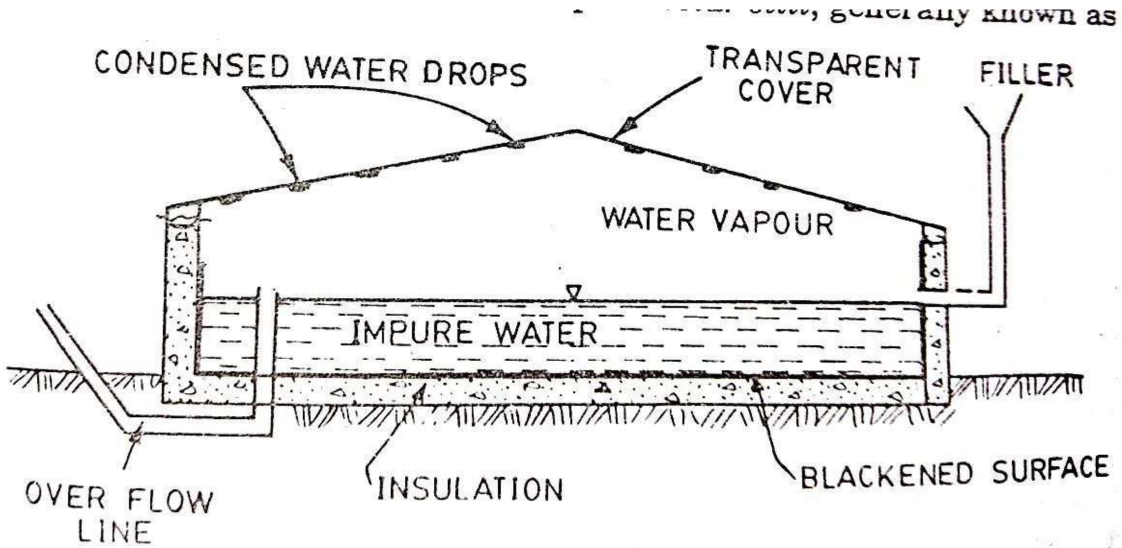

Fig. 5.8.1. Solar Water Still.

Potable or fresh water is one of the fundamental necessities of life for a man. Industries and agriculture also require fresh water without which they cannot thrive. Man has been dependent on rivers, lakes and underground water reservoir to fulfill his need of fresh water.

The use of solar energy for desalting seawater and brackish well water has been demonstrated in several moderate sized pilot plants in the Unites States, Greece, Australia and several other countries. The idea was first applied in 1982.

A simple basin type solar still consists of a shallow blackened basin filled with saline or brackish water to be distilled. The depth of water is kept about 5-10 cm. It is covered with sloppy transparent roof. Solar radiation, after passing through the roof is absorbed by the blackened surface of the basin and thus increases the temperature of the water. The evaporated water increases the moisture content, which gets condensed on the cooler underside of the glass. The condensed water slips down the slope and is collected through the condensate channel attached to the glass. The construction is shown in figure above.

SOLAR POWER GENERATION BY THERMAL STORAGE

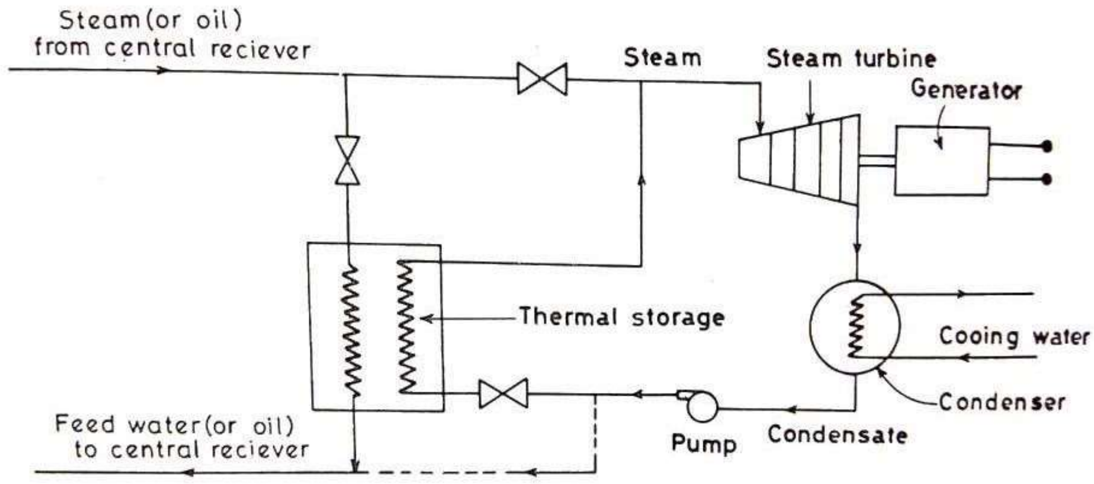

Fig. 5.5.6. Electric power generation using thermal storage.

Solar power generation by thermal storage the schematic diagram as shown in fig above. The cooling water from storage tank entering to condenser then its condensate passes to the pump to increase the pressure of water that high pressure of water flow to the expansion valve in that expansion valve regulate the pressure of water that water passes to the thermal storage tank here water gets evaporate to generate the steam that steam is flow to the expansion valve to regulate the pressure of steam then finally the steam is hit to turbine blades due rotation of the shaft mechanical energy is produced then mechanical energy is converted in to electrical energy in generator.