Solar Energy Collectors

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A mediator to harness solar energy

Introduction

It is device for collecting solar radiation and transfer the energy to a fluid passing in contact with it. The major component of any solar system is the solar collector. This is a device which absorbs the incoming solar radiation, converts it into heat, and transfers this heat to a fluid (usually air, water, or oil) flowing through the collector

Solar energy collectors are special kind of heat exchangers that transform solar radiation energy to internal energy of the transport medium

Broadly classified as

- **Non concentrating or flat plate type**

A non concentrating collector has the same area for intercepting and for absorbing solar radiation

It is simple in design has no moving parts and requires little maintenance

It can be used for a variety of applications in which temperature ranging from 40^oC to about 100^oC are required

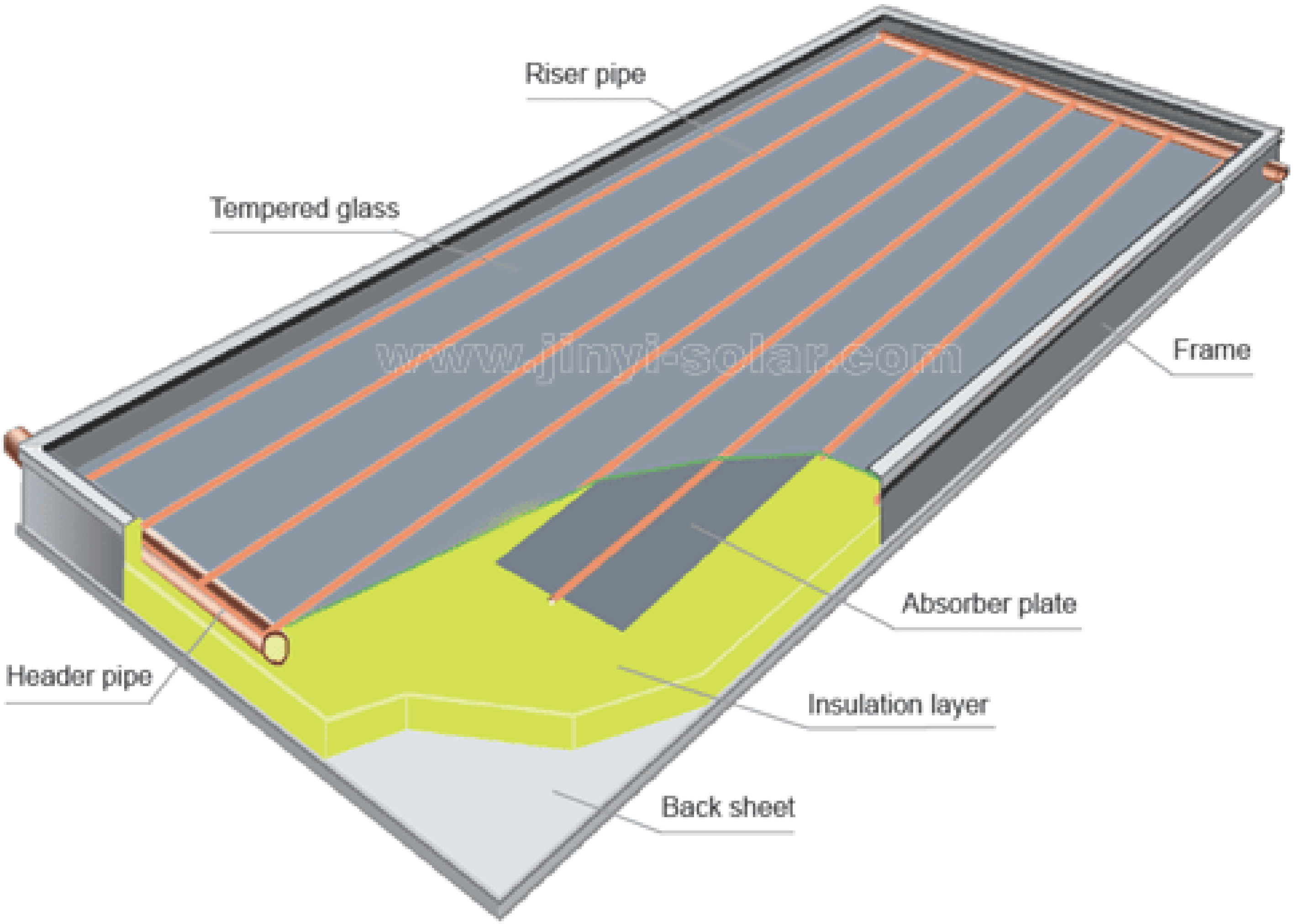
▪Concentrating (focusing) type

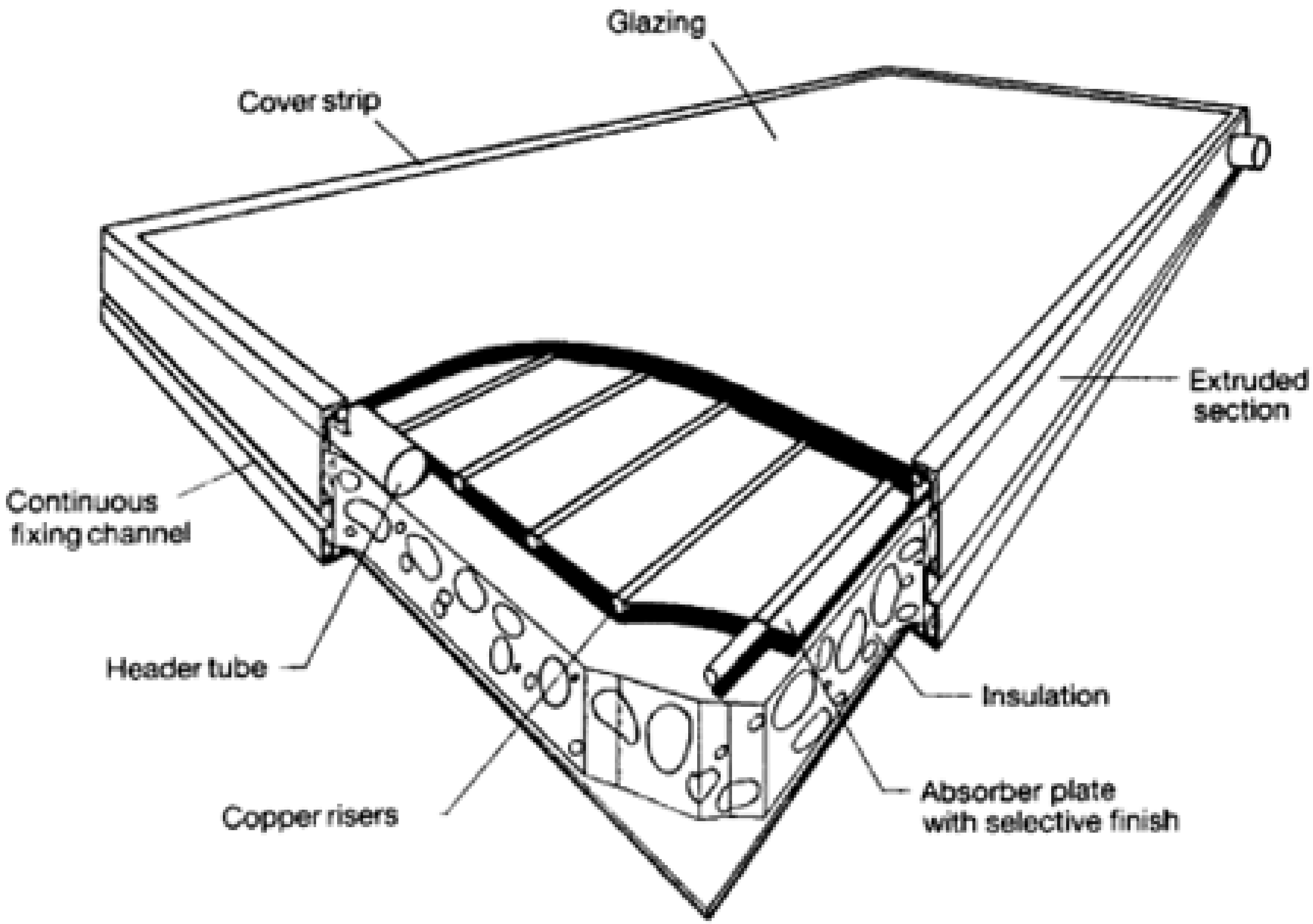
concentrating solar collector usually has concave reflecting surfaces to intercept and focus the sun’s beam radiation to a smaller receiving area, thereby increasing the radiation flux

Solar collectors available in the market

Motion	Collector type	Absorber type	Concentration ratio	Indicative temperature range (°C)
Stationary	Flat plate collector (FPC)	Flat	1	30–80
	Evacuated tube collector (ETC)	Flat	1	50–200
	Compound parabolic collector (CPC)	Tubular	1–5	60–240
Single-axis tracking			5–15	60–300
	Linear Fresnel reflector (LFR)	Tubular	10–40	60–250
	Parabolic trough collector (PTC)	Tubular	15–45	60–300
	Cylindrical trough collector (CTC)	Tubular	10–50	60–300
Two-axes tracking	Parabolic dish reflector (PDR)	Point	100–1000	100–500
	Heliostat field collector (HFC)	Point	100–1500	150–2000

Flat plate collectors




Glazing
Cover strip
Extruded section
Continuous fixing channel
Header tube
Insulation
Absorber plate with selective finish
Copper risers

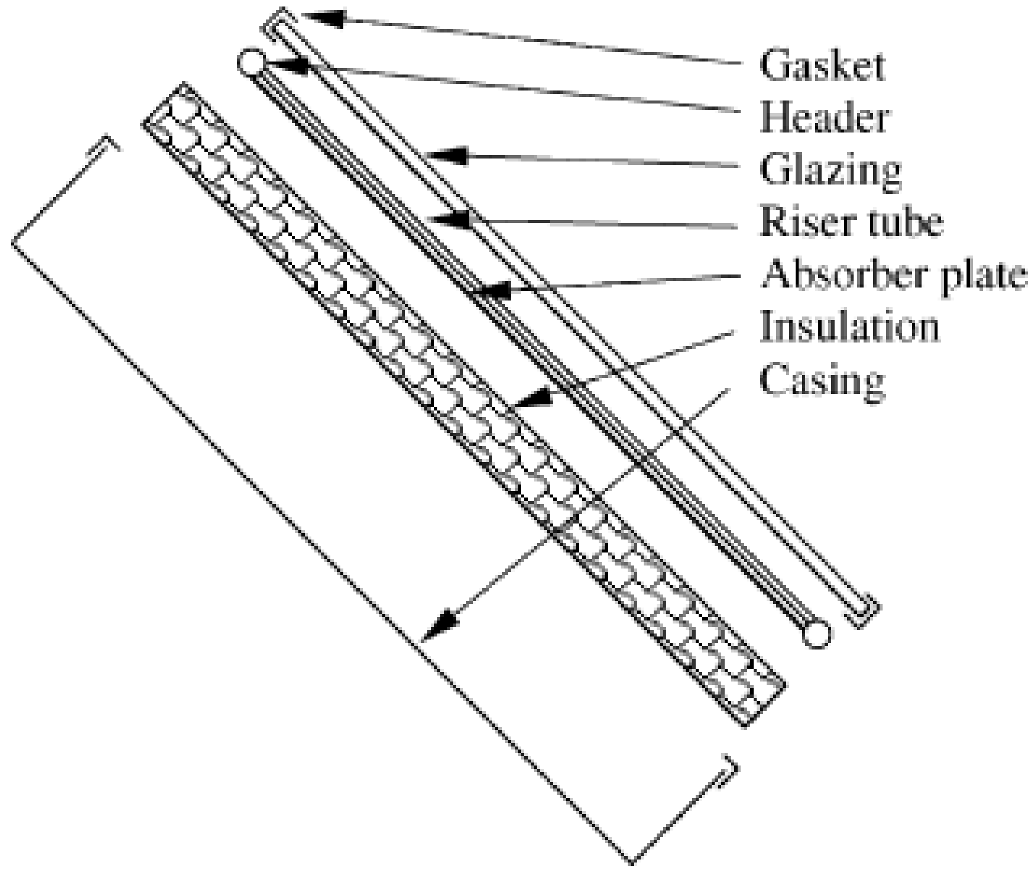
when solar radiation passes through a transparent cover and impinges on the blackened absorber surface of high absorptivity, a large portion of this energy is absorbed by the plate and then transferred to the transport medium in the fluid tubes to be carried away for storage or use. The underside of the absorber plate and the side of casing are well insulated to reduce conduction losses. The liquid tubes can be welded to the absorbing plate, or they can be an integral part of the plate. The liquid tubes are connected at both ends by large diameter header tubes.

The transparent cover is used to reduce convection losses from the absorber plate through the restraint of the stagnant air layer between the absorber plate and the glass.

It also reduces radiation losses from the collector as the glass is transparent to the short wave radiation received by the sun but it is nearly opaque to long-wave thermal radiation emitted by the absorber plate (greenhouse effect).

FPC are usually permanently fixed in position and require no tracking of the sun. The collectors should be oriented directly towards the equator, facing south in the northern hemisphere and north in the southern. The optimum tilt angle of the collector is equal to the latitude of the location with angle variations of 10–15^{o} more or less depending on the application

Exploded view of flat plate collector



Glazing. One or more sheets of glass or other diathermanous (radiation-transmitting) material.

Glass has been widely used to glaze solar collectors because it can transmit as much as 90% of the incoming shortwave solar irradiation while transmitting virtually none of the longwave radiation emitted outward by the absorber plate. Glass with low iron content has a relatively high transmittance for solar radiation (approximately 0.85–0.90 at normal incidence), but its transmittance is essentially zero for the longwave thermal radiation (5.0–50 mm) emitted by sun-heated surfaces.

Collector absorbing plates. The collector plate absorbs as much of the irradiation as possible through the glazing, while loosing as little heat as possible upward to the atmosphere and downward through the back of the casing.

The collector plates transfer the retained heat to the transport fluid.

The absorptance of the collector surface for shortwave solar radiation depends on the nature and colour of the coating and on the incident angle.

Usually black colour is used

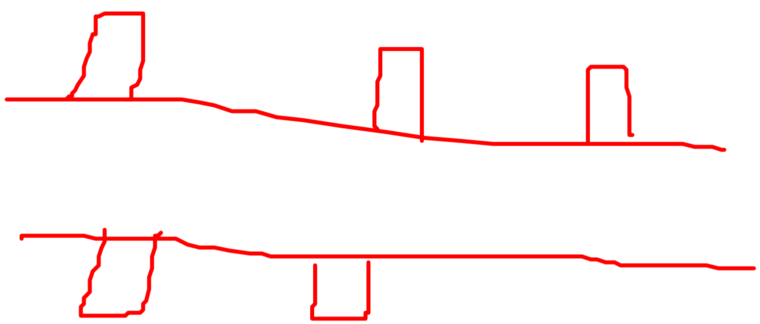
By suitable electrolytic or chemical treatments, surfaces can be produced with high values of solar radiation absorptance (a) and low values of longwave emittance .

Essentially, typical selective surfaces consist of a thin upper layer, which is highly absorbent to shortwave solar radiation.

But relatively transparent to long wave thermal radiation, deposited on a surface that has a high reflectance
and a low emittance for longwave radiation.

Selective surfaces are particularly important when the collector surface temperature is much higher than the ambient air temperature.

Today, commercial solar absorbers are made by electroplating, anodization, evaporation, and by applying solar selective paints.
Much of the progress during recent years has been based on the implementation of vacuum techniques for the production of fin type absorbers used in low temperature applications.
The chemical and electrochemical processes used for their commercialization were readily taken over from the metal finishing industry.



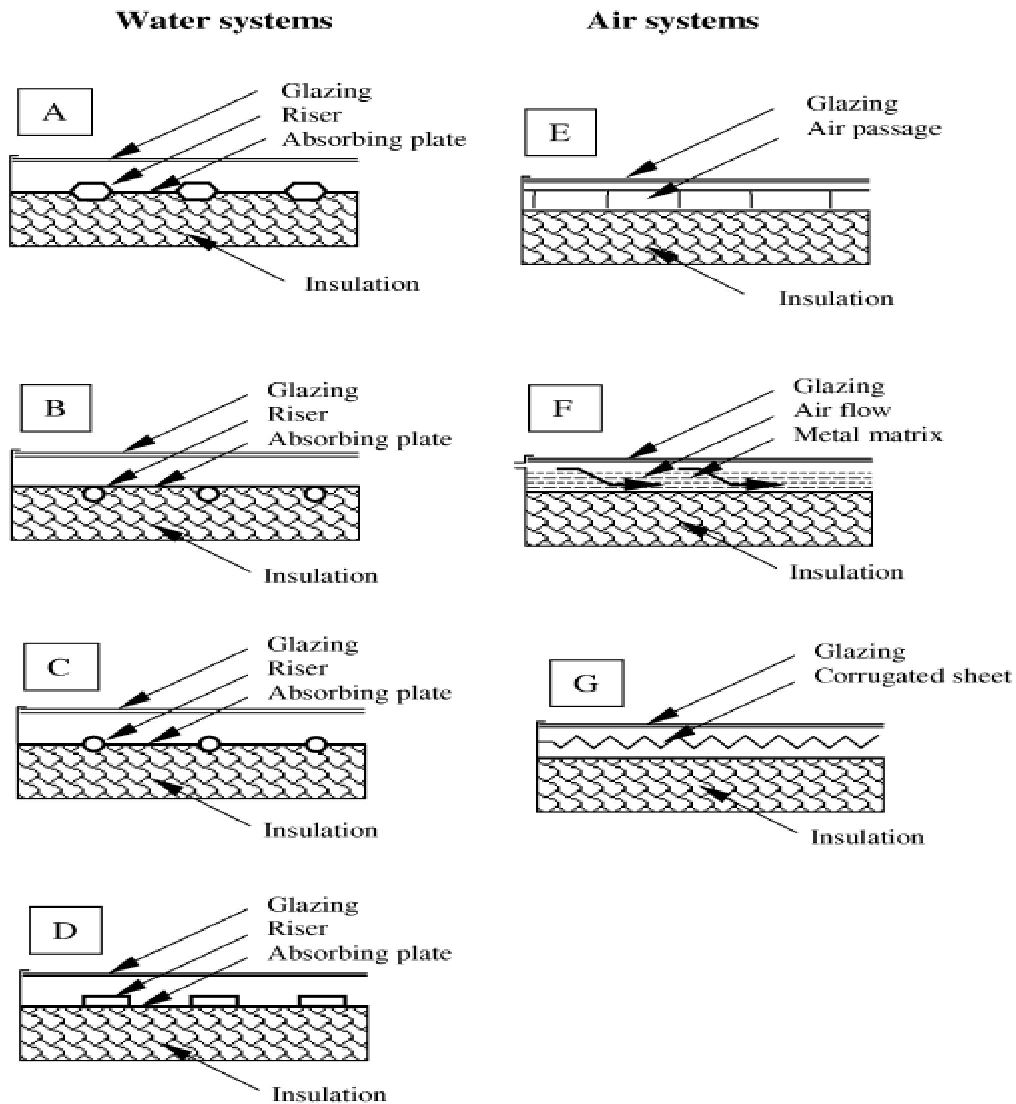
Tubes, fins, or passages. To conduct or direct the heat transfer fluid from the inlet to the outlet

Headers or manifolds. To admit and discharge the fluid.

Insulation. To minimize the heat loss from the back and sides of the collector

Container or casing. To surround the aforementioned components and keep them free from dust, moisture, etc.

Various types of flat-plate solar collectors



Concentrating:

Focusing: Is a device to collect solar energy with high intensity solar radiation

Use optical systems

reflectors or refractors

In these collectors the radiation falling on a relatively large area is focused on to a receiver (absorber) of considerably small area

Track the solar system so that beam radiation falls on absorber

Fluids can be heated up to 500^{o}C

Optical efficiency
Losses in the mirrors or lenses and losses due to geometrical imperfections .

The combined effect of all the losses are represented by optical efficiency

Some definition
Aperture(W): is the plane opening of the concentrator through which solar radiation passes

Concentration ratio(C) : is the ratio of the effective area of the aperture to the surface area of the absorber

The acceptance angle:
Is the angle over which beam radiation may deviate from normal to the aperture plane and reach absorber

Exit temperatures can be increased by decreasing the area from which the heat losses occur.

Temperatures far above those attainable by FPC can be reached if a large amount of solar radiation is oncentrated on a relatively small collection area.

This is done by interposing an optical device between the source of radiation and the energy absorbing surface.

Advantages of concentrating collectors

1.The working fluid can achieve higher temperatures in a concentrator system when compared to a flat-plate system of the same solar energy collecting surface. This means that a higher thermodynamic efficiency can be achieved.

2. It is possible with a concentrator system, to achieve a thermodynamic match between temperature level and task.

3. The thermal efficiency is greater because of the small heat loss area relative to the receiver area.
4. Reflecting surfaces require less material and are structurally simpler than FPC. For a concentrating collector the cost per unit area of the solar collecting surface is therefore less than that of a FPC.

5. Owing to the relatively small area of receiver per unit of collected solar energy, selective surface treatment and vacuum insulation to reduce heat losses and improve the collector efficiency are economically viable

Their disadvantages are:

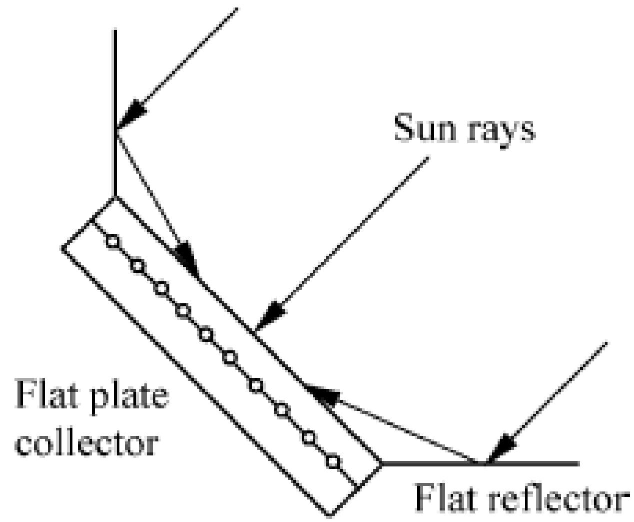
1. Concentrator systems collect little diffuse radiation depending on the concentration ratio.
2. Some form of tracking system is required so as to enable the collector to follow the sun.
3. Solar reflecting surfaces may loose their reflectance with time and may require periodic cleaning and refurbishing.

Many designs have been considered for concentrating collector

- Concentrators can be reflectors or refractors
- cylindrical or parabolic
- continuous or segmented
- Receivers can be convex, flat, cylindrical or concave and can be covered with glazing or uncovered

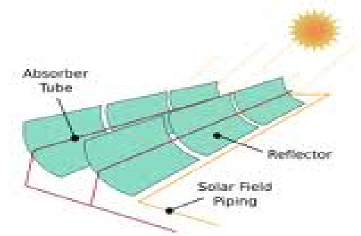
Concentration ratios, i.e. the ratio of aperture to absorber areas, can vary over several orders of magnitude, from as low as unity to high values of the order of 10 000. Increased ratios mean increased temperatures at which energy can be delivered but consequently these collectors have increased requirements for precision in optical quality and positioning of the optical system.

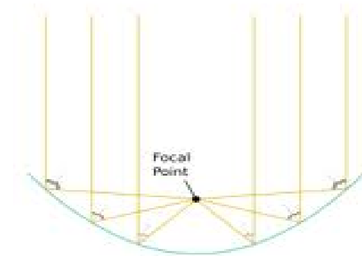
Flat plate collector with flat reflectors.



The first type of a solar concentrator, shown above is effectively a FPC fitted with simple flat reflectors which can increase the amount of direct radiation reaching the collector. This is a concentrator because the aperture is bigger than the absorber but the system is stationary.

Parabolic trough collectors





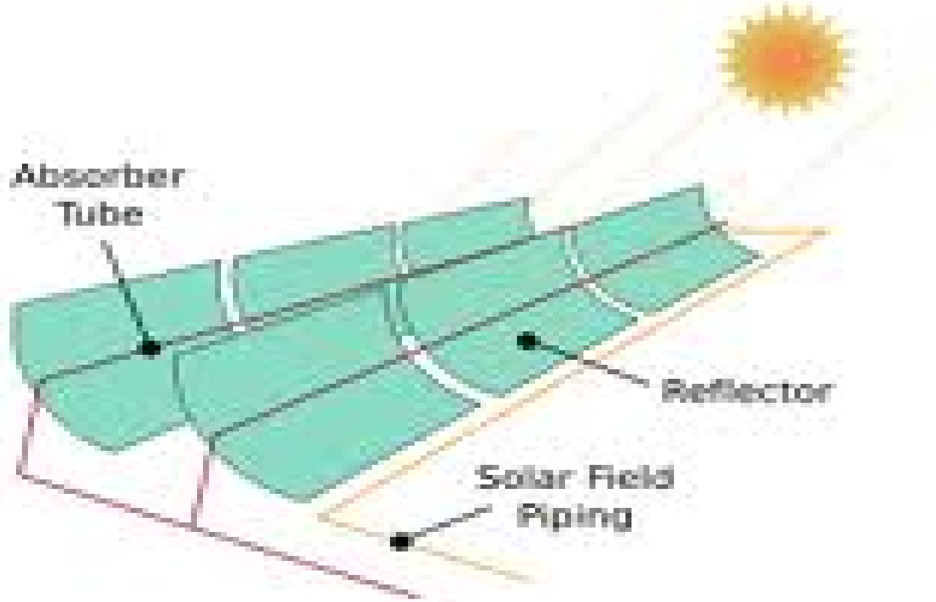
In order to deliver high temperatures with good efficiency a high performance solar collector is required. Systems with light structures and low cost technology for process heat applications up to 400°C could be obtained with parabolic through collectors (PTCs). PTCs can effectively produce heat at temperatures between 50 and 400 °C

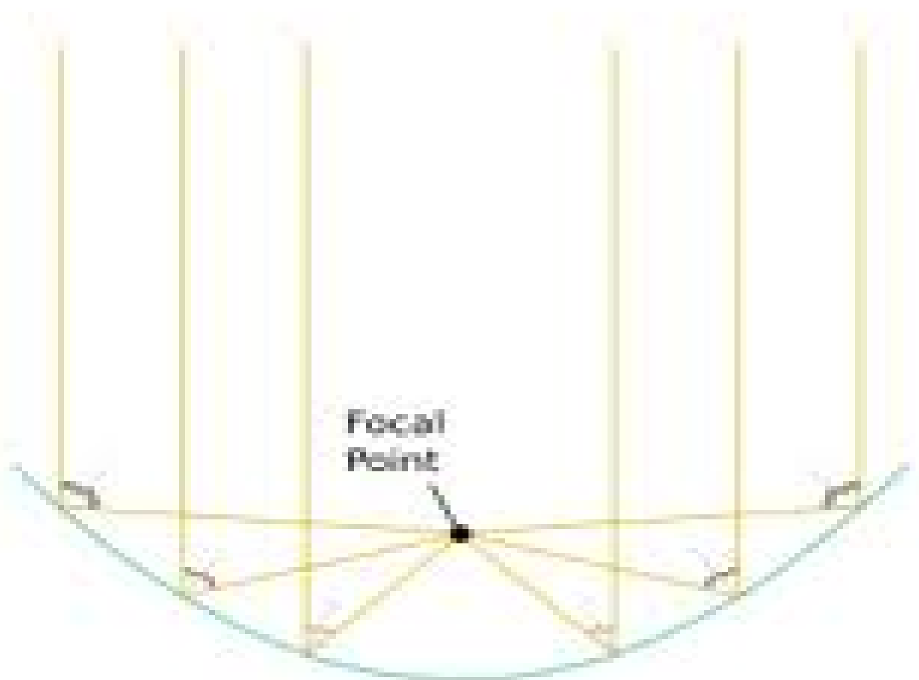
PTCs are made by bending a sheet of reflective material into a parabolic shape.

A metal black tube, covered with a glass tube to reduce heat losses, is placed along the focal line of the receiver.

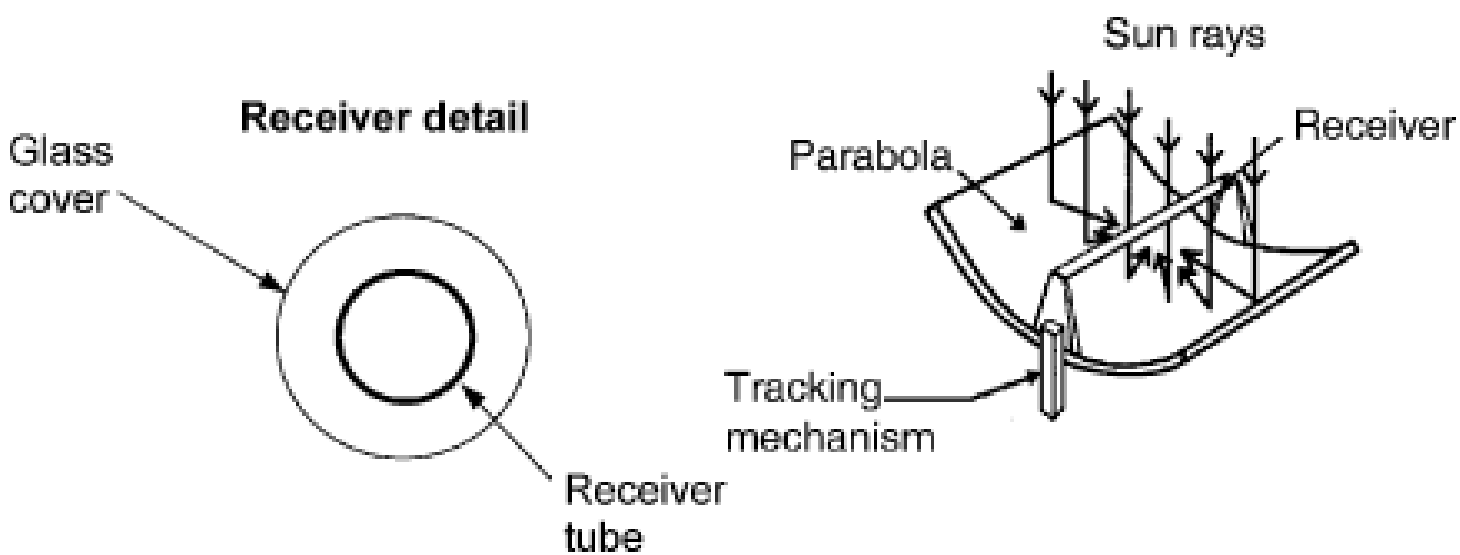
When the parabola is pointed towards the sun, parallel rays incident on the reflector are reflected onto the receiver tube.

It is sufficient to use a single axis tracking of the sun and thus long collector modules are produced.


Absorber Tube
Reflector
Solar Field Piping


Focal Point

The collector can be orientated in an east–west direction, tracking the sun from north to south, or orientated in a north–south direction and tracking the sun from east to west



The receiver of a parabolic trough is linear. Usually, a tube is placed along the focal line to form an external surface receiver.

The surface of the receiver is typically plated with selective coating that has a high absorptance for solar radiation, but a low emittance for thermal radiation loss.

Parabolic trough technology is the most advanced of the solar thermal technologies because of considerable experience with the systems and the development of a small commercial industry to produce and market these systems.

PTCs are built in modules that are supported from the ground by simple pedestals at either end.

A glass cover tube is usually placed around the receiver tube to reduce the convective heat loss from the receiver, thereby further reducing the heat loss coefficient.

A disadvantage of the glass cover tube is that the reflected light from the concentrator must pass through the glass to reach the absorber, adding a transmittance loss of about 0.9,when the glass is clean. The glass envelope usually has an antireflective coating to improve transmissivity.

One way to further reduce convective heat loss from the receiver tube and thereby increase the performance of the collector, particularly for high temperature applications, is to evacuate the space between the glass cover tube and the receiver.

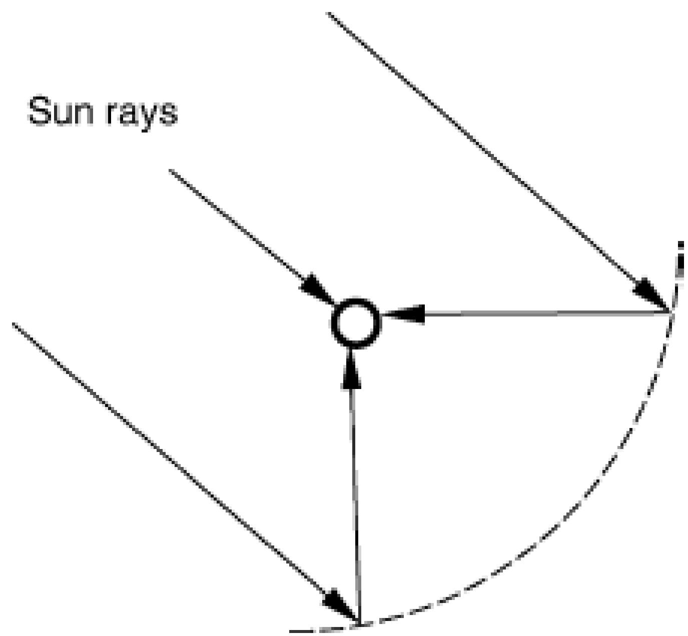
A tracking mechanism must be reliable and able to follow the sun with a certain degree of accuracy, return the collector to its original position at the end of the day or during the night, and also track during periods of intermittent cloud cover.

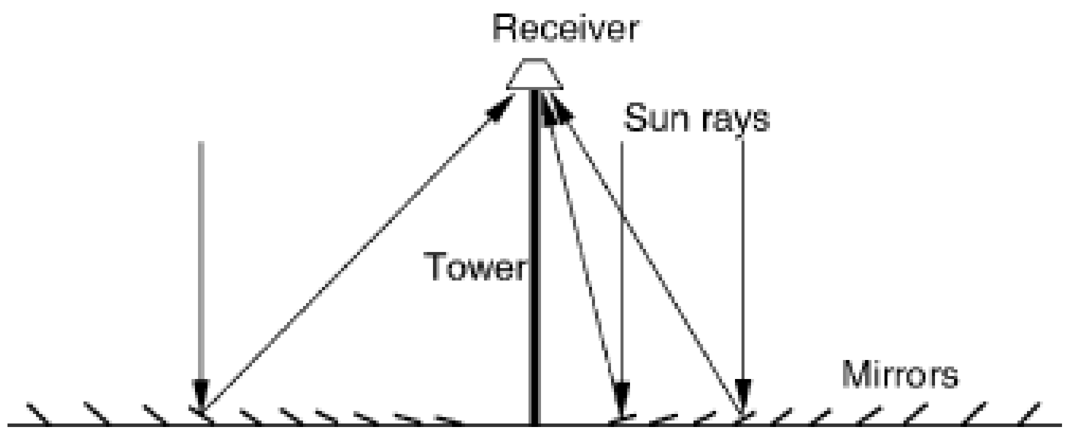
Additionally, tracking mechanisms are used for the protection of collectors, i.e. they turn the collector out of focus to protect it from the hazardous environmental and working conditions, like wind gust, overheating and failure of the thermal fluid flow mechanism.

The required accuracy of the tracking mechanism depends on the collector acceptance angle

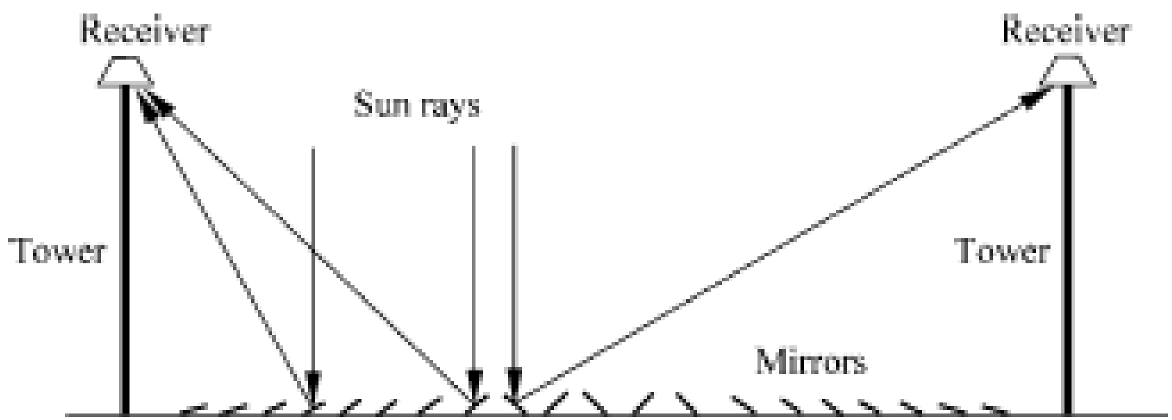
Linear Fresnel reflector

LFR technology relies on an array of linear mirror strips which concentrate light on to a fixed receiver mounted on a linear tower. The LFR field can be imagined as a broken-up parabolic trough reflector but unlike parabolic troughs, it does not have to be of parabolic shape.





Receiver
Sun rays
Tower
Mirrors

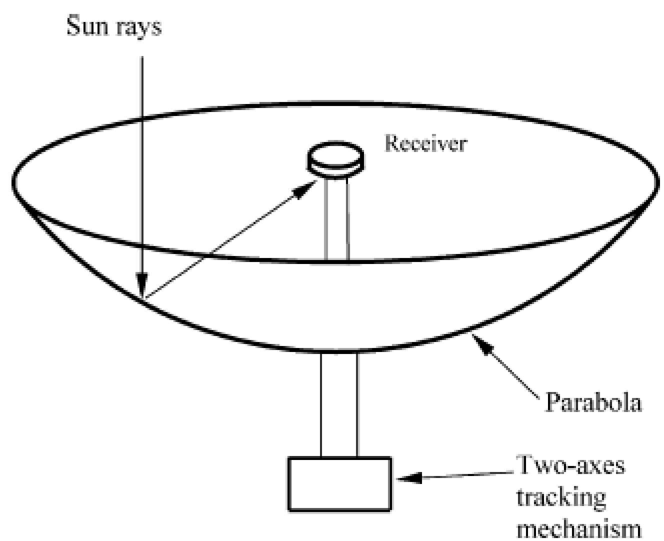


Receiver
Receiver
Sun rays
Tower
Tower
Mirrors

Parabolic dish reflector (PDR)

A parabolic dish reflector, is a point-focus collector that tracks the sun in two axes, concentrating solar energy onto a receiver located at the focal point of the dish.

The dish structure must track fully the sun to reflect the beam into the thermal receiver.



The receiver absorbs the radiant solar energy, converting it into thermal energy in a circulating fluid.
The thermal energy can then either be converted into electricity using an engine-generator coupled directly to the receiver, or it can be transported through pipes to a central power-conversion system.

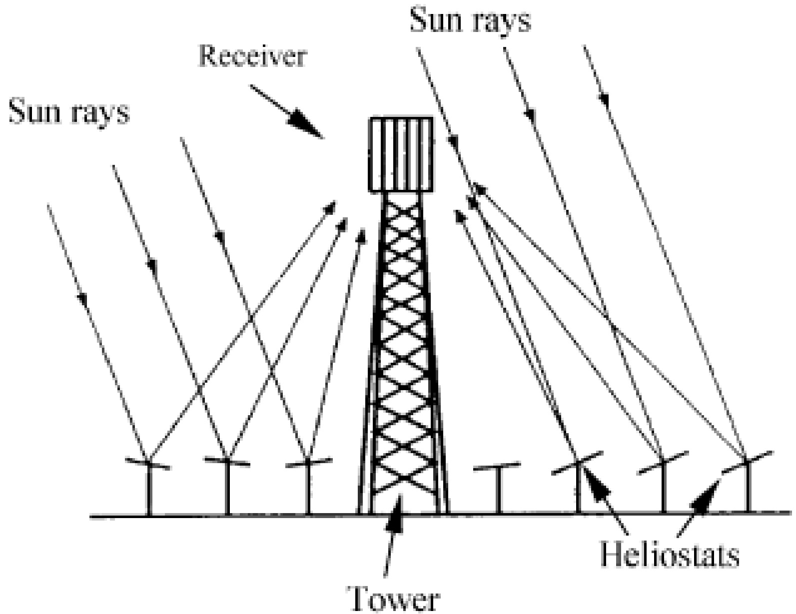
Parabolic-dish systems can achieve temperatures in excess of 1500^{o}C.

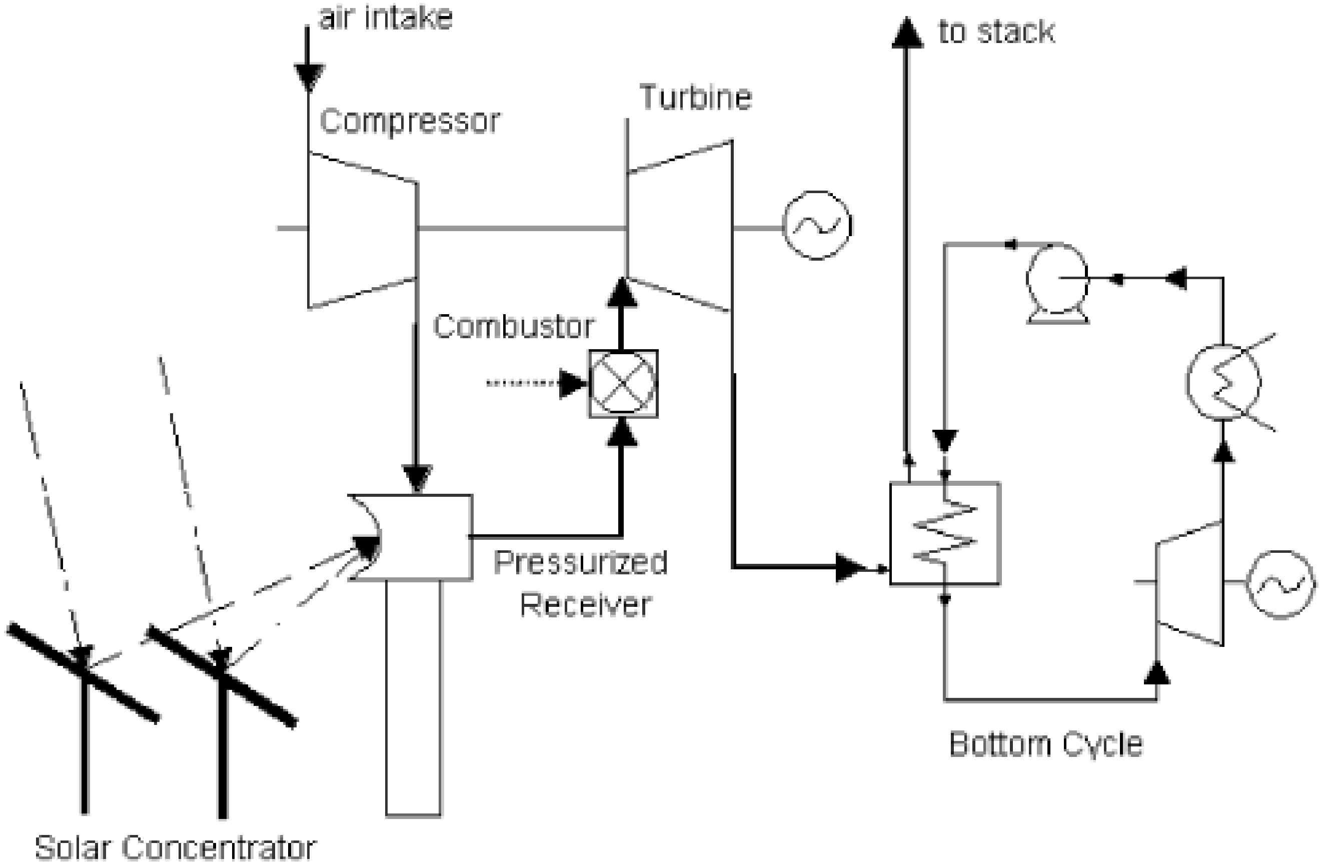
Because the receivers are distributed throughout a collector field, like parabolic troughs, parabolic dishes are often called distributed-receiver systems

Heliostat field collector

For extremely high inputs of radiant energy, a multi-.plicity of flat mirrors, or heliostats, can be used to reflect their incident direct solar radiation onto a common target

This is called the heliostat field or central receiver collector. By using slightly concave mirror segments on the heliostats, large amounts of thermal energy can be directed into the cavity of a steam generator to produce steam at high temperature and pressure.


Sun rays
Receiver
Sun rays
Heliostats
Tower



Hybrid power plant (Combined power plant)

1.They collect solar energy optically and transfer it to a single receiver, this minimizing thermal-energy transport requirements;
2. They typically achieve concentration ratios of 300–1500 and so are highly efficient both in collecting energy and in converting it to electricity;
3. They can conveniently store thermal energy;
4. They are quite large (generally more than 10 MW) and thus benefit from economies of scale.

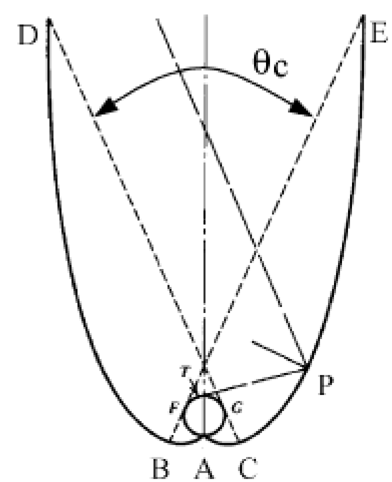
Each heliostat at a central-receiver facility has from 50 to 150 m2 of reflective surface. The heliostats collect and concentrate sunlight onto the receiver, which absorbs the concentrated sunlight, transferring its energy to a heat transfer fluid.

The heat-transport system, which consists primarily of pipes, pumps, and valves, directs the transfer fluid in a closed loop between the receiver, storage, and power-conversion systems

The average solar flux impinging on the receiver has values between 200 and 1000 kW/m2. This high flux allows working at relatively high temperatures of more than 1500^{o}C and to integrate thermal energy in more efficient cycles. Central receiver systems can easily integrate in fossil-fuelled plants for hybrid operation in a wide variety of options and have the potential to operate more than half the hours of each year at nominal power using thermal energy storage.

Compound parabolic collectors

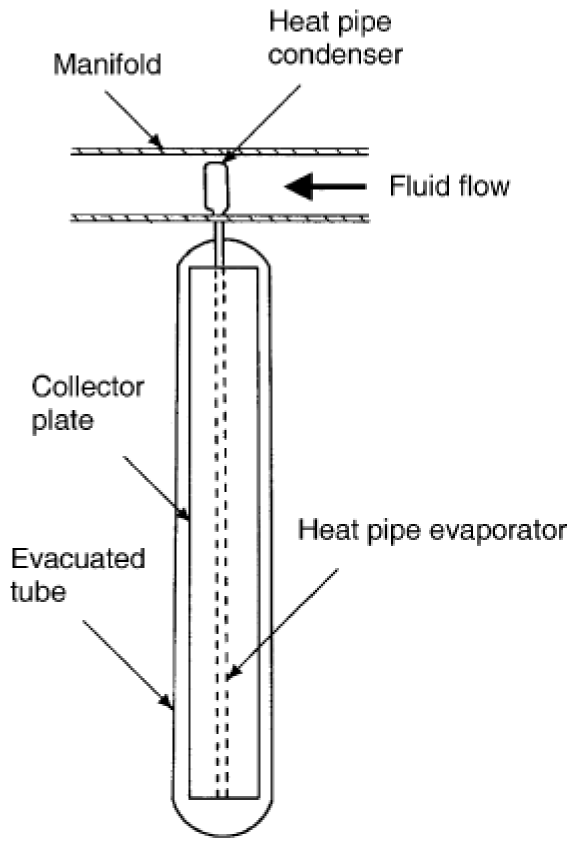
These have the capability of reflecting to the absorber all of the incident radiation within wide limits. The necessity of moving the concentrator to accommodate the changing solar orientation can be reduced by using a trough with two sections of a parabola facing each other



Compound parabolic concentrators can accept incoming radiation over a relatively wide range of angles. By using multiple internal reflections, any radiation that is entering the aperture, within the collector acceptance angle, finds its way to the absorber surface located at the bottom of the collector. The absorber can take a variety of configurations.

Evacuated tube collectors

Conventional simple flat-plate solar collectors were developed for use in sunny and warm climates. Their benefits however are greatly reduced when conditions become unfavorable during cold, cloudy and windy days. Furthermore, weathering influences such as condensation and moisture will cause early deterioration of internal materials resulting in reduced performance and system failure. Evacuated heat pipe solar collectors (tubes) operate differently than the other collectors available on the market. These solar collectors consist of a heat pipe inside a vacuum-sealed tube


Heat pipe
condenser
Manifold
Fluid flow
Collector
plate
Heat pipe evaporator
Evacuated
tube

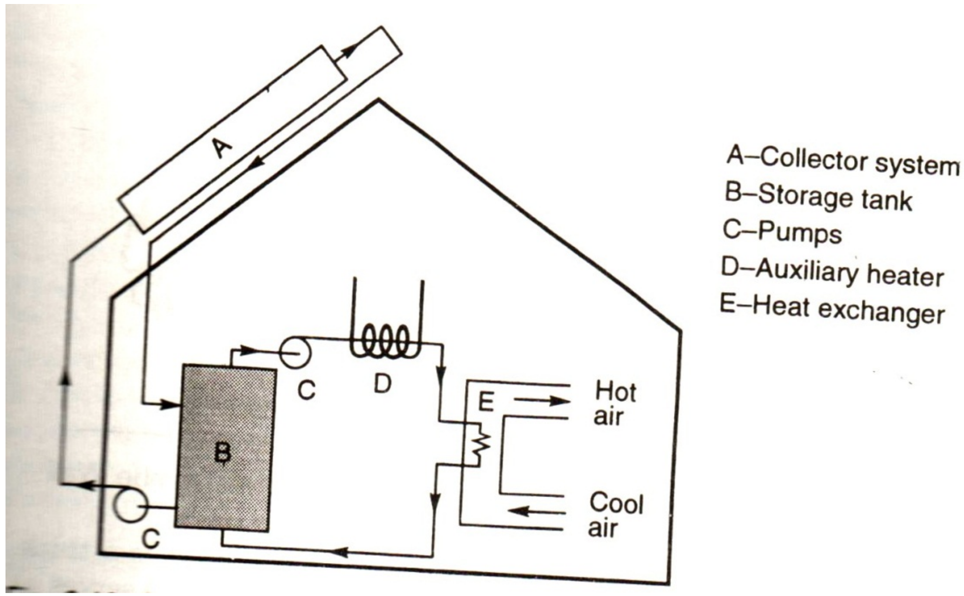
ETC use liquid–vapour phase change materials to transfer heat at high efficiency. These collectors feature a heat pipe (a highly efficient thermal conductor) placed inside a vacuum-sealed tube. The pipe, which is a sealed copper pipe, is then attached to a black copper fin that fills the tube (absorber plate). Protruding from the top of each tube is a metal tip attached to the sealed pipe (condenser).

The heat pipe contains a small amount of fluid (e.g. methanol) that undergoes an evaporating-condensing cycle. In this cycle, solar heat evaporates the liquid, and the vapour travels to the heat sink region where it condenses and releases its latent heat. The condensed fluid return back to the solar collector and the process is repeated. When these tubes are mounted, the metal tips up, into a heat exchanger (manifold) as shown in. Water, or glycol, flows through the manifold and picks up the heat from the tubes. The heated liquid circulates through another heat exchanger and gives off its heat to a process or to water that is stored in a solar storage tank.

Thermal applications

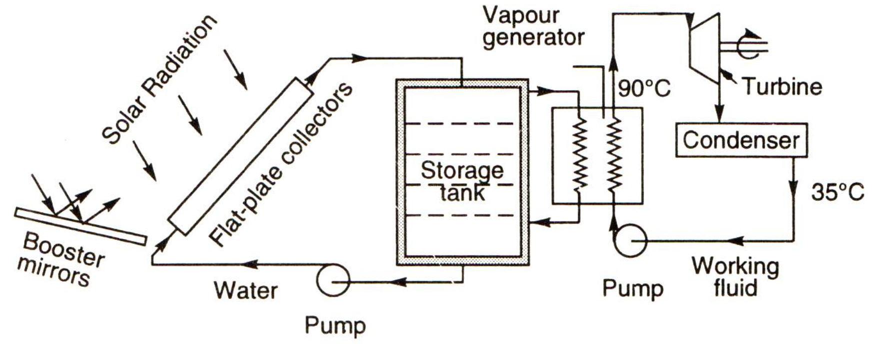
1) Water heating
2) Space heating
3) Power generation
4) Refrigeration
5) Distillation
6) Drying
7) Cooking

Space heating

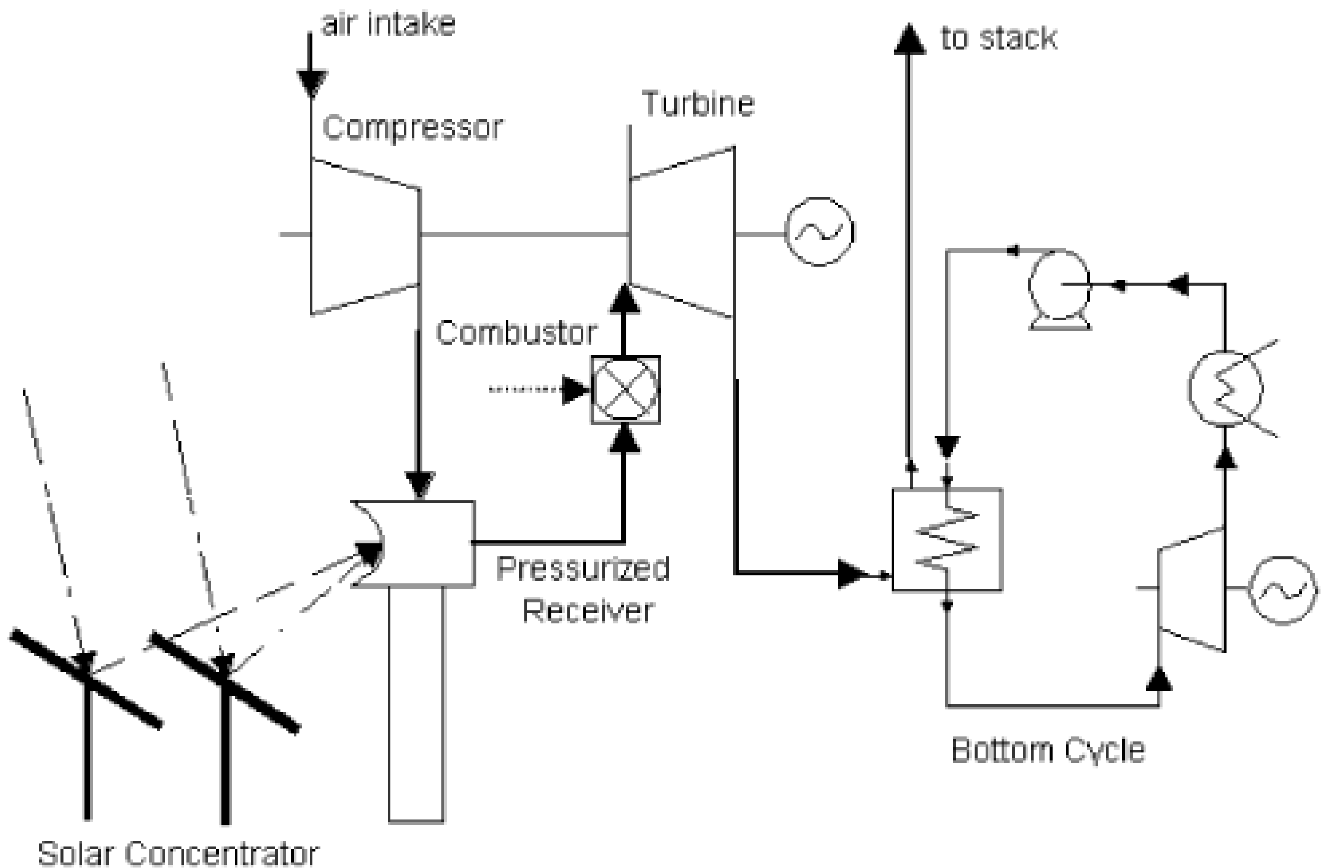


Power generation

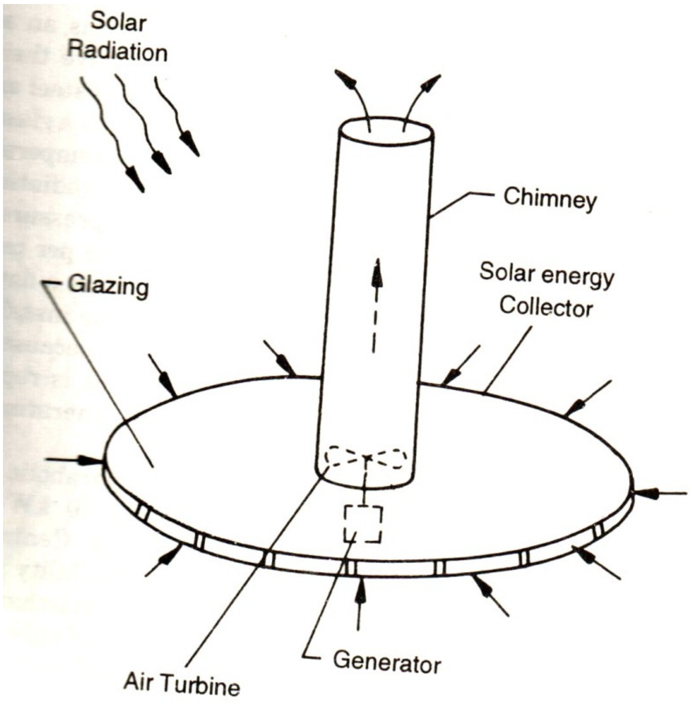
Low temperature power generation cycle



High Temperature Power Systems

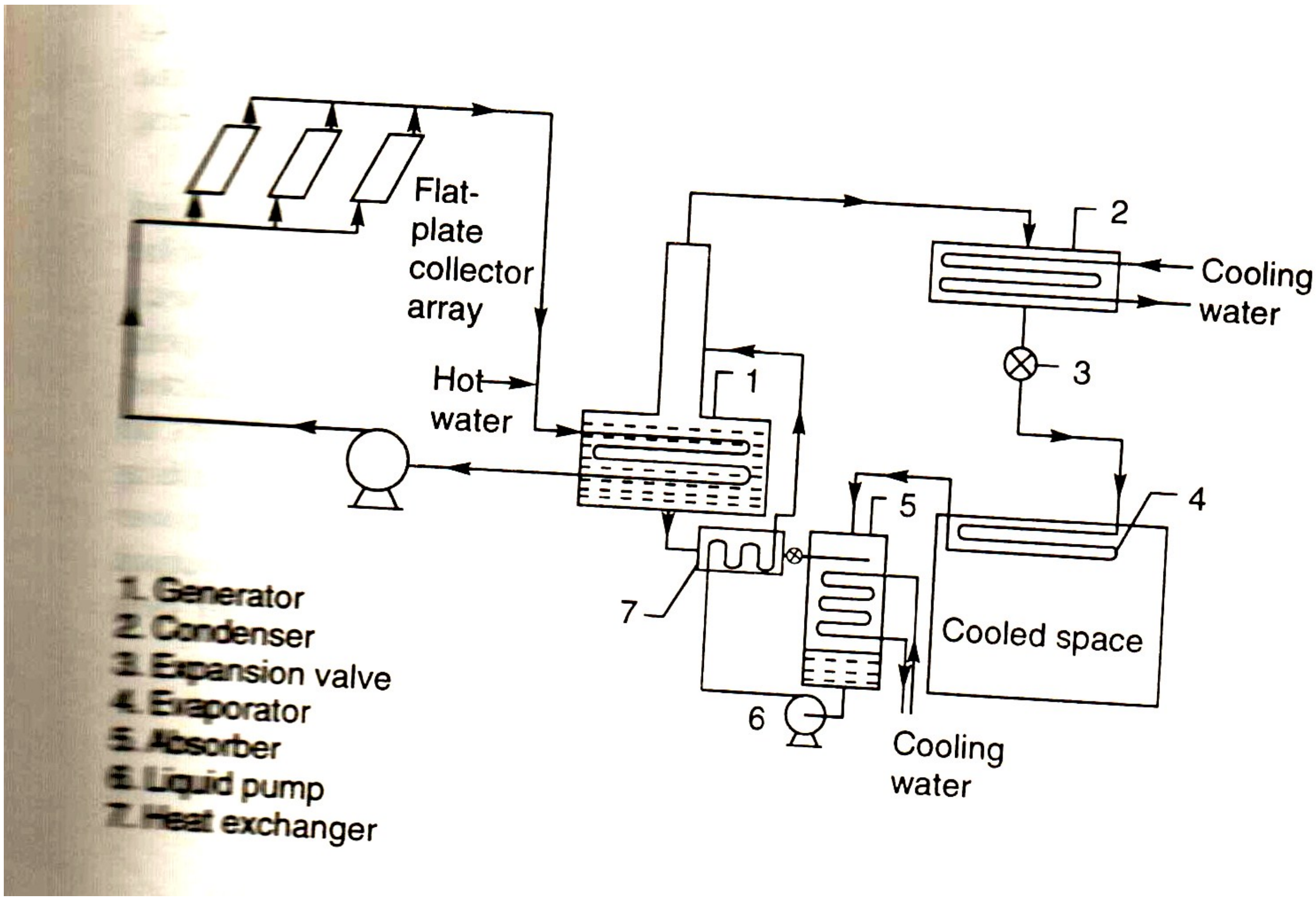


Solar Chimney power plant

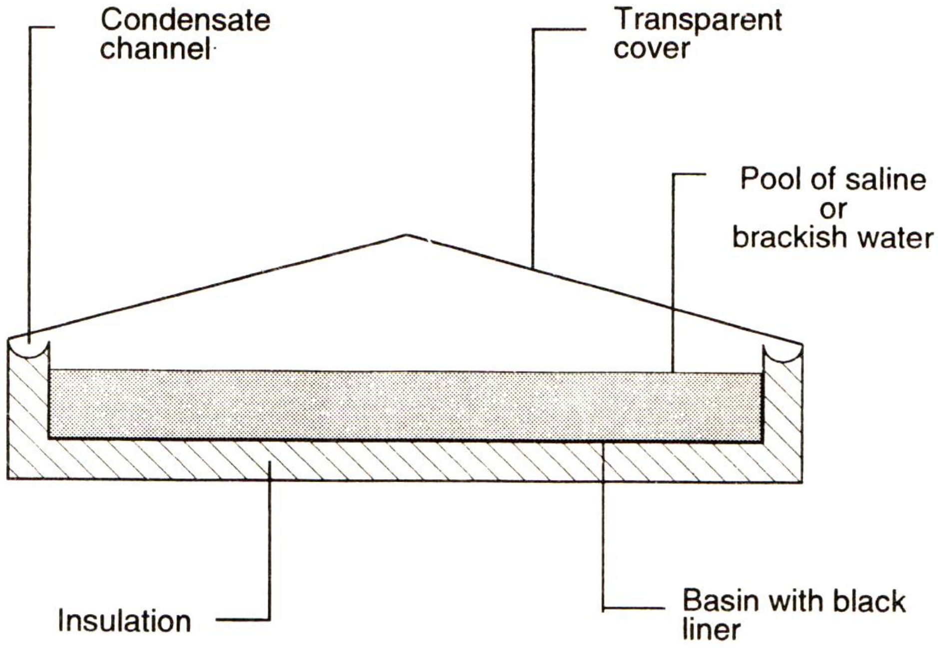


Only Solar Plant built on this technology is in Spain:
With 50kW capacity, 200m high and 10.3m diameter

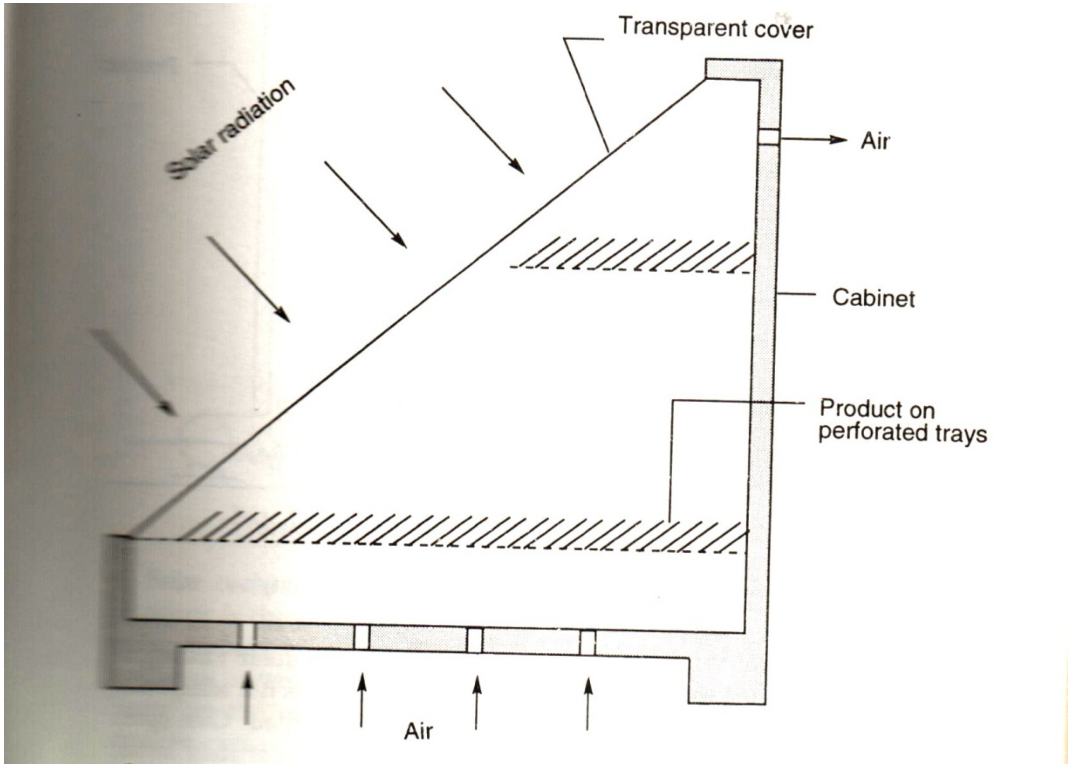
Solar refrigeration



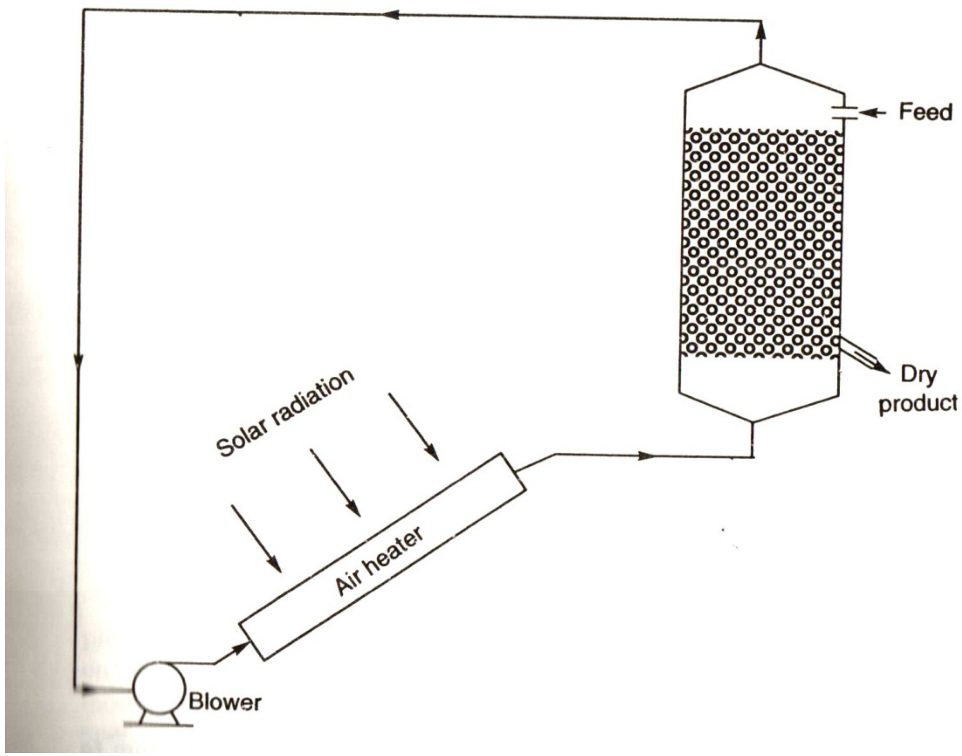
Distillation



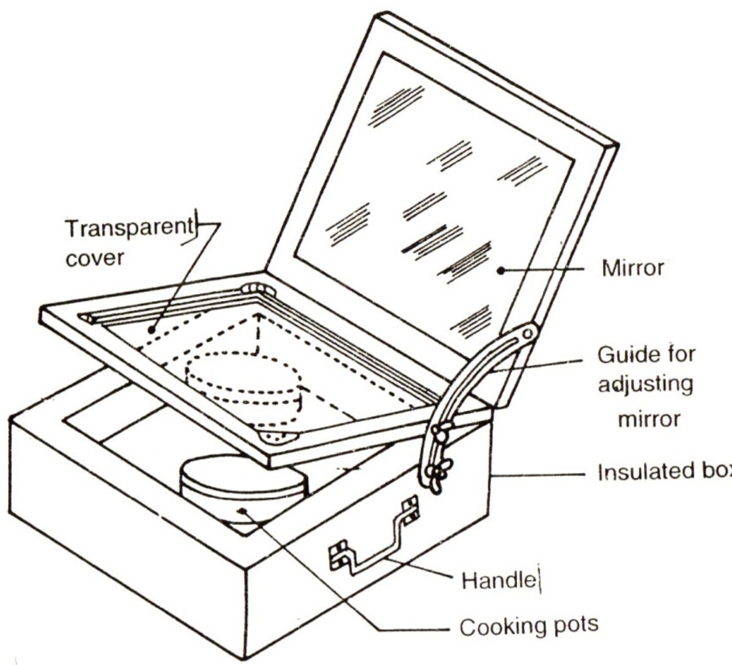
Dryers


Transparent cover
Solar radiation
Air
Cabinet
Product on
perforated trays
Air

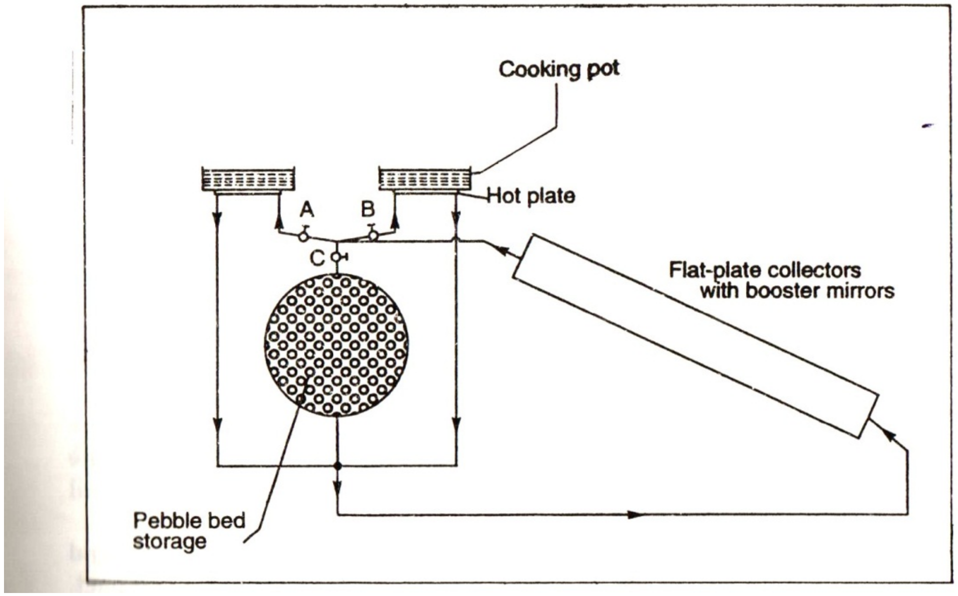
Forced circulation drying



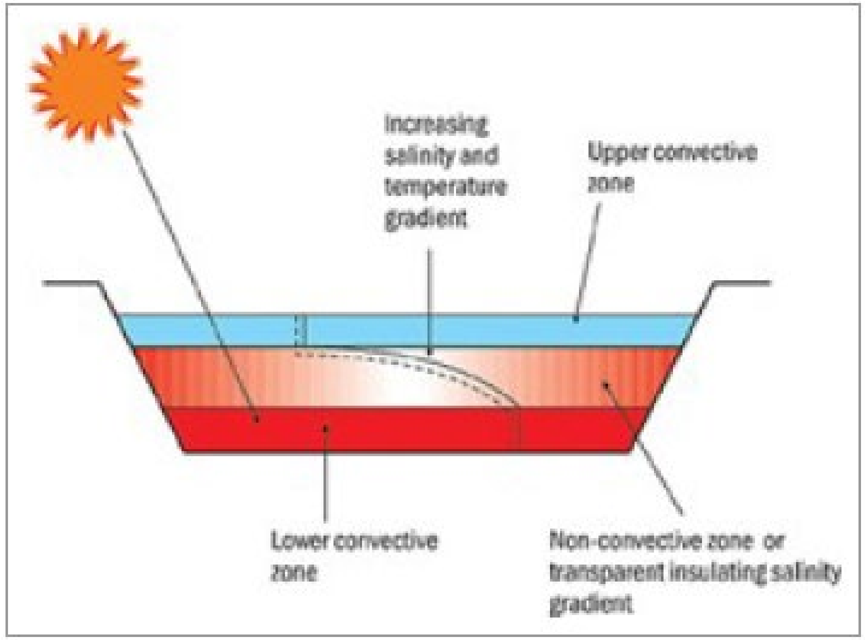
Cooking


Transparent cover
Mirror
Guide for adjusting mirror
Insulated box
Handle
Cooking pots

Community solar cookers



Solar Pond



A solar pond is simply a pool of water, which collects and stores solar energy. It contains layers of salt solutions with increasing concentration (and therefore density) to a certain depth, below which the solution has a uniform high salt concentration.

When sunlight is absorbed, the density gradient prevents heat in the lower layers from moving upwards by convection and leaving the pond. This means that 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. 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

Solar Energy Storage

Why storage required?

Energy storage is the storage of some form of energy that can be drawn upon at a later time to perform some useful operation.

Many renewable energy technologies such as solar and wind energy cannot be used for base-load power generation as their output is much more volatile and depends on the sun, water currents or winds.

Advantage's of storage

- Permits solar energy to be captured when insolation is highest
- To meet the peak load demand
- Improve reliability
- Better match

The capacity of storage depends upon

- Availability of solar energy
- Nature of loads
- Degree of reliability
- The cost
- Environmental and safety