Solar Radiation

solar radiation is an electromagnetic radiation, including X-rays, ultraviolet and infrared radiation, and radio emissions, as well as visible light, emanating from the Sun. Of the 3.8×10^{33} ergs emitted by the Sun every second, about 1 part in 120 million is received by its attendant planets and their satellites. The small part of this energy intercepted by Earth (the solar constant, on average 1.4 kilowatts per square metre) is of enormous importance to life and to the maintenance of natural processes on Earth's surface. The energy output of the Sun has its peak at a wavelength of 0.47 micrometre (0.000019 inch; a micrometre is 10^{-6} metre), and the Sun radiates about 8 kilowatts per square cm of its surface.

Solar Radiation can be classified as follow:

Direct radiation also known as "beam radiation" or "direct beam radiation" is used to describe solar radiation travelling on a straight line from the sun down to the surface of the earth.

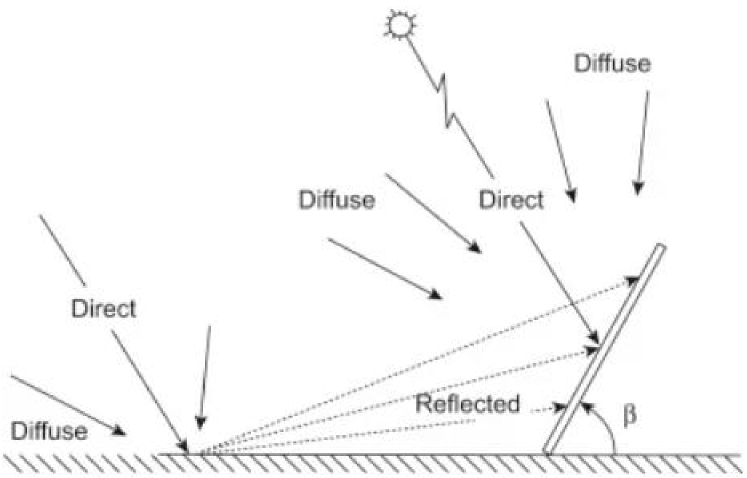
Diffuse radiation, on the other hand, describes the sunlight that has been scattered by molecules and particles in the atmosphere but that has still made it down to the surface of the earth.

In simple terms,

- direct radiation has a definite direction but diffuse radiation follows a much more scattered, uncertain path. Because when the radiation is direct, the rays are all travelling in the same direction, an object can block them all at once. Therefore, it can be noted that shadows are only produced when direct radiation is blocked.
- During times when the sky is clear and the sun is very high in the sky, direct radiation is around 85% of the total insolation striking the ground and diffuse radiation accounts for about 15%. As the sun lowers into the sky, the percent of diffuse radiation keeps increasing until it reaches 40% when the sun is 10° above the horizon.
- Atmospheric conditions like clouds and pollution also increase the chances of diffused radiation. On an extremely overcast day, pretty much 100% of the solar radiation is diffuse radiation. Technically speaking, the larger the percentage of diffuse radiation, the less the total insolation.
- Direct/diffuse ratio varies with latitude and climate.

Reflected radiation, This refers to the kind of radiation that has been reflected off the ground. Asphalt reflects about 4% of the light that strikes it and a lawn of about 25%. However, solar panels tend to be tilted away from where the reflected light is going. Moreover, reflected radiation rarely accounts for a significant part of the sunlight striking their surface.

An exception is in very snowy conditions which can sometimes raise the percentage of reflected radiation quite high. Fresh snow reflects 80 to 90% of the radiation striking it.



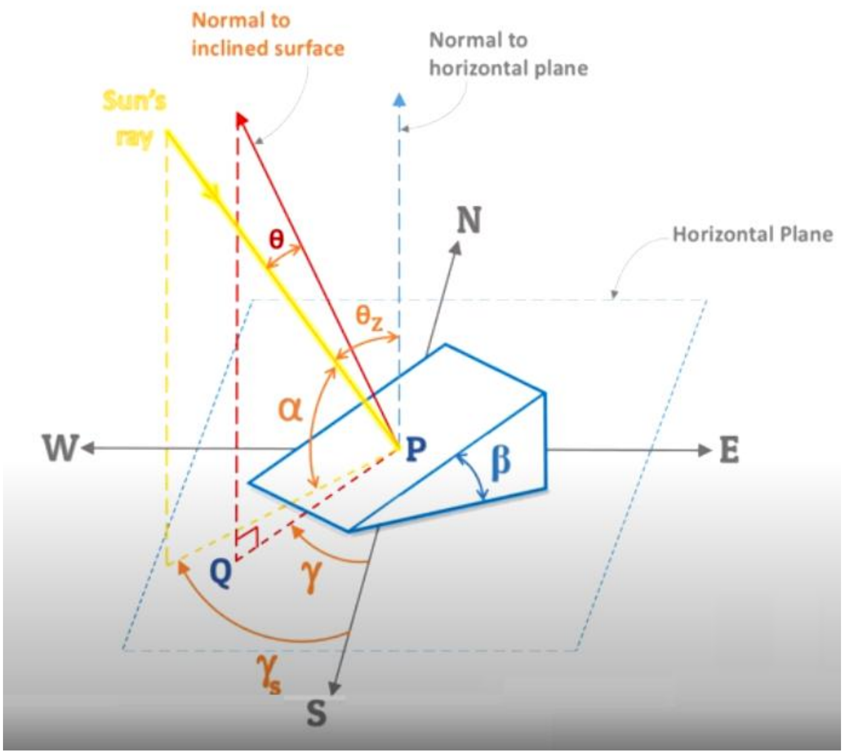
Solar Constant-

The solar constant is the incident ray of solar energy per unit area per second on the earth surface.

Solar constant = Energy / (Unit area x Unit time)

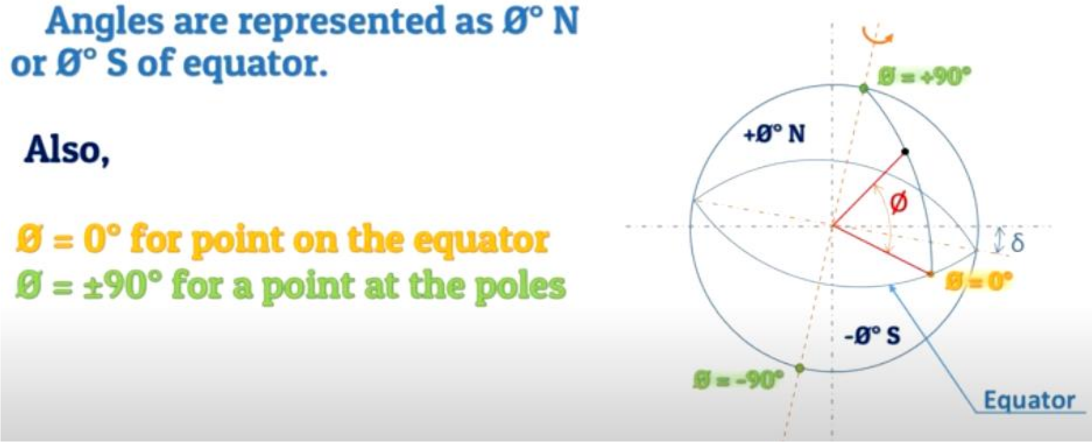
The measure of the solar electromagnetic radiation in a meter squared at Earth's distance from the sun is called a solar constant. To quantify the rate at the unit surface of a solar panel in which the energy is received upon the solar constant is used. In this case, the solar constant is absorbed at a given point and provides a total measurement of the sun's radiant energy. They are used in several atmospheric and geological sciences. Though it is called a constant, the solar constant is just nearly constant. Once every eleven years, the relative constant varies by 0.2% in a cycle that peaks. In 1838, Claude Pouillet made the first attempt to estimate the solar constant at 1.228 kW/m^2. At a solar minimum of 1.361 kW/m2 and a solar maximum of 1.362 kW/m^2, the constant is rated.To measure the solar constant and not just the visible light, the entire spectrum of electromagnetic radiation is included in it. From the satellites, the solar constant is taken at the best direct measurements. To calculate a solar constant, the Stefan-Boltzman constant is used. In this case, the constant refers to the power per unit area emitted by a black body as a function of its thermodynamic temperature.

Solar Angles / Sun Angles

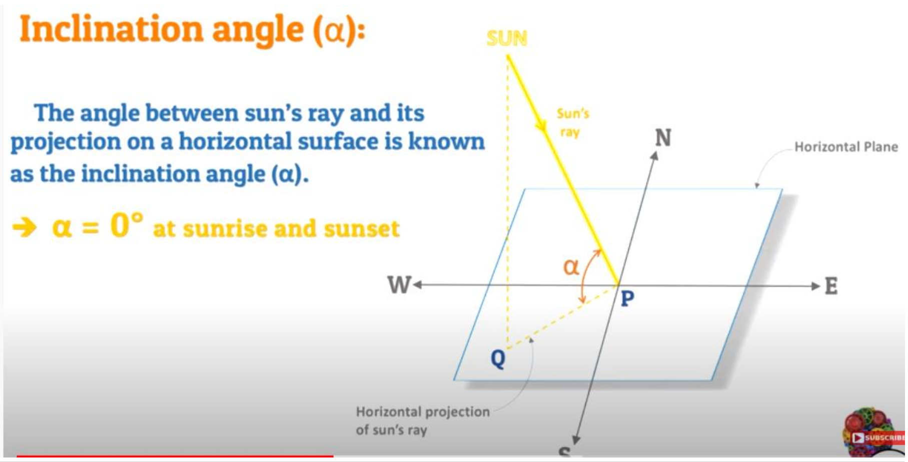


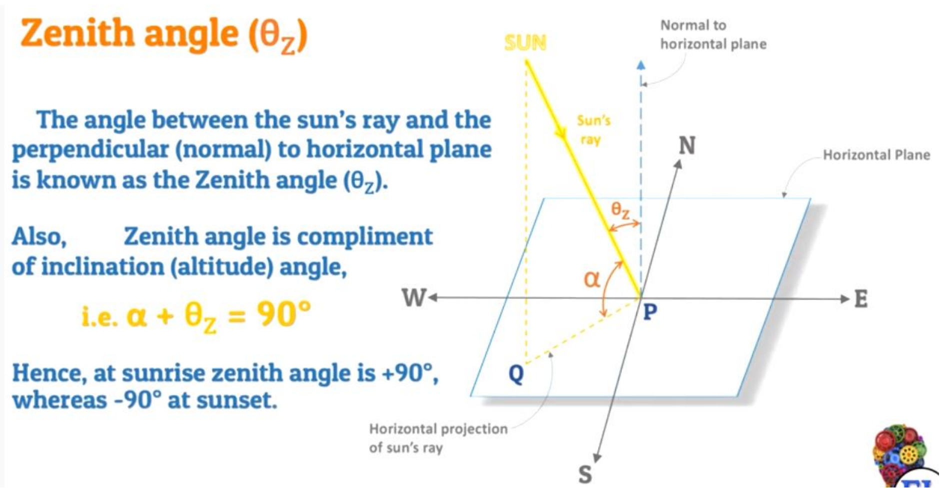
- ✓ Angle of Latitude (ϕ)
- ✓ Inclination Angle (α)
- ✓ Zenith Angle (θ_Z)
- ✓ Solar Azimuth Angle (γ_S)
- ✓ Tilt Angle or Slope (β)
- ✓ Angle of Incidence (θ)
- ✓ Surface Azimuth Angle (γ)

Angle of Latitude (ϕ)- The vertical angle between the line joining that point of location to the center of the earth and its projection on an equatorial plane. When the point is north of the equator, the angle is positive, when south it is negative.



Inclination Angle (α)-



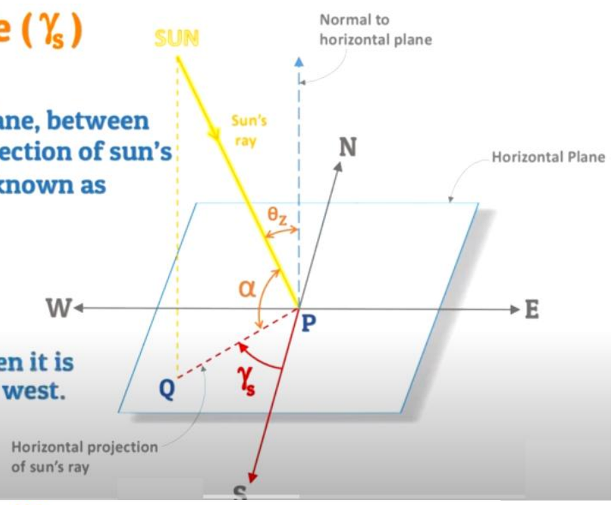


Solar azimuth angle (γ_s)

The angle on a horizontal plane, between the line due south and the projection of sun's ray on the horizontal plane is known as Solar azimuth angle (γ_s).

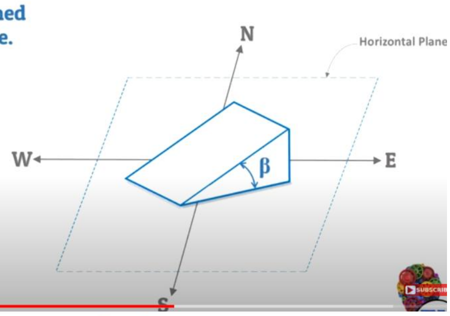
W +ve S

It is considered as positive when it is measured from south towards west.



Tilt angle or slope (β)

It is an angle between the inclined surface and the horizontal plane.



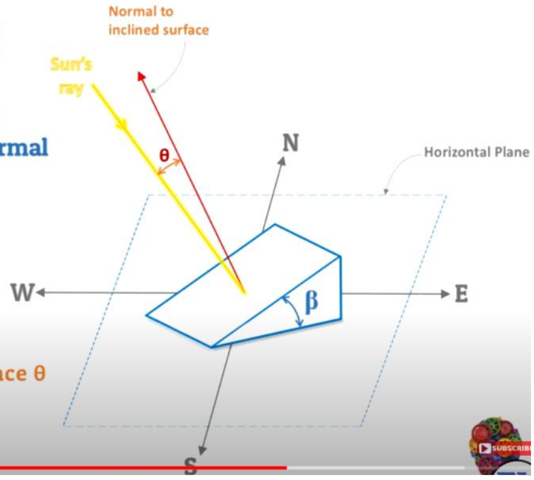
Angle of incidence (θ)

It is an angle between sun's ray incident on plane surface and normal to that surface.

For Horizontal Surface,

Slope, $\beta = 0°$

Zenith Angle θ_Z = Angle of Incidence θ

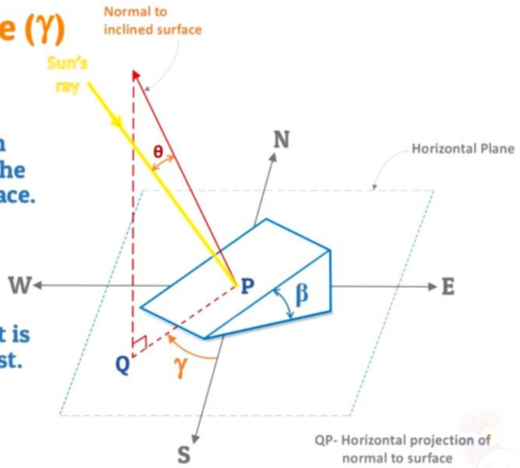


Surface azimuth angle (γ)

It is the angle in the horizontal plane, between the line due south and the horizontal projection of the normal to the inclined plane surface.

W +ve S

It is considered as positive when it is measured from south towards west.



Flate Plate Collector

The flat-plate solar collectors are probably the most fundamental and most studied technology for solar-powered domestic hot water systems. The overall idea behind this technology is pretty simple. The Sun heats a dark flat surface, which collect as much energy as possible, and then the energy is transferred to water, air, or other fluid for further use.

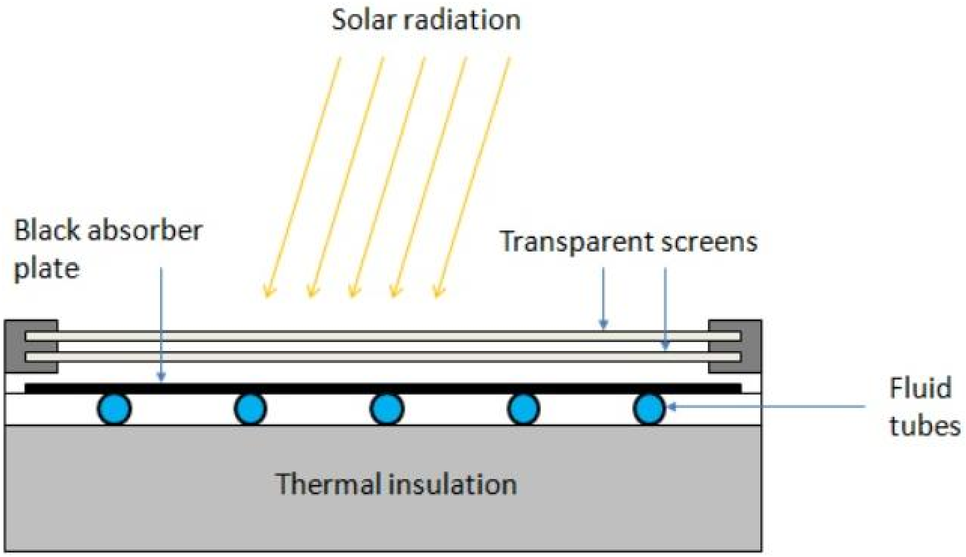


Fig. 1 Schematic of a flat plate solar collector with liquid transport medium.

The solar radiation is absorbed by the black plate and transfers heat to the fluid in the tubes. The thermal insulation prevents heat loss during fluid transfer; the screens reduce the heat loss due to convection and radiation to the atmosphere.
The **main components** of a typical flat-plate solar collector:

- **Black surface** - absorbent of the incident solar energy
- **Glazing cover** - a transparent layer that transmits radiation to the absorber, but prevents radiative and convective heat loss from the surface
- **Tubes** containing heating fluid to transfer the heat from the collector
- **Support structure** to protect the components and hold them in place
- **Insulation** covering sides and bottom of the collector to reduce heat losses

The flat-plate systems normally operate and reach the maximum efficiency within the temperature range from 30 to 80 °C, however, some new types of collectors that employ vacuum insulation can achieve higher temperatures (up to 100 °C). Due to the introduction of selective coatings, the stagnant fluid temperature in flat-plate collectors has been shown to reach 200 °C.

The **advantages** of the flat-plate collectors are that they are:

- Easy to manufacture
- Low cost
- Collect both beam and diffuse radiation
- Permanently fixed (no sophisticated positioning or tracking equipment is required)
- Little maintenance

Installation Guideline- Flat-plate collectors are installed facing the equator (i.e. South oriented in the Northern hemisphere and North oriented in the Southern hemisphere). The optimal tilt of the collector plate is close to the latitude of the location (+/- 15 °). If the application is solar cooling, the optimum installation angle is Latitude - 10 °, so that the solar beam is perpendicular to the collector during summertime. If the application is solar heating, the optimum installation angle is Latitude + 10 °. It was found however, that for year-round hot water application, the optimum angle is Latitude + 5 °, which provides somewhat better performance during winter, when the hot water is more needed.

Concentrating Collector

Two types- **Focusing Type** and **Non-focusing type.**

Focusing Type-

- Device to collect solar energy with high efficiency of solar radiation on the energy absorbing surface.
- Such collectors generally use optical systems in the form of reflectors or refactors.
- It can be treated as a special form of flate plate collector modified by introducing a reflecting (refracting) surface (concentrator) between the solar radiation and absorber.

These type of collectors can have radiation increase from low value of 1.5 to 2 to high values of the order of 10,000. In these collectors radiation falling on a relatively large area is focused on to a receiver (or absorber) of considerably smaller area. As a result of the energy concentration, fluids can be heated to temperatures 500°C or more.

An importance difference between collectors of the non-focusing and focusing types in that the latter concentrate only direct radiation coming from a specific direction, since diffuse radiation arrives from all directions, only a very small proportion is from the direction for which focusing occurs. The optical system directs the solar radiation on-to an absorber of smaller area which is usually surrounded by a transparent cover. Because of the optical system, certain losses (in addition to those which occur while the radiation is transmitted through the cover) are introduced. These include reflection or absorption losses in the mirrors or lenses and losses due to geometrical imperfections in the optical system. The combined effect of all losses is indicated through the introduction of a term called the *optical efficiency*. The introduction of more optical losses is compensated for by the fact that the flux incident on the absorber surface is concentrated on a smaller area. As a result, the thermal loss terms do not dominate to the same extent as in a flat-plate collector and the collection efficiency is usually higher.

Further classification of Focusing Type - Line Focusing and Point Focusing.

- The line is a collector pipe, and the point is a small volume through which the heat transport fluid flows. Since the sun has a finite size, the focusing does in fact occur over a small area or volume rather than a line or point.

The main type of concentrating collectors are-

1) Parabolic trough collector
2) Mirror strip reflector
3) Fresnel Lens Collector
4) Flat Plate collector with adjustable Mirror
5) Compound Parabolic Concentrator

Solar Air Heaters

The solar air heater is a solar collector or heat ex-changer, which absorbs the incident solar radiation, convert it into heat and finally transfer this heat to a heat removal fluid (also called working fluid) for an end use system. The air is used as a working fluid in solar air heaters.

Note- If the working fluid is water, solar collector is called solar water collector or solar water heater.

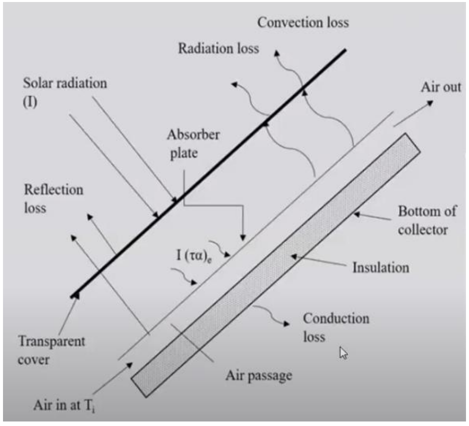


Fig: Basic elements of solar air heater.

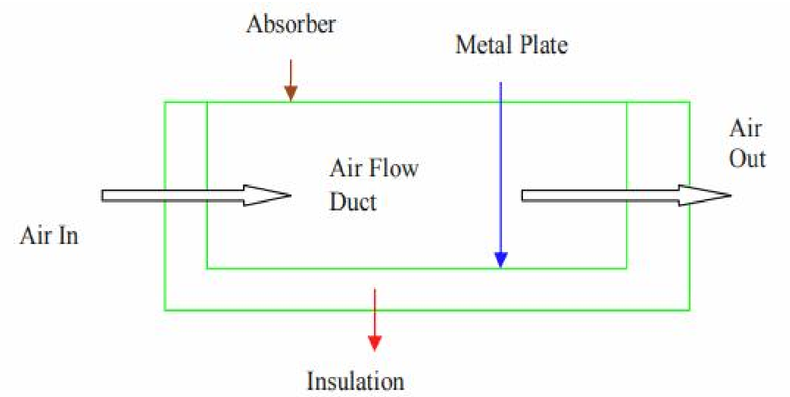


Fig: Solar Air Heater (Non-porous)

Solar air heaters can be broadly classified under two categories : **Solar air heater with non-porous absorber and Solar air heater with porous absorber.**

Solar air heater with non-porous absorber- Air stream does not flow through the absorber plate. Air may flow above and/or below the absorber plate.

- ✓ The simplest type of nonporous solar air heater is the one which consists of a bare metallic plate, the top of which is suitably blackened.
- ✓ Another plate, the rear of which is insulated, below the absorber plate is used to form the duct for air flow.
- ✓ The incident solar radiation on the blackened surface gets absorbed and the resulting heat is partially transferred to the flowing air within the duct.
- ✓ **Disadvantages**- high thermal losses to the ambient due to convection and radiation.
- ✓ The convective losses can be reduced by covering the absorber plate with one or more transparent covers, usually called glazing.

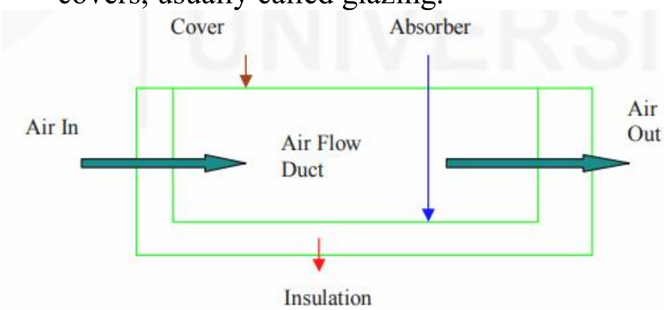


Fig. Nonporous Type Solar Air Heater with Glazing (*The flow of the air is above the absorber*)

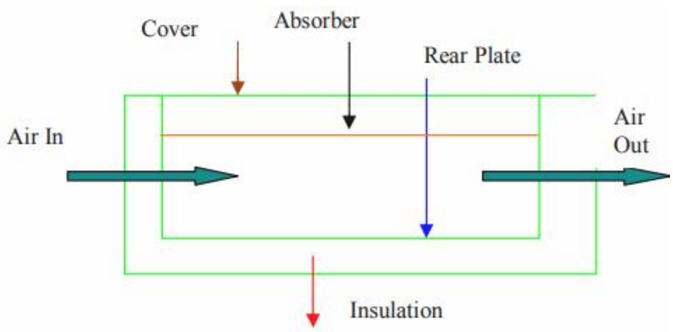


Fig. : Nonporous Type Solar Air Heater with Glazing (*The air flow is below the absorber in the solar air heater*)

Solar air heater with porous absorber- Air stream flows through the absorber plate.

- ✓ The problem of the non-porous absorber solar air heater are overcome here in following way:
- ✓ Solar radiation penetrates to greater depths and is absorbed gradually depending upon the porosity of the absorber.

- ✓ The incoming air introduced from the upper surface of the matrix is first heated by the upper layers. The air stream gets heated while traveling through the matrix layers. The lower matrix layers are hotter than the upper ones resulting into better heat transfer from the matrix.
- ✓ The pressure drop for the porous matrix is usually much lower than the nonporous absorber.

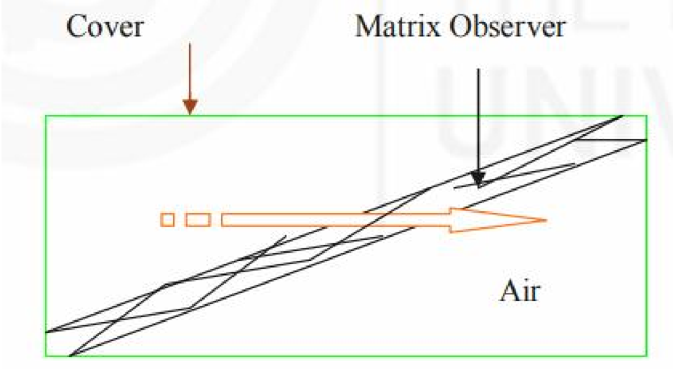


Fig: Porous Type Solar Air Heater.

Applications- Space heating, Solar drying, Solar water heating.

Solar Dryer

Solar dryers are devices that use solar energy to dry substances, especially food. Solar dryers use the heat from sun to remove the moisture content of food substances.

- ➢ There are two general types of solar dryers: **Direct** and **indirect**.

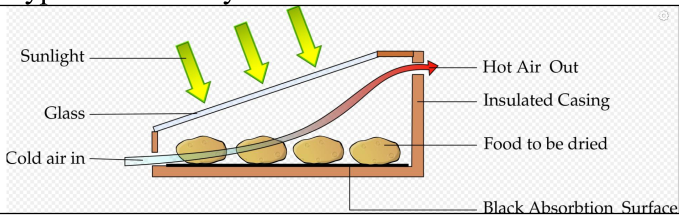


Fig: The schematic of direct solar dryer.

Direct Solar Dryer- Direct solar dryers expose the substance to be dehydrated to direct sunlight. One modern type of solar dryer has a black absorbing surface which collects the light and converts it to heat; the substance to be dried is placed directly on this surface. These driers may have enclosures, glass covers and/or vents in order to increase efficiency.

Indirect Solar Dryer- In indirect solar dryers, the black surface heats incoming air rather than directly heating the substance to be dried. This heated air is then passed over the substance to be dried and exits upwards often through a chimney, taking moisture released from the substance with it.

- ➢ One of the advantages of the indirect system is that it is easier to protect the food, or other substance, from contamination whether wind-blown or by birds, insects, or animals.
- ➢ Solar drying is mostly carried out between 50-70 degree Celsius.

Storage of Solar Energy

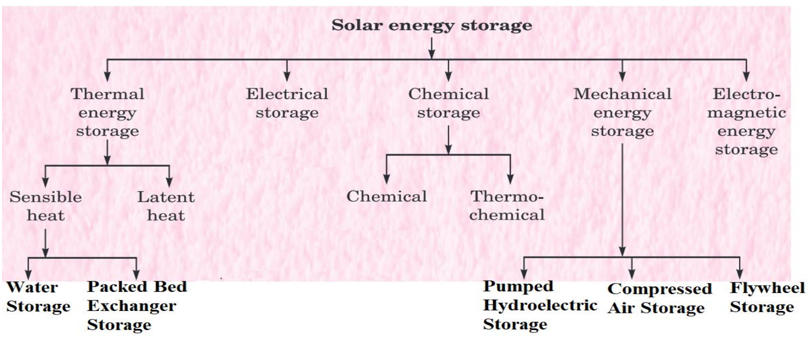


Fig: Classification of solar energy storage Systems.

1) Thermal Energy Storage-

- The energy can be stored by heating melting and evaporation of material and the energy becomes available as heat, when the process is reversed.
- This type of storage is essential for domestic water and space heating applications and for high temperature storage systems needed for thermal power applications.
- The storage is also required for the process industries and horticultural.
- The choice of storage materials depends on applications.

1.1) Sensible Heat Storage- The storage by causing a material to rise in temperature is called sensible Heat Storage.

- It involve in a material that undergoes no change in phase over a temperature domain encountered in a storage process.

1.1.1) Water Storage-

The most common heat transfer fluid for a solar system is water, and the easiest way to store thermal energy is by storing the water directly in a well insulated tank. The optimum tank size for flat-plate collector system is usually about 70 kg/m^2 (2 gal/ft^2). Water has the following characteristics for storage medium.

(*i*) It is an inexpensive, readily available and useful material to store sensible heat.

(*ii*) It has high thermal storage capacity.

(*iii*) Energy addition and removal from this type of storage is done by medium itself, thus eliminating any temperature drop between transport fluid and storage medium.

(*iv*) Pumping cost is small.

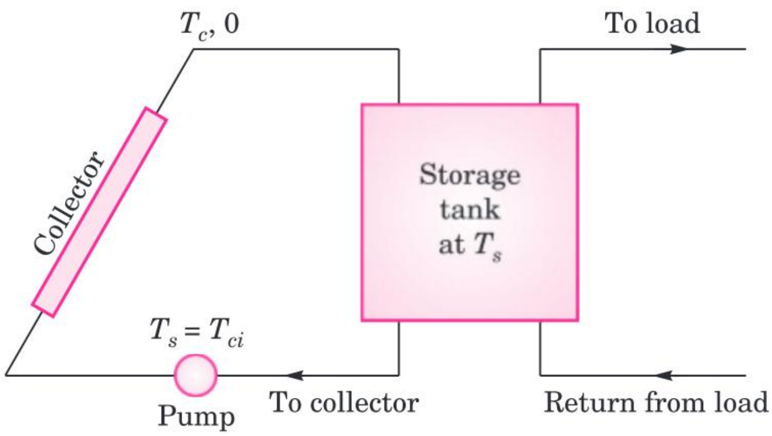


Fig: Water Tank Storage Unit in which energy is added by circulating water through collector and removed by circulating water through load.

1.1.2) Packed Bed Ex-changer Storage-

For sensible heat storage with air as the energy transport mechanism, rock, gravel, or crushed stone in a bin has the advantage of providing a large, cheap heat transfer surface. Its thermal capacity, however, is only about half that of water, and the bin volume will be about 3 times the volume of a water tank, that is heated over the same temperature interval. Water is superior because of its lower material cost and lower volume required per unit of energy stored. Rock does have the following advantages over water:

1. Rock is more easily contained than water.
2. Rock acts as its own heat exchanger, which reduces total system cost.
3. It can be easily used for thermal storage at high temperatures, much higher than 100°C; storage at high temperature where water cannot be used in liquid form without an experience, pressurized storage tank.
4. The heat transfer coefficient between the air and solid is high.
5. The cost of storage material is low.
6. The conductivity of the bed is low when air flow is not present.

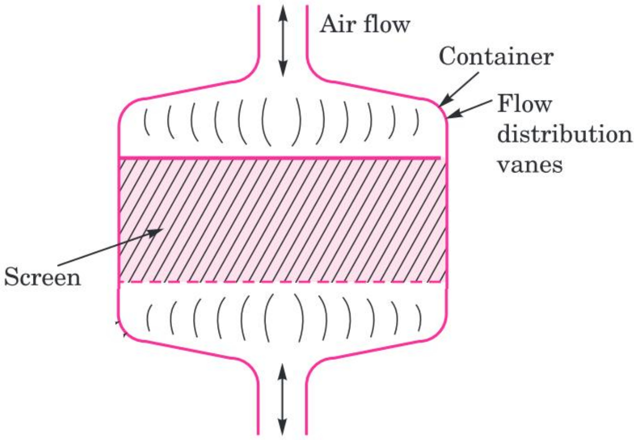


Fig: Schematic diagram of packed bed exchanger storage.

1.2 Latent Heat Storage- The storage by phase change , transition from solid to liquid or from or from liquid to vapour is the mode of thermal storage called Latent Heat Storage.

In this system, heat is stored in a material when it melts and extracted from the material when it freezes. Materials that undergo a change of phase in a suitable temperature range may be useful for energy storage if the following criteria can be satisfied:

(*i*) The phase change must be accompanied by high latent heat effect.

(*ii*) The phase change must be reversible over a very large number of cycles without degradation.

(*iii*) The phase change must occur with limited super cooling.

(*iv*) Means must be available to contain the material and transfer heat into it and out of it.

(*v*) The cost of materials and its containers must be reasonable.

(*vi*) Its phase change must occur close to its actual melting temperature.

(*vii*) The phase change must have a high latent heat effect, that is, it must store large quantities of heat.

(*viii*) The material must be available in large quantities.

(*ix*) The preparation of the phase changing material for use must be relatively simple.

(*x*) The material must be harmless (non-toxic, non-inflammable, non-combustible, non-corrosive).

(*xi*) A small volume change during the phase change.

(*xii*) The material should have high thermal conductivity in both the phases.

Solar Pond

A solar pond is a solar energy collector, generally fairly large in size, that looks like a pond. This type of solar energy collector uses a large, salty lake as a kind of a flat plate collector that absorbs and stores energy from the Sun in the warm, lower layers of the pond. These ponds can be natural or man-made, but generally speaking the solar ponds that are in operation today are artificial.

How Solar Pond Works?

The key characteristic of solar ponds that allow them to function effectively as a solar energy collector is a salt-concentration gradient of the water. This gradient results in water that is heavily salinated collecting at the bottom of the pond, with concentration decreasing towards the surface resulting in cool, fresh water on top of the pond. This collection of salty water at the bottom of the lake is known as the "storage zone", while the freshwater top layer is known as the "surface zone". The overall pond is several meters deep, with the "storage zone" being one or two meters thick.

These ponds *must* be clear for them to operate properly, as sunlight cannot penetrate to the bottom of the pond if the water is murky. When sunlight is incident on these ponds, most of the incoming sunlight reaches the bottom and thus the "storage zone" heats up. However, this newly heated water cannot rise and thus heat loss upwards is prevented. The salty water cannot rise because it is heavier than the fresh water that is on top of the pond, and thus the upper layer prevents convection currents from forming. Because of this, the top layer of the pond acts as a type of insulating blanket, and the main heat loss process from the storage zone is stopped. Without a loss of heat, the bottom of the pond is warmed to extremely high temperatures - it can reach about 90°C. If the pond is being used to generate electricity this temperature is high enough to initiate and run an organic Rankine cycle engine.

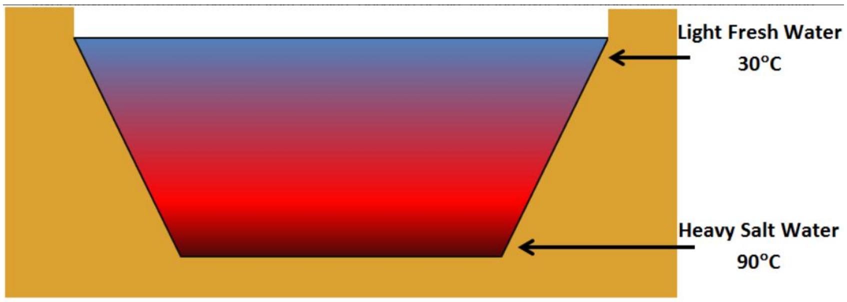


Fig: Diagram of a solar pond showing the temperature and saline gradient.

It is vital that the salt concentrations and cool temperature of the top layer are maintained in order for these ponds to work. The surface zone is mixed and kept cool by winds and heat loss by evaporation. This top zone must also be flushed continuously with fresh water to ensure that there is no accumulation of salt in the top layer, since the salt from the bottom layer diffuses through the saline gradient over time. Additionally, a solid salt or brine mixture must be added to the pond frequently to make up for any upwards salt loses.

Application:-

- Heating and Cooling of Buildings
- Production of Power
- Industrial Process Heat
- Desalination
- Heat for Biomass conversion

Solar Water Heater/ Hot Water Supply System

Solar water heating system is a device that helps in heating water by using the energy from the SUN. Water is easily heated to a temperature of (60-80) degree C.
The **basic elements** of solar water heater are-

- Flat Plate Collector

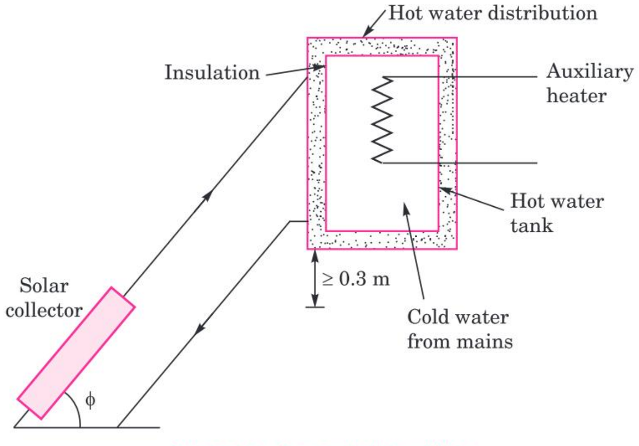
- Storage Tank
- Circulation System and Auxiliary Heating System
- Control of the system

The simplest type of solar water heater is Thermoshiphon system.

Commercial design of solar water heater are-
1) **Natural Circulation Solar Water Heater (Pressurized)**
2) **Natural Circulation Solar Water Heater (Non-Pressurized)**
3) **Forced Circulation Solar Water Heater**.

<u>Natural Circulation Solar Water Heater (Pressurized)-</u>

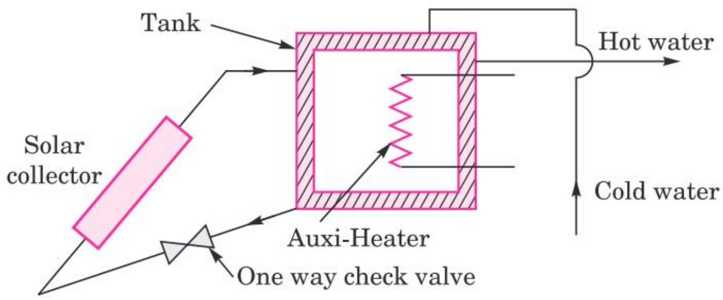
- ✓ It consist of tilted collector (south facing), with transparent cover glasses, a separate highly insulated water storage tank and well insulated pipe connected the two.
- ✓ The bottom of the tank is at least 1 feet the top of the collector and no auxiliary energy is required to circulate water through it.
- ✓ Circulation occurs through natural convection, or thermosiphoning. As the water is heated in its passage through the collector, its density decreases and hence it rises and flows at the top of the storage tank. The colder water from the bottom of the tank has a higher density and so tends to sink and enter the lower heater of the collector for further heating.
- ✓ The density difference between hot and cold water thus provides the driving force (convection) for the circulation of water through the collector and storage tank. The hot water is drawn from the top of the tank as required and replaced by the cold water from the service.
- ✓ As long as sun shines, water will quitely circulates to get it warmer. After sun set, the thermosiphon can reverse its flow and loss heat to the environment during the night.
- ✓ To avoid reverse flow, the top heater of the absorb er is kept stated above 0.3 m below the cold leg fitting on the storage tank.
- ✓ To provide heat during long cloudy period, an electrical immersion heater can be used a backup to the solar heating system.
- ✓ The thermosiphon solar water heater are passive system and do not requires a mechanical pump to circulate the water.



Schematic of a neutral circulation solar water heater (pressurized).

<u>Natural Circulation Solar Water Heater (Non- Pressurized)-</u>

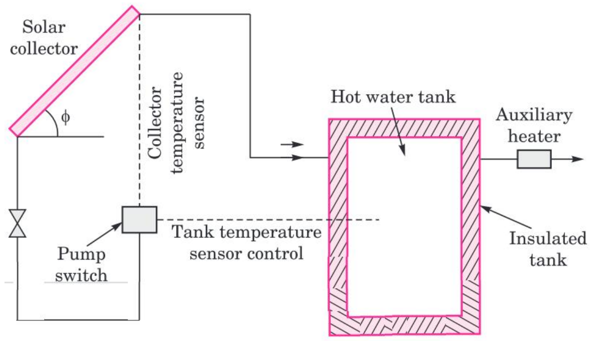
- ✓ The non-pressurized supply hot water by gravity.
- ✓ The only one way check valve may be desirable to prevent reverse circulation and thus for loss of heat at night.



Non-pressurized solar water heater.

Forced Solar Water Heater-

- Electric pump are included in the return circuit between between the bottom of the storage tank and the lower header of the collector.
- The tank can be placed as per the convenience level (e.g, at the basement).
- This works as an active system.
- A control unit permits the pump to operate only when the temperature of the water at the bottom of the tank is below that of the water in the upper header.
- The check valve is used to prevent the reverse circulation and resultant night time thermal losses from the collector.



Forced Solar Water Heater

Solar Distillation

In the Solar distillation process solar energy is used to evaporate water and its condensate is collected within the same closed system. Unlike other forms of water purification methods like desalination, this methodology can be used to turn salt or brackish water into fresh drinking water. Solar still is the structure that houses the distillation equipment. In other words, the solar still process as: "A place where an influent solution enters the system and the more volatile solvents leave in the effluent leaving behind the salty solute behind". Solar distillation differs from a more energy-intensive methodology like the reverse osmosis, or simply boiling water due to its usage of 'free' and eco-friendly solar energy.

Implementation- Solar water distillers find application mostly in remote areas where there is limited access to freshwater and centralized distribution systems. In these areas technical expertise is made use of to introduce the system and personnel in usage and maintenance of the system. An important criterion for installation of these systems is that the area should be flat and open with good access to water and sunlight. The "roof" of the system is fitted with a transparent glass cover tilted at an angle so as to catch maximum sunlight. Solar energy can access the underlying still basin by penetrating through the cover. The untreated water is collected in the still basin. Solar energy heats up this water and then evaporates and separates it from the contaminants. It is important that the material used in still basin should be able to absorb heat. Examples of such materials are leather sheet, silicon, reinforced plastic, or steel plate. The slanted cover funnels the condensed water into a pipe tube, which is attached to a storage container so it can be used for drinking water.

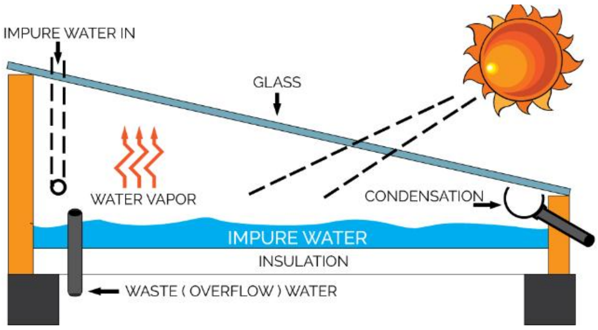


Fig: Solar Distillation of Water.

Socioeconomic Benefits -

- The operational energy costs and installation is very low.
- Provides safe drinking water hence alleviating water supply stress and health risks from contaminated drinking water.

Environmental Benefits-

- This method offers a way to diversify the existing sources of fresh water so that the stress on local sources of supply is reduced.
- Solar is a renewable and free source of energy hence this method is a less energy intensive process.

Other Benefits-

- No moving parts
- Water taste is better

Disadvantages

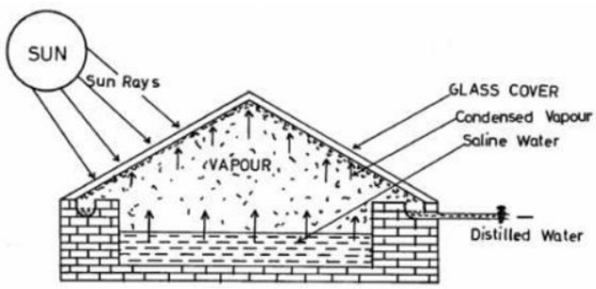
- Solar distillers don't kill bacteria and they don't break down harmful chemicals because they don't boil the water
- The large area tilted glass cover might be an attraction to bugs and insects

Solar Stills

A solar still distills water with substances dissolved in it by using the heat of the Sun to evaporate water so that it may be cooled and collected, thereby purifying it.

- Communities especially women, especially those living in saline water regions have a hard time collecting drinking water and purifying it for making it potable. Water Still purifies brackish water by utilising the sun rays - hence a simple, inexpensive and sustainable renewable energy technology.

Construction- This technology is based on the simple evaporation-condensation principle by the virtue of which the sun evaporates the sea-water and then condenses it to culminate into pure rain water. Saline water is fed into the tank which is exposed to the sun. The black bottom of the tank absorbs solar energy and gets heated. The heat evaporates the tank water which condenses on the glass sheet and finally converts into drops of pure drinking water. This purified water collects in the channel running through a tap. Hence, you get clean hygienic drinking water by simply turning on the tap and storing this water for further usage. The average output of the still is 2 to 3 litres of drinking water per day per square metre of the area.



Solar Cooker

A solar cooker is a device which uses the energy of direct sunlight to heat, cook or pasteurize drink and other food materials.

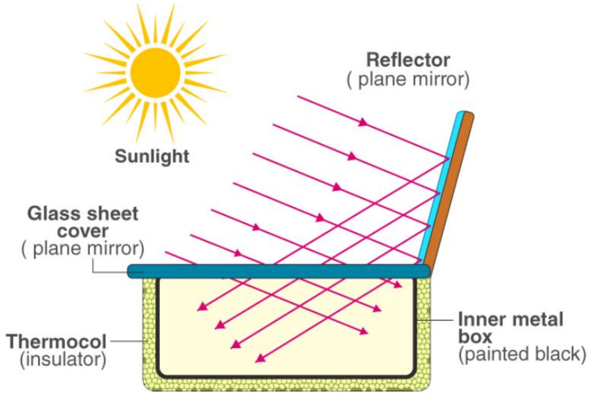


Fig: Solar Cooker.

- Sunlight isn't hot in and of itself. It is radiation generated by fluctuating electric and magnetic fields. The sunlight to heat conversion occurs when the photons of light waves interact with molecules of the substance. The electromagnetic radiation emitted by the Sun possesses energy in them. When they strike, the energy causes the molecules of the matter to vibrate. The molecules get excited and jump to higher levels. This activity generates heat.

Working Principle:-

- *Concentrating Sunlight:* A mirror surface with high specular reflection is used to concentrate and channelise light from the sun into a small cooking space. The sunlight can be concentrated by several orders of magnitude, producing magnitudes high enough to melt salt and metal. For household solar cooking applications, such high temperatures are not required. Solar cookers available in the market are designed to achieve temperatures of 65 degree C to 400 degree C.
- *Converting Light Energy to Heat Energy:* The concentrated sunlight is focused onto a receiver such as a cooking pan. The interaction between the light energy and the receiver material helps to converts light into heat by a process called conduction. The conversion is maximised by making use of materials that conduct and retain heat. Pots and pans used in solar cookers should be matte black in colour to maximise the absorption.
- *Trapping Heat Energy:* The occurrence of convection is reduced by isolating the air inside the cooker from the air outside. Using a glass lid on the pot enhances light absorption from the top of the pan and decreases the convection energy loss along with improving heat holding capacity of the cooker. The glazing taps the incoming sunlight but is opaque to escaping infrared thermal rays.

Box-Type Solar Cooker

The most commonly used form of solar cooker is the box-type solar cooker. In this section, we will be discussing the construction and working principle of a box-type solar cooker.

A box-type solar cooker consists of the following components:

Black Box – The box is an insulated metal or wooden box which is painted black from the inside to absorb more heat.

Glass Cover – A cover made two sheets of toughened glass held together in an aluminium frame is used as a cove for box B.

Plane Mirror reflector – The plane mirror reflector is fixed to the box B with the help of hinges. The mirror reflector can be positioned at any desired angle to the box. The mirror is positioned so as to allow the reflected sunlight to fall on the glass cover of the box.

Cooking Containers – A set of aluminium containers blackened from the outside are kept in box B.

- ✓ The solar cooker placed in sunlight and a plane mirror reflector is adjusted in a way such that the strong beam of sunlight enters the box through the glass sheet. The blackened metal surfaces in the wooden box absorb infra-red radiations from the beam of sunlight and heat produced raises the temperature of a blackened metal surface to about 100°C.

Advantages-

- ❖ Solar cookers use no fuel.
- ❖ This saves cost as well as the environment by not contributing to pollution.
- ❖ Reduces carbon footprint by cooking without carbon dioxide-based fuels.

Disadvantages-

- ❖ Solar cookers are less useful in cloudy weather.
- ❖ Some solar cookers take longer to cook food than a conventional stove or an oven.
- ❖ Some solar cookers are affected by strong winds which can slow the cooking process.
- ❖ It might get difficult to cook some thick foods such as large roasts and loaves of bread.

Solar heating & cooling of buildings

Space Heating- It consist of passive system, a active system or the combination of both. The passive systems are relatively less costly and less complex than active system.

Solar Passive Heating System- The heating system which does not includes any mechanical devices and make use of natural process (conduction, convection, radiation) of heat transport.

- ❖ The design is more important to process solar passive heating system. These are specially designed houses.
- ❖ The passive heating and cooling both are possible for space, but cooling is less developed than heating.
- ❖ Passive solar space heating takes the advantages of warmth from the sun through design features, such as large south facing windows and materials in the floor and the walls that absorbs warmth during the day and releases it at night when it needed more.

Passive solar Design System-

The **Direct Gain** Stores and slowly releases the collected energy from sun shining directly into the building and warming materials such as tile and concrete.

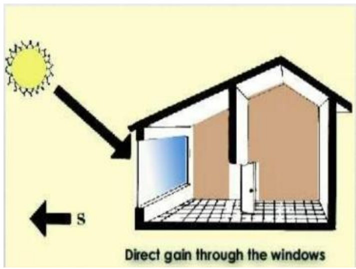


Fig: Direct Gain through the window.

Indirect Gain uses materials that hold, store and releases heat; the material is located between sun and living space.

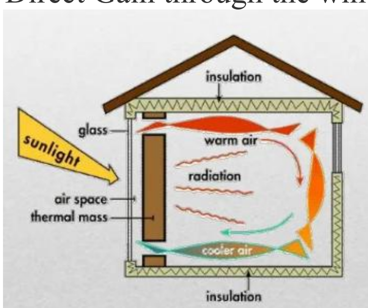


Fig: Indirect Gain.

The **isolated gain** collects solar energy remote from the location of primary living area.

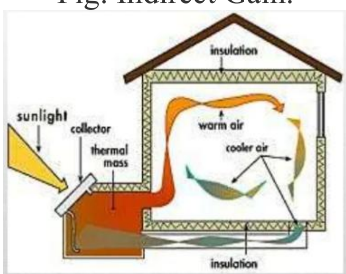


Fig: Isolated Gain.

Active Solar Space Heating- It consists of collector that collect and absorbs solar radiation combined with electric fans or pumps to transfer and distribute that solar heat. It also have an energy storage system to provide heat when sun is not shining.

- The two basic types of active solar heating systems uses either liquid or air as the heat transfer medium in their solar energy collector.
- Liquid based system heat water and air based system heat air in the collector.
- Both of these system collects and absorbs solar radiation then transfers the solar heat directly to the interior space or the storage system from which the heat is distributed.
- An auxilliary or backup system provides heat when storage is discharged.
- Liquid systems are more often used when storage is included.

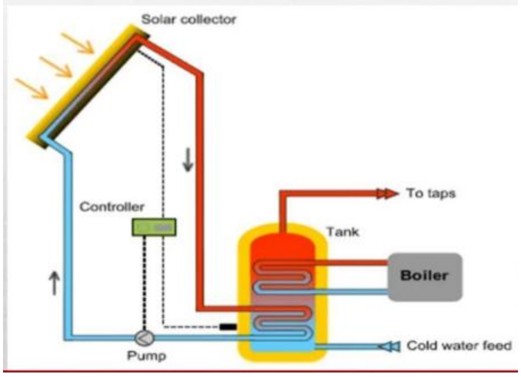


Fig: Active Solar Heating System.

Solar Space Cooling- In the chiller, refrigerant vapor from the evaporator is absorbed by a solution mixture in the absorber.

- This solution is then pumped to the generator.
- There the refrigerant re-vaporizes using a waste steam heat source. The refrigerant - depleted solution then returns to the absorber via a throttling device.
- The two most common refrigerant/ absorbent mixture used in absorption chiller are water/ lithium bromide and ammonia / water.
- The next it is expanded to a low- pressure mixture of liquid and vapor (in the expander valve), which boils in the evaporator section, absorbing heat and and producing the cooling effect.
- Then the cycle is repeated.
- Heat provided in the system is by solar collector in the form of hot water.

Solar Cell

- A solar cell (also known as a photovoltaic cell or PV cell) is defined as an electrical device that converts light energy into electrical energy through the photovoltaic effect.
- A solar cell is basically a p-n junction diode. Solar cells are a form of photoelectric cell, defined as a device whose electrical characteristics – such as current, voltage, or resistance – vary when exposed to light.
- Individual solar cells can be combined to form modules commonly known as solar panels

Types of Solar Photovoltaic Cells

- ***Monocrystalline silicon solar Cell-*** The most effective of the solar PV cells with 15% efficiency*, monocrystalline silicon is therefore the more expensive option. They require less space than other cells simply because they produce more energy and can yield up to four times more power than thin-film solar panels. They also last longer than other panels and perform better at low light.

  The main disadvantage is the cost which often means that it's not the first choice for home owners. It can also be effected by dirt or shade, which can break the circuit and the production process is often seen as wasteful because the cells have to be cut into wafers.
- ***Polycrystalline (or multi-crystalline) solar Cell-*** With an efficiency of 13%, polycrystalline solar panels are often seen as a better economic choice, particularly for home owners. They are made from a number of smaller silicon crystals that are melted together and then recrystallized. The process to create them is simpler and less wasteful than with monocrystalline panels. They do suffer

more at high heats that can reduce their lifespan but overall perform just as well as their more expensive counterpart.

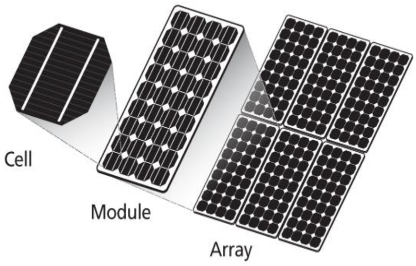
The main disadvantage for polycrystalline solar panels is that you need more of them because of the lower energy conversion efficiency.

✧ ***Amorphous/thin film solar cell-*** At 7%, thin film solar panels are among the least efficient on the market but they are the cheapest option. They work well in low light, even moonlight, and are made from non-crystalline silicone that can be transferred in a thin film onto another material such as glass. The main advantage is that it can be mass produced at a much cheaper cost but is more suitable for situations where space is not a big issue.

The main disadvantage for thin film solar panels are not generally used for residential purposes and will degrade quicker than crystalline cells.

✧ **Hybrid silicon solar Cell**- With an efficiency of 18%, hybrid solar panels are made from a mix of amorphous and monocrystalline cells to generate maximum efficiency. There are a variety of types of hybrid cells and they are still very much at the research and development stage which is why they are currently a more expensive option.

The other types of solar Cell are listed below-



❖ Biohybrid solar cell
❖ Cadmium telluride solar cell (CdTe)
❖ Concentrated PV cell (CVP and HCVP)
❖ Copper indium gallium selenide solar cells (CI(G)S)
❖ Float-zone silicon
❖ Dye-sensitized solar cell (DSSC)
❖ Gallium arsenide germanium solar cell (GaAs)
❖ Luminescent solar concentrator cell (LSC)
❖ Micromorph (tandem-cell using a-Si/μc-Si)
❖ Multi-junction solar cell (MJ)
❖ Nanocrystal solar cell
❖ Organic solar cell (OPV)
❖ Perovskite solar cell
❖ Photoelectrochemical cell (PEC)
❖ Plasmonic solar cell
❖ Quantum dot solar cell
❖ Solid-state solar cell
❖ Wafer solar cell, or wafer-based solar cell crystalline
❖ Non concentrated hetrogeneos PV cell

Working Principle of Solar Cell-

When light reaches the p-n junction, the light photons can easily enter in the junction, through very thin p-type layer. The light energy, in the form of photons, supplies sufficient energy to the junction to create a number of electron-hole pairs. The incident light breaks the thermal equilibrium condition of the junction. The free electrons in the depletion region can quickly come to the n-type side of the junction. Similarly, the holes in the depletion can quickly come to the p-type side of the junction.

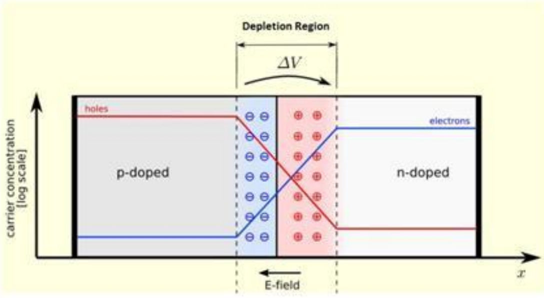
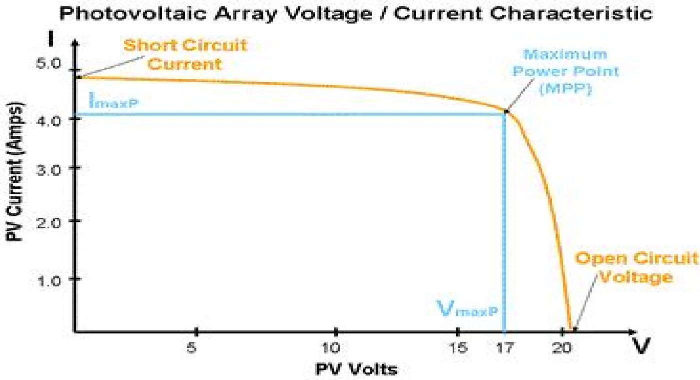


Fig: Working of PV Cell.

V-I Characteristics of a Photovoltaic Cell-



Short circuit current: The rate of production of current in a solar cell also depends upon the intensity of light and the angle at which the light falls on the cell. As the current production also depends upon the surface area of the cell exposed to light, it is better to express maximum current density instead maximum current.

$$J_{sc} = \frac{I_{sc}}{A}$$

Open Circuit Voltage of Solar Cell: It is measured by measuring voltage across the terminals of the cell when no load is connected to the cell. This voltage depends upon the techniques of manufacturing and temperature but not fairly on the intensity of light and area of exposed surface. Normally open circuit voltage of solar cell nearly equal to 0.5 to 0.6 volt. It is normally denoted by V_{oc}

Maximum Power Point Techniques:-

THE HILL CLIMBING Techniques-

It is important to maximize the energy utilization efficiency of photovoltaic systems by using an efficient maximum power point tracking scheme.

The most commonly applied MPPT algorithms are hill-climbing algorithms in which the algorithm tries to climb the power-voltage curve of the PV array to reach the maximum power point (MPP).

The location of the MPP varies depending on weather conditions and is usually unknown for the MPPT algorithm. The hill climbing based techniques are so named because of the shape of the power-voltage (P-V) curve.

This technique is sub-categorized in three types:

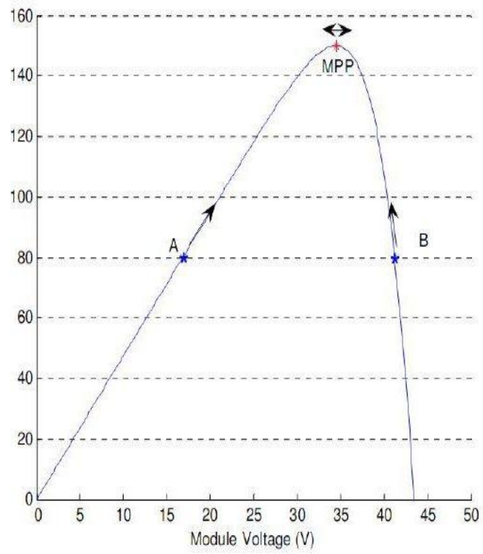
- **Perturb & Observe Algorithm (P&O)**
- **Modified Adaptive P & O Method**
- **Incremental Conductance Algorithm (INC)**

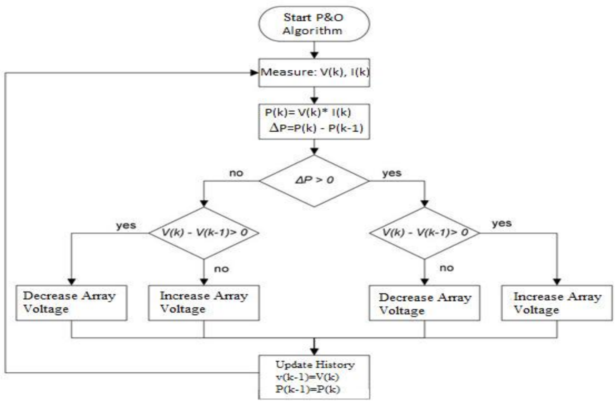
- ✓ The efficiency of P&O and INC algorithms is 96.5% and 98.2% respectively. The average increase in energy extraction is found to be 16% to 43% by using conventional hill climbing MPPT .
- ✓ Among hill-climbing algorithms, the P&O and the INC algorithms have gained a lot of popularity and acceptance in different PV applications. These are simple algorithms that do not require previous knowledge of the PV generator characteristics or the measurement of solar intensity and cell temperature and is easy to implement.
- ✓ The P&O algorithm regularly perturbs the operating point of the PV generator by increasing or decreasing a control parameter by a small amount (step size) and measures the PV array output power before and after the perturbation.
- ✓ If the power increases, the algorithm continues to perturb the system in the same direction; otherwise the system is perturbed in the opposite direction.
- ✓ The operation of the INC algorithm is based on the fact that the power-voltage curve of a PV generator at constant solar irradiance and cell temperature levels normally has only one maximum power point (MPP)
- ✓ At this MPP, the derivative of the power with respect to the voltage equals zero which means that the sum of the instantaneous conductance (IPV/VPV) and the incremental conductance (dIPV/dVPV) equals zero

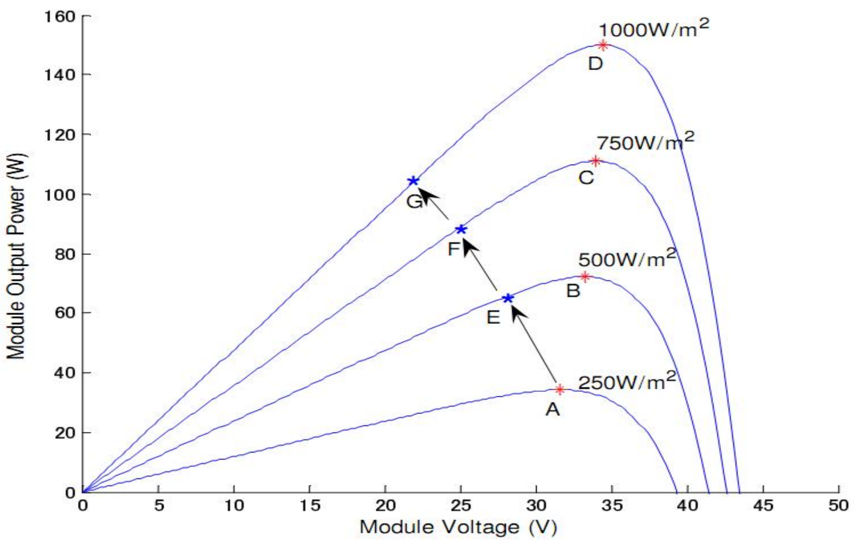
Perturb & Observe Algorithm

The Perturb & Observe algorithm states that when the operating voltage of the PV panel is perturbed by a small increment, if the resulting changes in power ΔP is positive, then we are going in the direction of MPP and we keep on perturbing in the same direction.

If ΔP is negative, we are going away from the direction of MPP and the sign of perturbation supplied has to be changed.





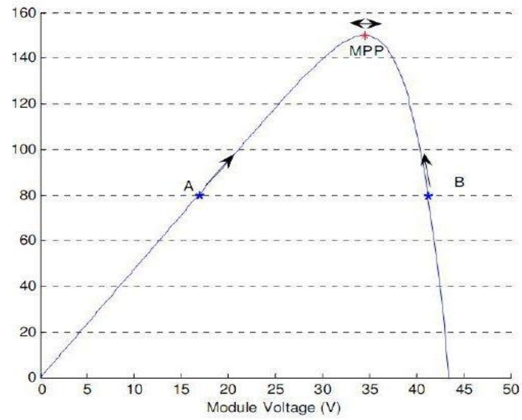


Incremental Conductance-

Incremental conductance method uses two voltage and current sensors to sense the output voltage and current of the PV array.
At MPP the slope of the PV curve is 0.
(dP/dV)MPP=d(VI)/dVMPP

dI/dVMPP = - I/V
dI/dVMPP > - I/V left of the MPP
dI/dVMPP < - I/V right of the MPP

The left hand side is the instantaneous conductance of the solar panel. When this instantaneous conductance equals the conductance of the solar then MPP is reached.



Here we are sensing both the voltage and current simultaneously. Hence the error due to change in irradiance is eliminated.
However the complexity and the cost of implementation increase. As we go down the list of algorithms the complexity and the cost of implementation goes on increasing which may be suitable for a highly complicated system.
This is the reason that Perturb and Observe and Incremental Conductance method are the most widely used algorithms.

Net metering concepts

Net metering is an electricity policy for utility customers who operate their own on-site self-generation solar power systems. It allows consumers to feed surplus solar power into the grid when they don't need it, and receive a credit on their electricity bill. This takes care of the problem of matching power supply and demand, which will never match perfectly for any building. Net metering effectively uses the grid as a huge battery, which helps to balance this demand/supply mismatch.
Without solar net metering, many rooftop solar plants – and residential ones in particular – would require a battery backup to even out the power consumption through the day. Battery costs have been falling rapidly, and will become an important part of the solar industry someday – but today, very few solar plants would be financially attractive once battery costs are built in. Although, the concept of net metering first emerged in United States in 1979 as a way to compensate customers for their investment in renewable energy, it makes much more sense than just being a financial implication.

How it works?

- The solar power systems are connected to the utility grid via the customers' main service panel and meter and, when generating more power than is needed at the site, return excess electricity to the grid through the power meter, reversing the meter from its usual direction. Thus, a bi-directional meter is needed to avail net metering. Since the meter works in both directions (i.e. bi-directional meter)– one way to measure power purchased (when on-site demand is greater than on-site power production), and the other way to measure power returned to the grid – the customer pays the "net" of both transactions.
- The solar net metering policy makes solar energy more attractive and affordable for users. It can help users save a huge amount of money, and it makes the process of accounting for the energy flowing to and from the utility simpler and easier to administer.
- For example, if you live in a state which has implemented the solar net metering policy, then you get credited for the electricity you deliver back to the grid at the same retail price that you pay for the electricity you take from the grid. The banking happens for a period of time, usually annually. This not only brings down the energy cost drastically, but helps create small power generation units in almost every nook and corner of the country.

Net Metering: The challenges

With fundamental economics getting stronger, solar doesn't require subsidies so much as enabling policies like net metering.

Many states in India have now created net metering policies, although implementation has been slow in most cases, and in others there are arbitrary constraints and limits. For example, net metering in Tamil Nadu is not allowed for high-tension consumers, which are the largest consumers. In many states, there is a cap on the size of the project which can avail net metering, which prevents large customers from fully using their rooftops.

For example, in Maharshtra, there is an artificial capacity constraint of 1 MWp. This means that even if the consumer has the space to accommodate more than 1 MWp system, net metering policy would allow only 1 MWp system to be installed under its scheme.

"Rooftop solar sector has not really taken off mainly due to the poor implementation of net metering policy," Kuldeep Jain, Managing Director, CleanMax recently stated in The Hindu. He further suggested that the net metering policies in most states are not being implemented. There is a lack of follow-through. For example, in Maharashtra, no forms have been released and no processes have been put in place on how to implement net metering.

The below tabs gives you and easy to use reference of the different Net Metering policies across Indian states and the different approvals, charges applicable across states.