ANKARA UNIVERSITY
DEPARTMENT OF ENERGY ENGINEERING
SOLAR ENERGY

__INSTRUCTOR__

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CONTENTS

Thermal Solar Energy Systems

a. Direct heating systems

b. Heliostats

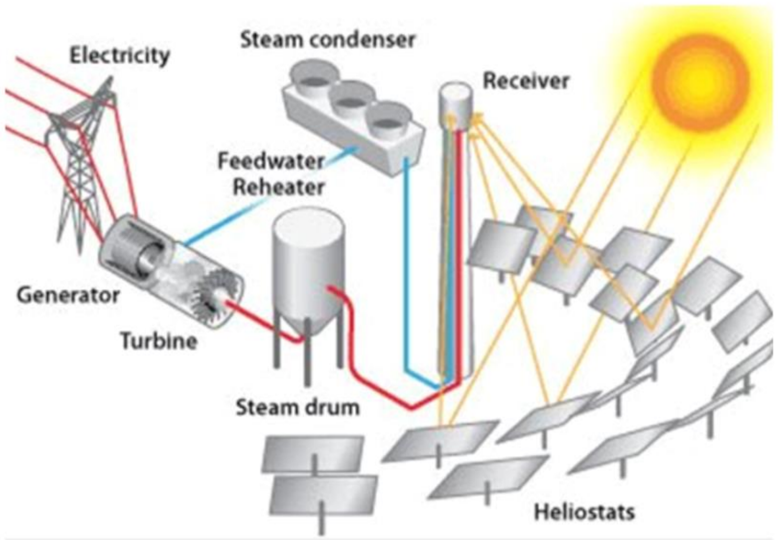
c. Solar thermal collectors

HELIOSTATS

A heliostat is a device that includes a mirror, which turns so as to keep reflecting sunlight toward a predetermined target, compensating for the sun's apparent motions in the sky.

To do this, the reflective surface of the mirror is kept perpendicular to the bisector of the angle between the directions of the sun and the target as seen from the mirror.

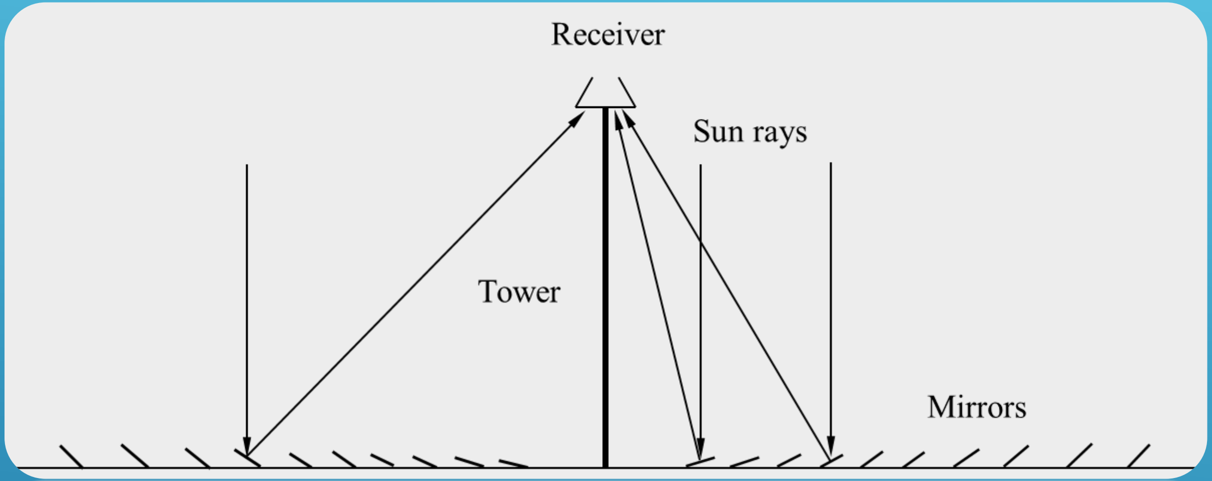
In almost every case, the target is stationary relative to the heliostat, so the light is reflected in a fixed direction.



Most heliostats are used for daylighting or for the production of concentrated solar power, usually to generate electricity.

Heliostats also used in solar cooking.

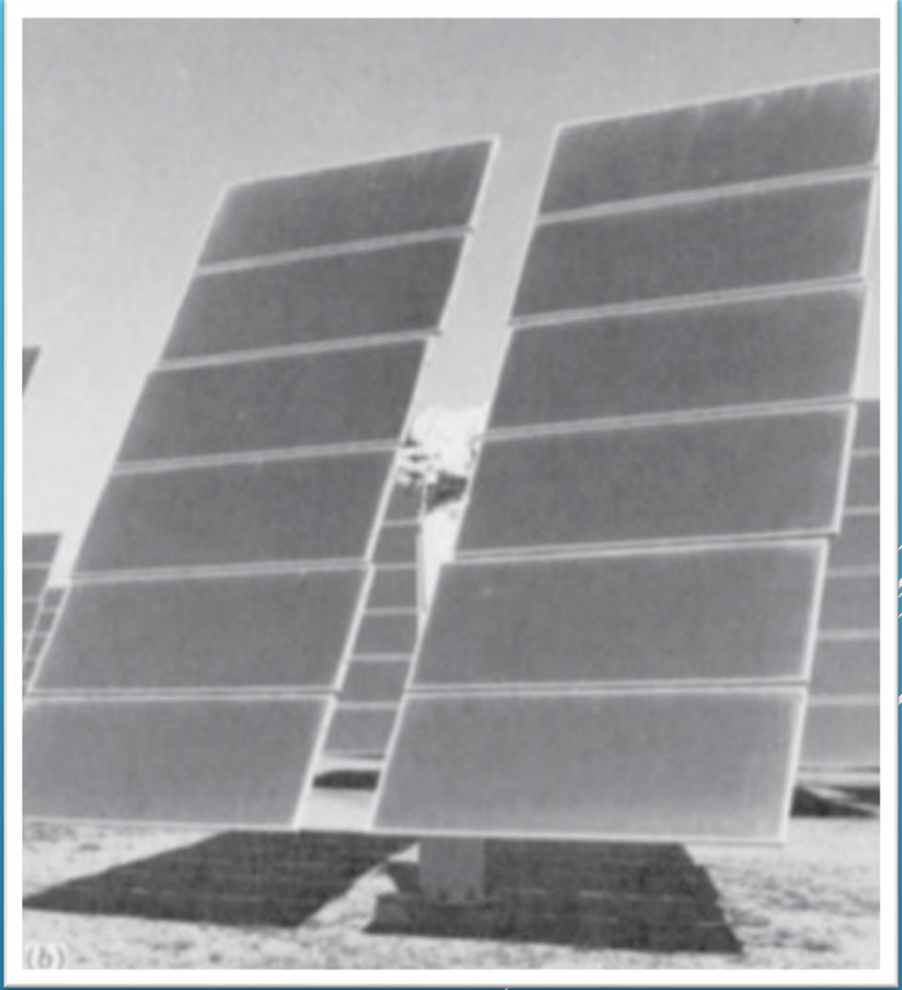
LİNEAR FRESNEL REFLECTOR (LFR)



The heliostats are mirrors with solar tracking on two axes and capable of concentrating the reflected solar radiation on a focal point located at the top of a tower in which the receiver element is placed

Large-scale systems must collect energy from large areas. In these systems beam radiation from a large array of (relatively) small heliostats is focused on a central receiver, thus collecting by optical rather than thermal means.

The heliostat system consists of 1818 individually oriented reflectors, each consisting of 12 concave panels with a total area of 39.13 m^2, for a total array area of 71,100 m^2. The reflecting material is back-silvered glass.

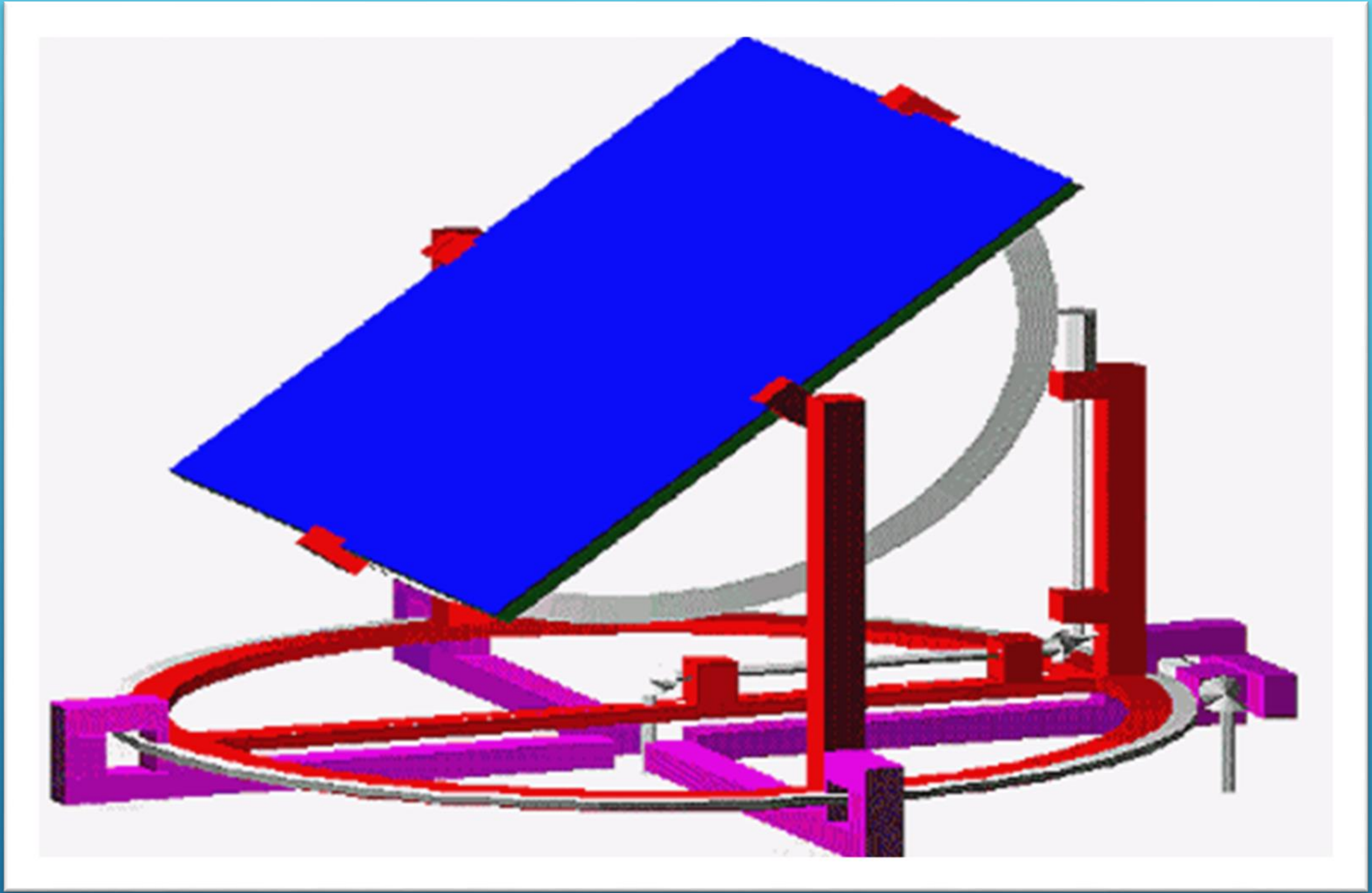


- Heliostats’ sizes varies according to the the receiver used on the tower. Heliostats are generally made from iron glass.
- Heliostats made from low iron float glass have a reflectivity 0.903. However, dirt reduces reflectivity to 0.82.

How Heliostats Move ?

- The mirrors are mounted on individual frames that are tipped up and down and rotated east to west by small motors much like those used in electric clocks.

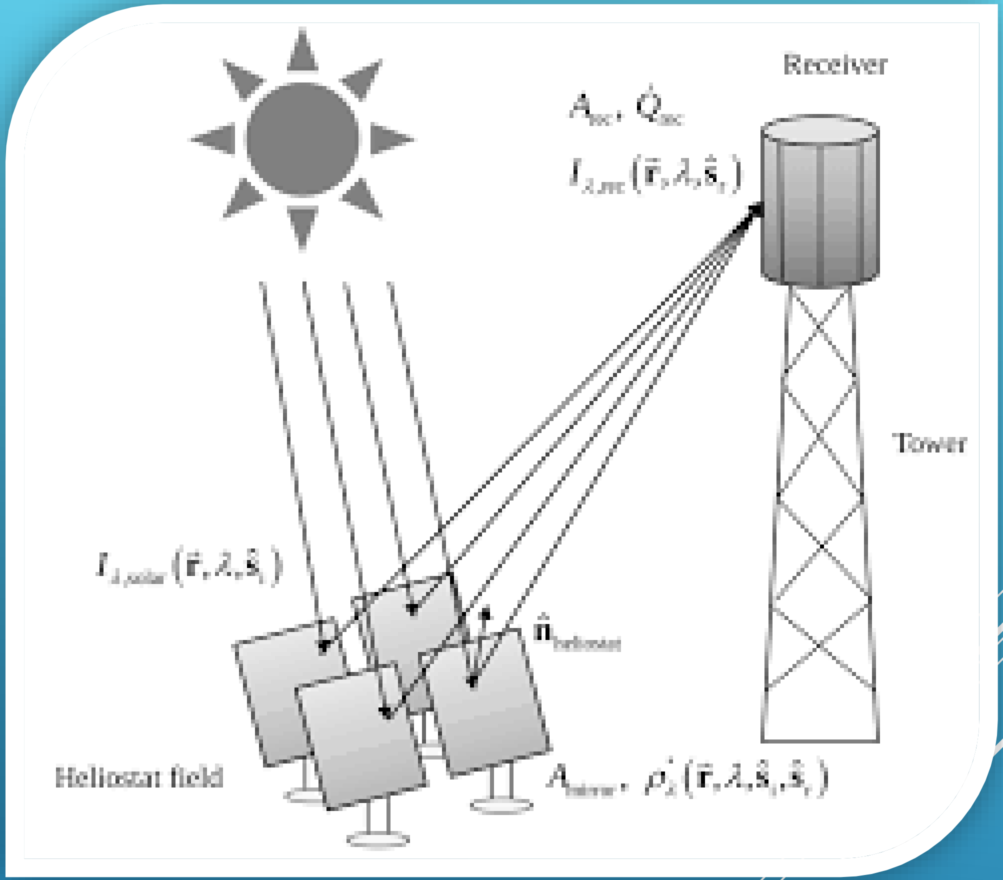
- The motors are controlled by a computer which determines how to position each heliostat so that its reflection hits the receiver at any time of the day and any day of the year



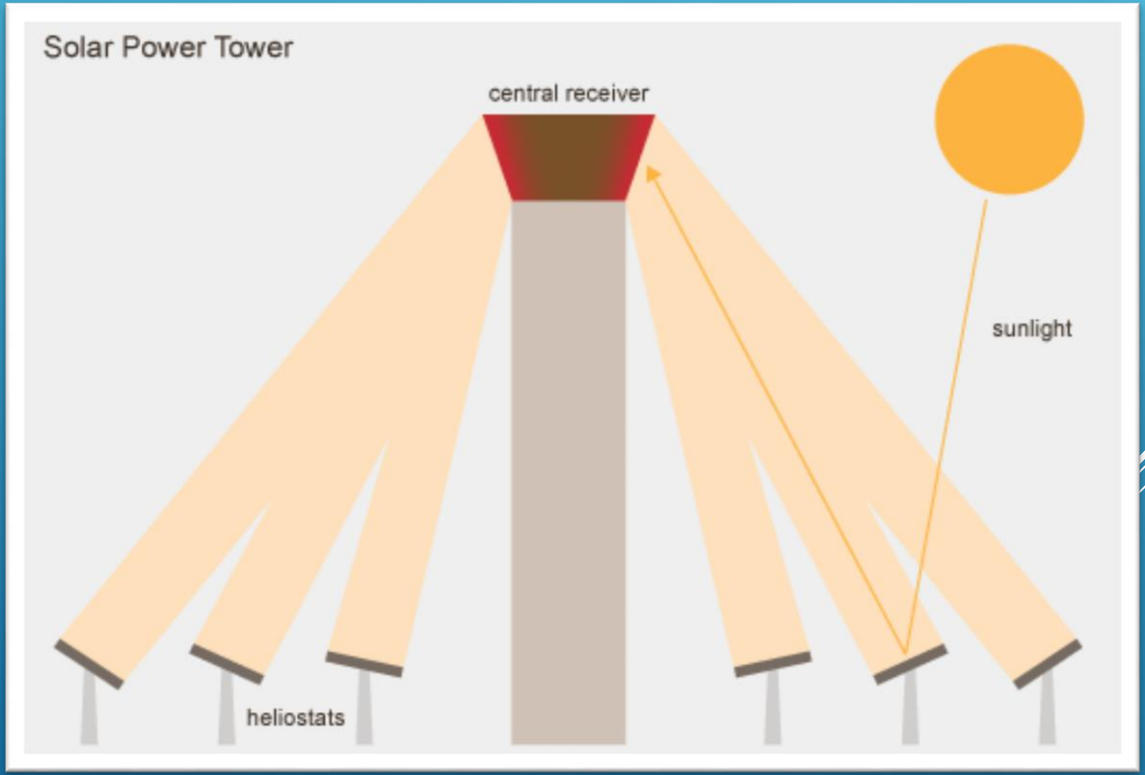
Example Of Sun Tracking Heliostat Design

Ideal Heliostat

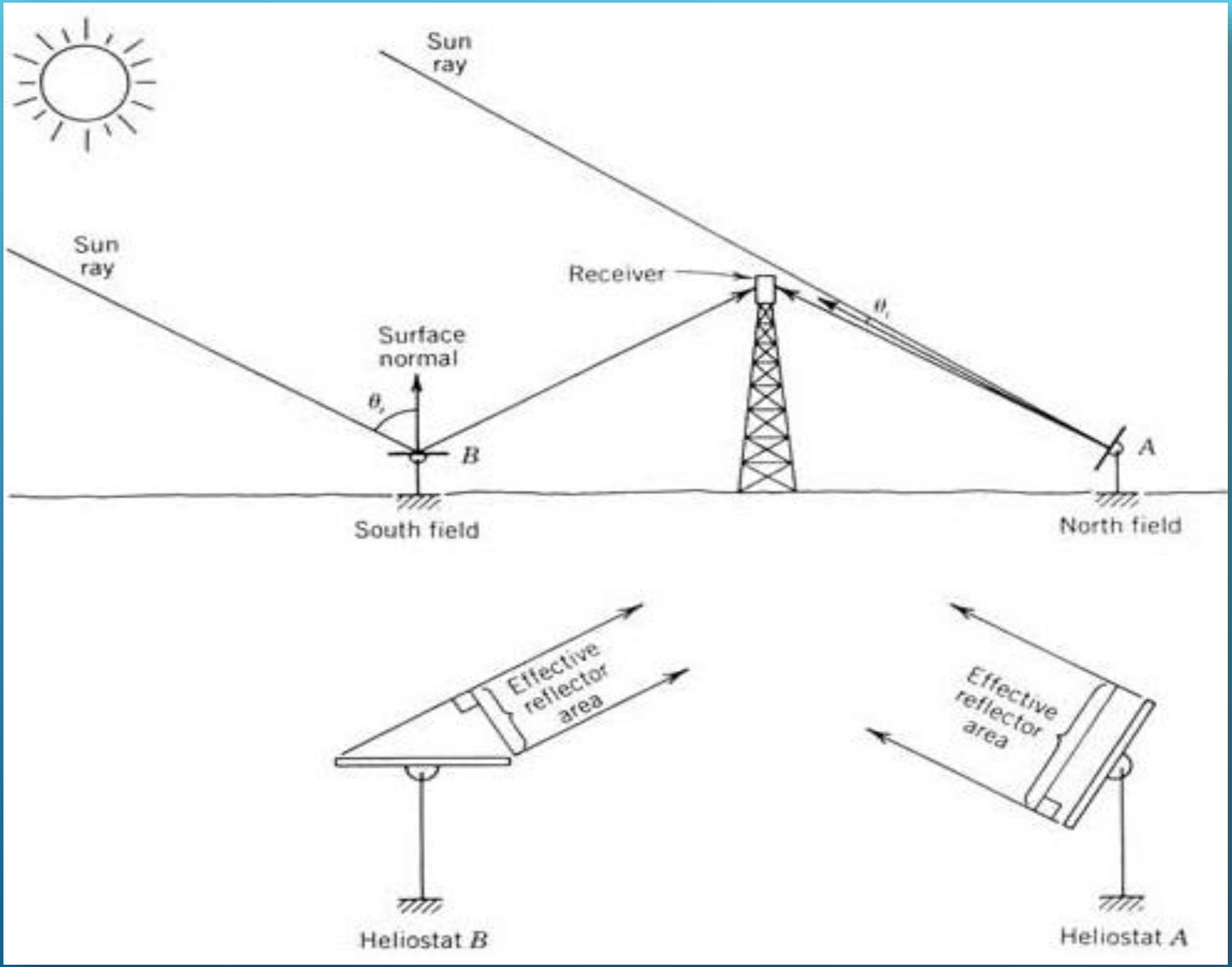
- Low Cost
- Maximum Reflection
- No Absorbtion & Transmission



The panels are coated with a nonselective flat-black paint which was heat cured in place with solar radiation. Average absorptance for solar radiation, after a second coating was applied, was about 0.96.



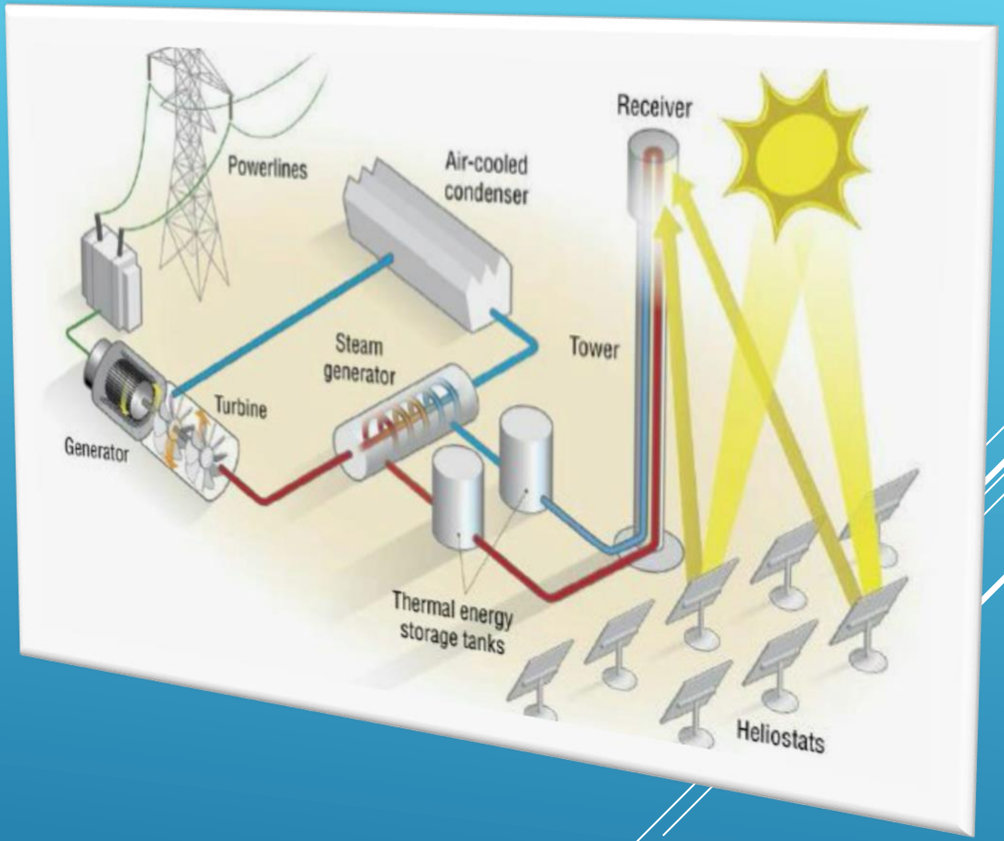
	%	E
		Average
Surface	**Reflectivity**	**Emissivity**
Aluminum foil, bright	92 - 97	0.05
Reflective Mylar Film	90 - 93	0.05
Aluminum sheet	80 - 95	0.12
Plate glass mirrors coated with aluminum on back	85	
Aluminum-coated paper, polished	75 - 84	0.20
Steel, galvanized, bright	70 - 80	0.25
Aluminum paint	30 - 70	0.50
Building materials: wood, paper, glass, masonry, nonmetallic paints	5 - 15	0.90



The cosine effect for two heliostats in opposite directions from the tower.

For the noontime sun condition shown, heliostat A in the north field has a much greater cosine efficiency than does heliostat.

The central-receiver, or “power tower,” concept for generation of electrical energy from solar energy is based on the use of very large concentrating collectors. The optical system consists of a field of a large number of heliostats, each reflecting beam radiation onto a central receiver.



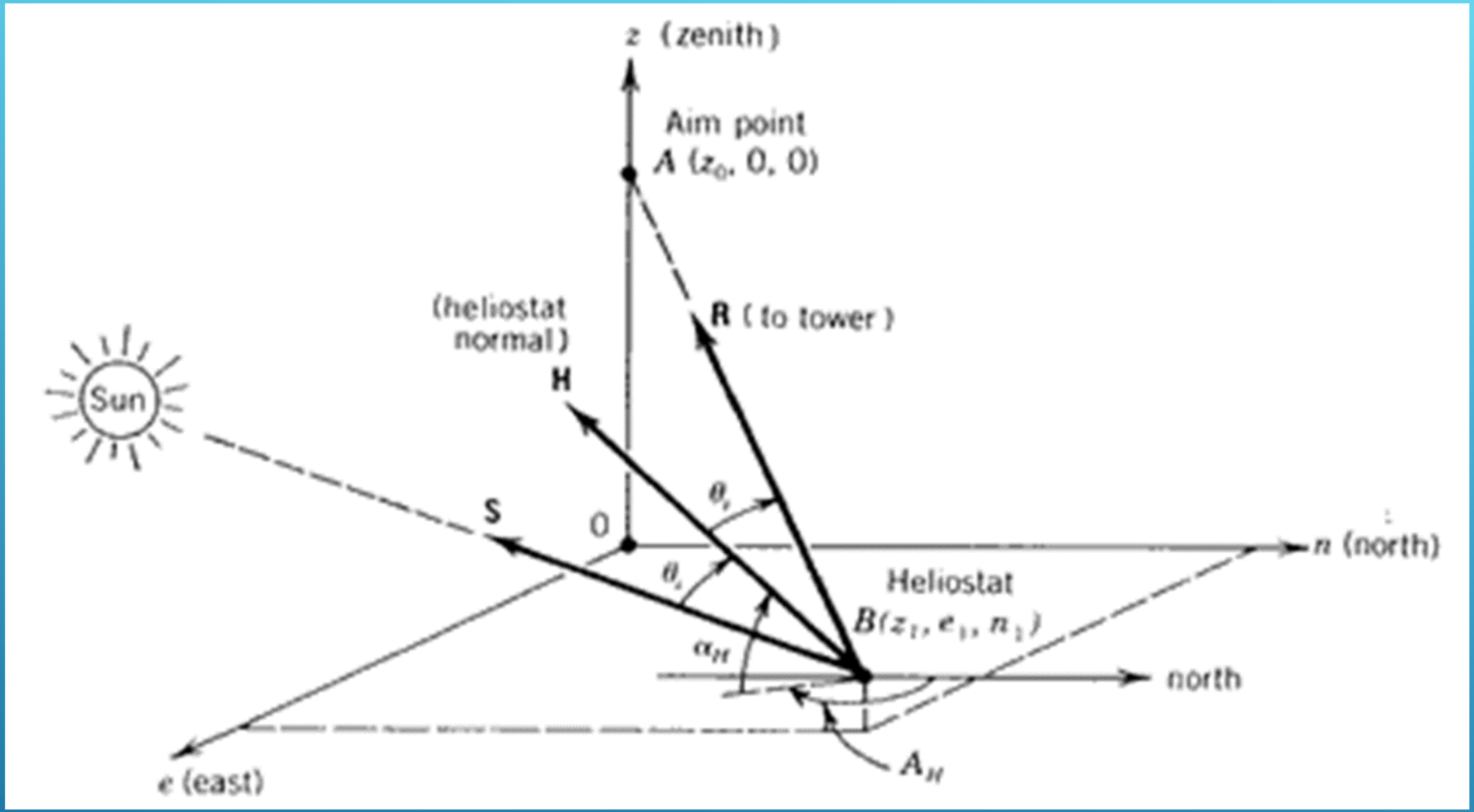
The heliostats are spaced apart, and only a fraction of the ground area ψ is covered by mirrors. A ψ of about 0.3 to 0.5 has been suggested as a practical value.

The maximum concentration ratio for a three-dimensional concentrator system with radiation incident at an angle θ_i on the plane of the heliostat array ($\theta_i = \theta_z$ for a horizontal array), a rim angle of φ_r , and a dispersion angle of δ, if all reflected beam radiation is to be intercepted by a spherical receiver, is

$$C_{max} = \frac{\psi \sin^2 \phi_r}{4 \sin^2(0.267 + \delta/2)} - 1$$

For a flat receiver, the concentration ratio is

$$C_{max} = \psi \left[\frac{\sin \phi_r \cos(\phi_r + 0.267 + \phi/2)}{\sin(0.267 + \delta/2)} \right]^2 - 1$$

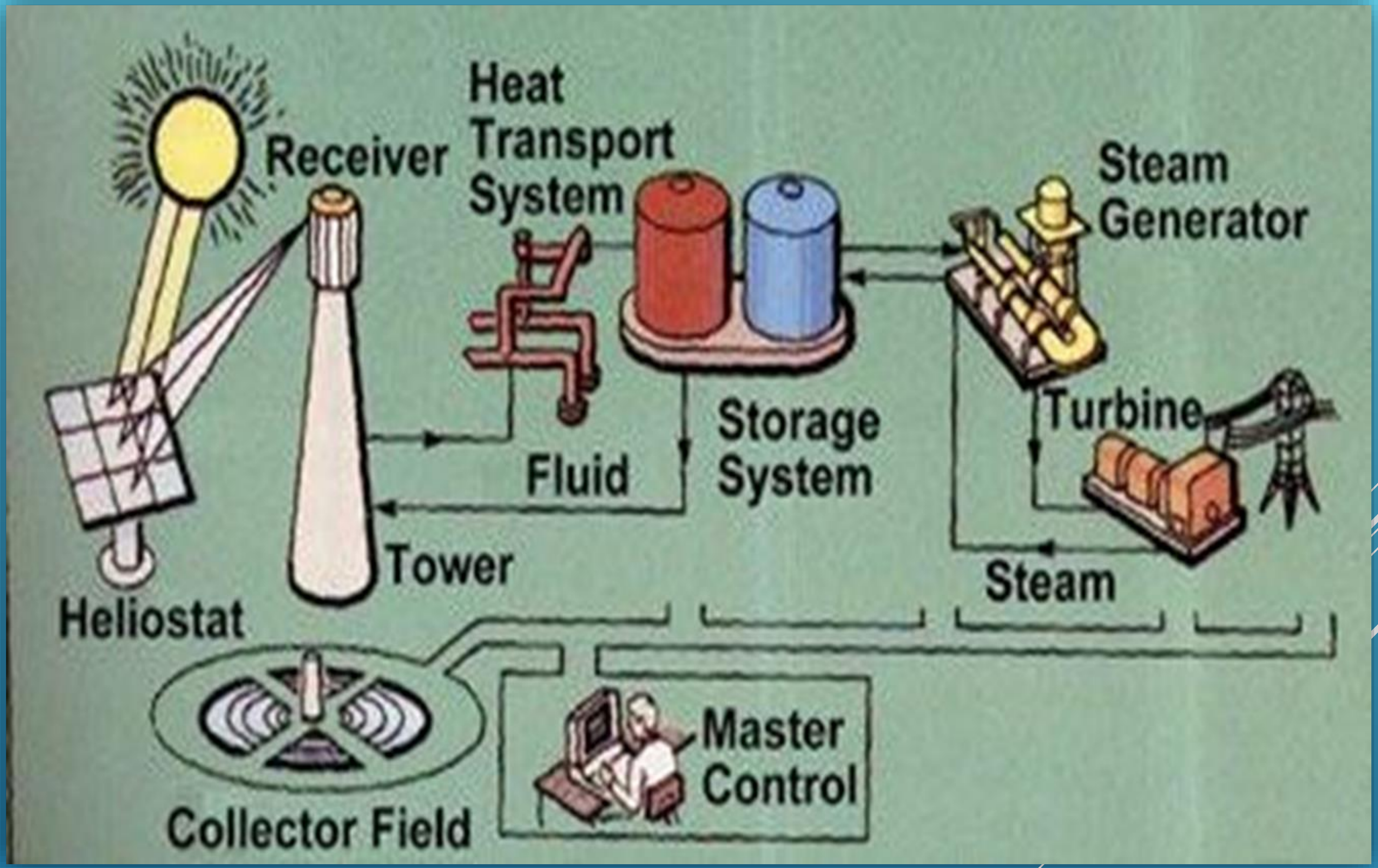


Coordinates defining the reflection of the sun's rays by a heliostat to a single aim point.

Vector H is normal to the heliostat reflecting surface

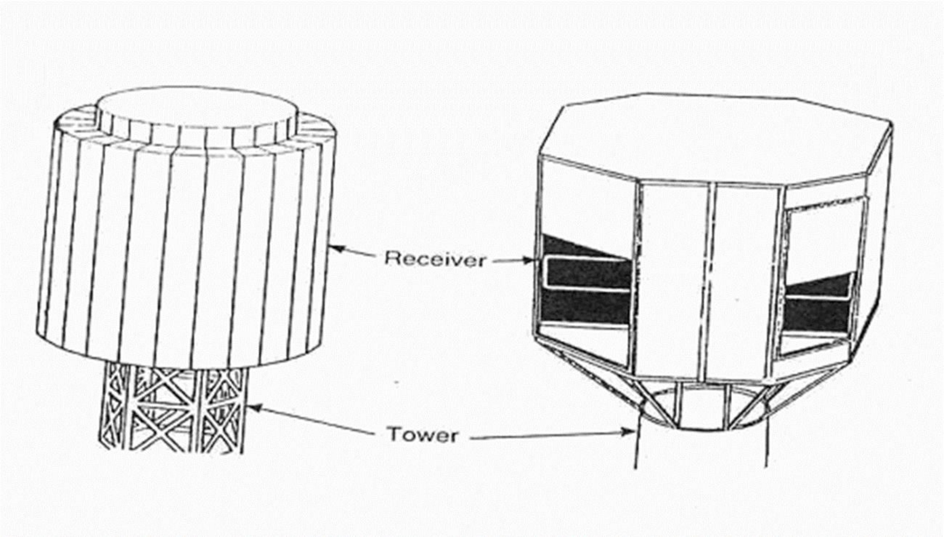
Central Receiver :

- ➢ Solar Concentrator (Heliostat Field)
- ➢ Receiver
- ➢ Storage System
- ➢ Power Generator



RECEİVER

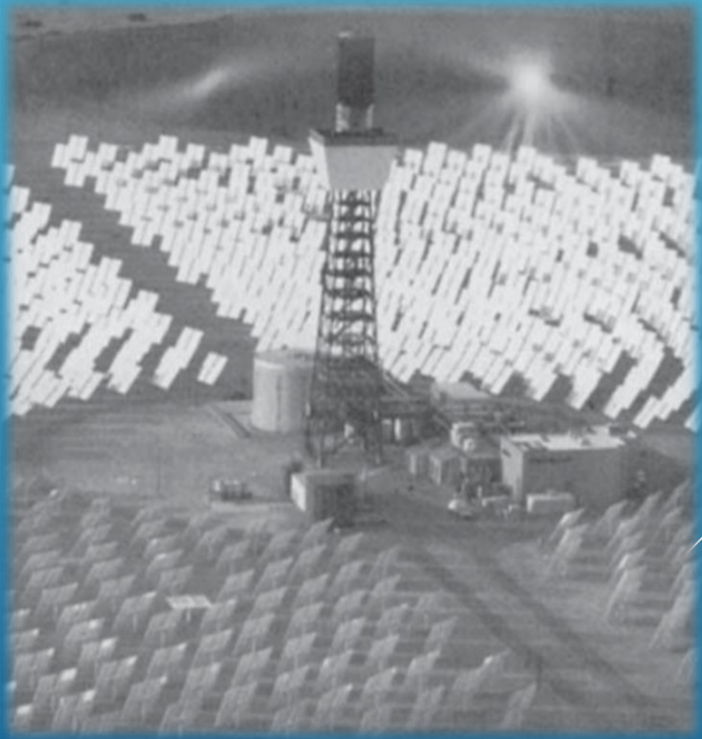
The receivers normally consist of a large number of metal tubes that contain a flowing fluid. The outer surface of the tubes are black to assure that the light is absorbed and converted to heat. The metals used for the tubes are the same as those used in other high-temperature, non-solar processes. Central receivers are usually very large and have a capacity to generate 100 MW of useful power or more.



The receiver is a single-pass superheat boiler, generally cylindrical in shape, 13.7 m high, 7m in diameter, with the top 90m above ground. It is an assembly of 24 panels, each 0.9 m wide and 13.7 m long.

TOWER DESİGN

The height of the tower is limited by its cost. The weight and wind age area of the receiver are the two most important factors in the design of the tower. Seismic considerations are also important in some locations.



STORAGE SYSTEM

A storage system makes it possible to run the steam turbine under constant conditions even during periods of varying insolation (clouds) or after sunset. It consists of two main parts which are hot and cold storage tanks.

An electric generator is a device that converts mechanical energy to electric energy

SOLAR COLLECTORS

Solar collectors are devices that collect the solar radiation converting it to thermal energy of a fluid which can be used directly or stored for use during cloudy periods or nighttime.

There are various types of solar collectors the use of which is determined from the required temperature.

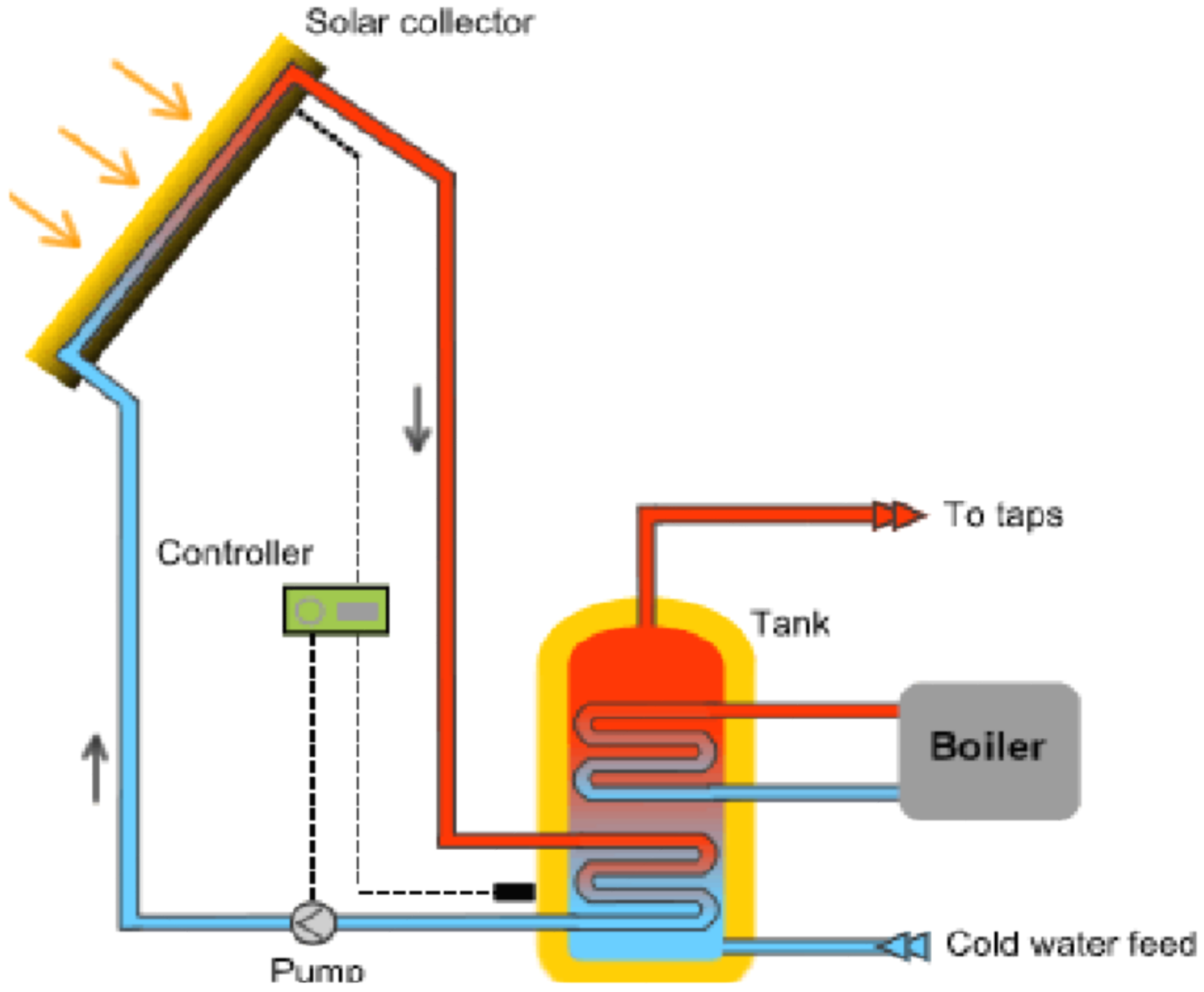
Types of Solar Collectors

There are basically two types of solar collectors:

- **Non-concentrating or stationary: it has the same area for intercepting and absorbing solar radiation**
- Concentrating: a sun-tracking 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.

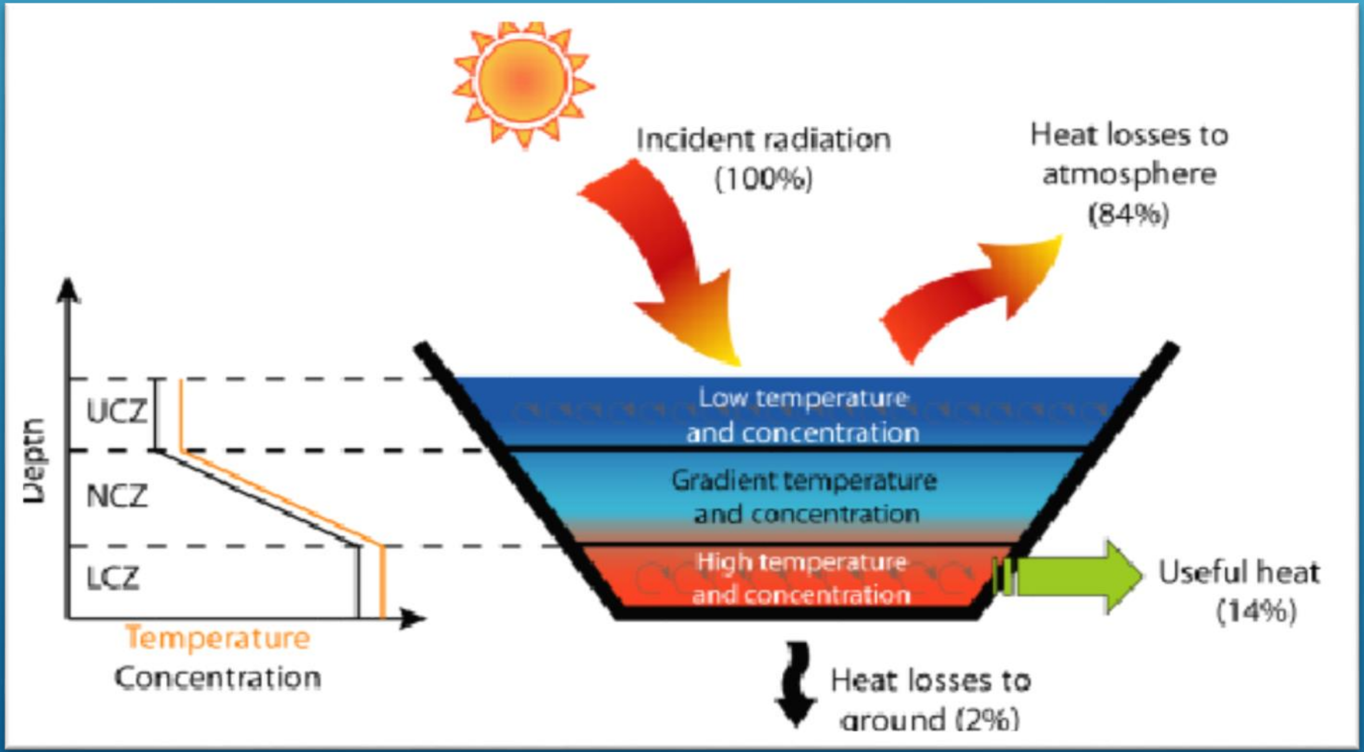
Concentrating collectors are suitable for high-temperature applications.

Solar Energy Collector System



Solar Ponds

Solar ponds (or salt gradient solar ponds). These are artificial lakes and constitute the simplest type of solar collector. They consist of layers of water at different concentration of salts. Generally there is no large application of solar ponds in desalination systems. The greatest temperature of the heat supplied is ~90°C.

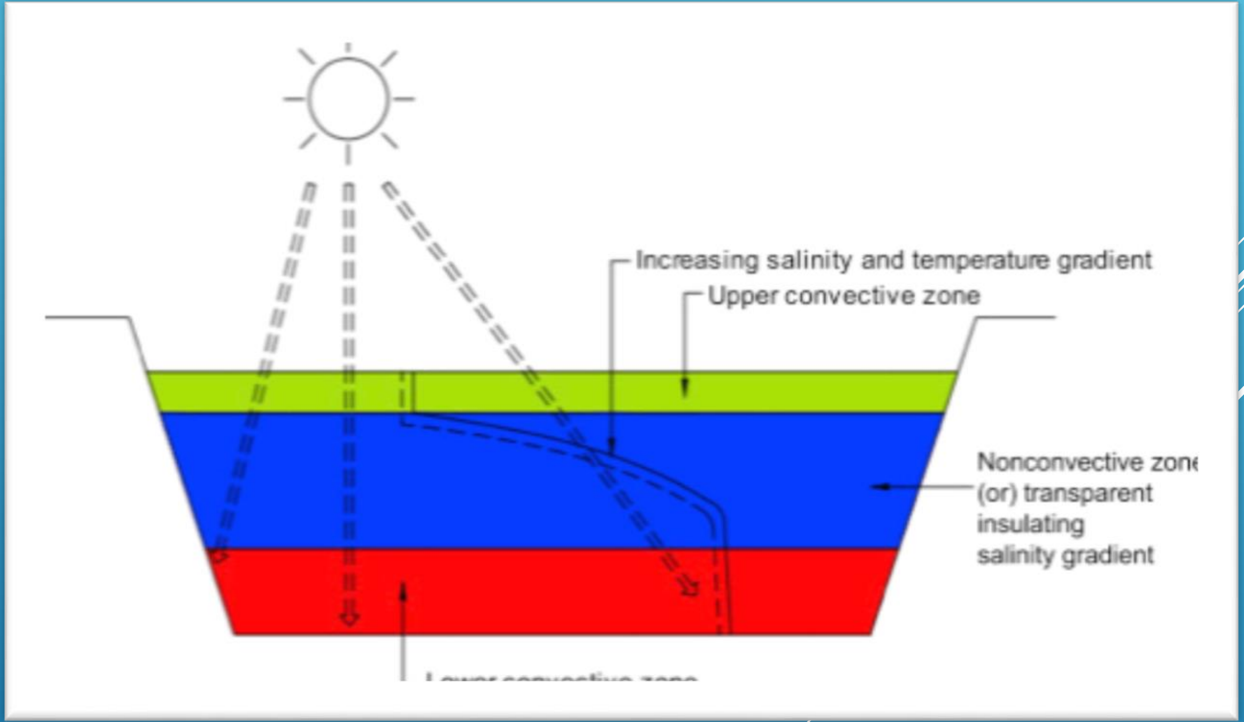


The desirable properties of salt to be used in solar ponds are as follows:

- a high value of solubility to allow for high solution densities, and the solubility should not vary appreciably with the temperature;
- transparency of the salt solution to solar irradiation;
- environmentally benign and safe to handle;
- low cost.

Some commonly preferred salts for solar ponds:

- sodium chloride
- sodium carbonate
- natural brine, magnesium, chlorine
- magnesium chloride
- potassium nitrate
- ammonium nitrate



Flat-Plate Collectors

Flat-plate collectors consist of a black absorbing plate, at the bottom of which pipes or channels are installed. This is mounted in a hermetically sealed frame with transparent cover which is penetrable to the solar radiation at the top and good thermal insulation at the bottom.

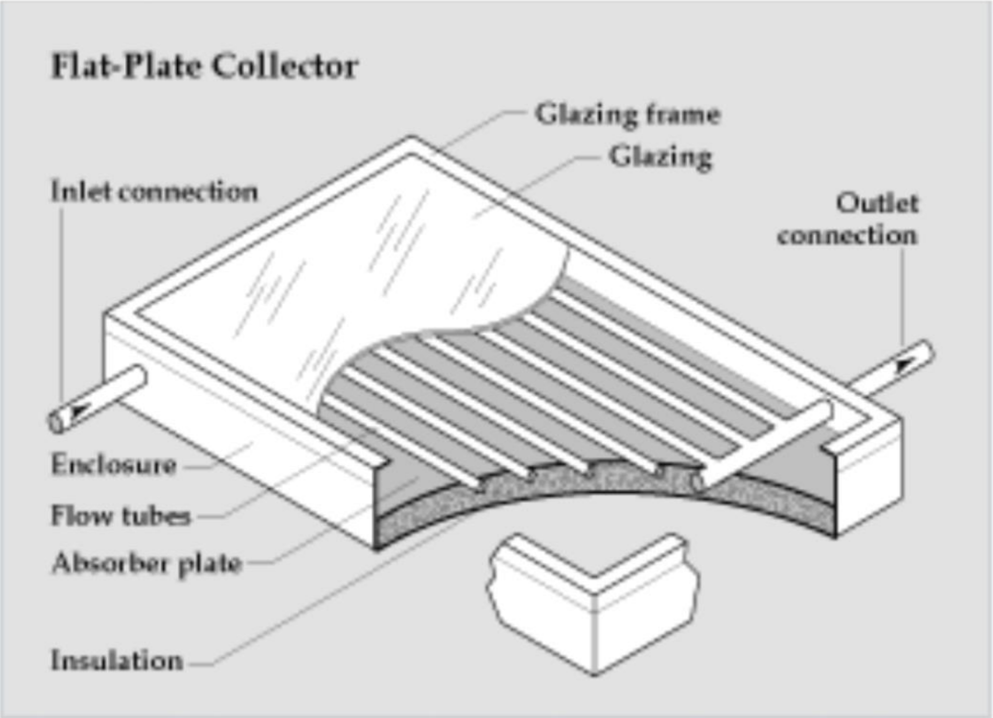
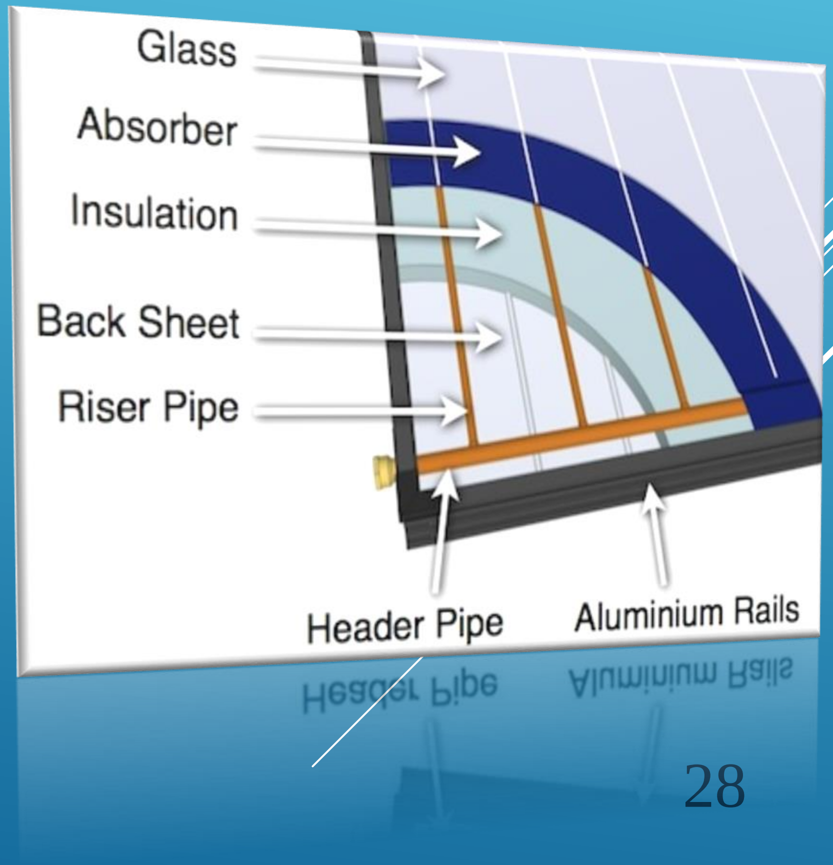
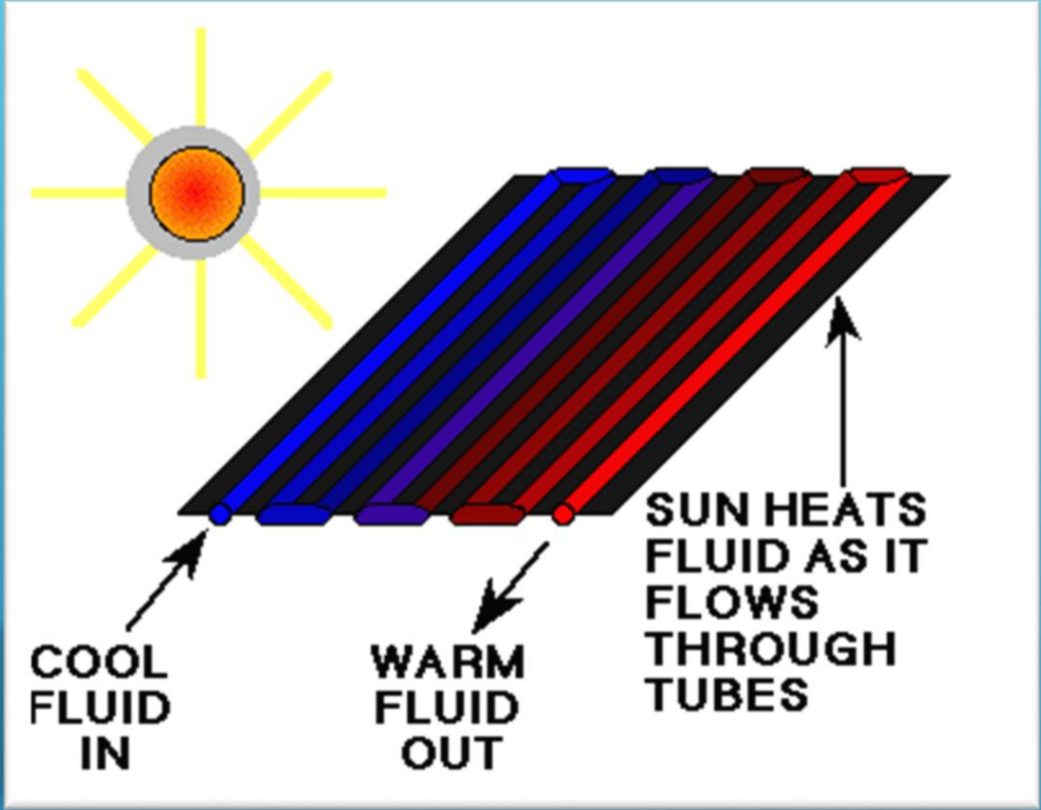


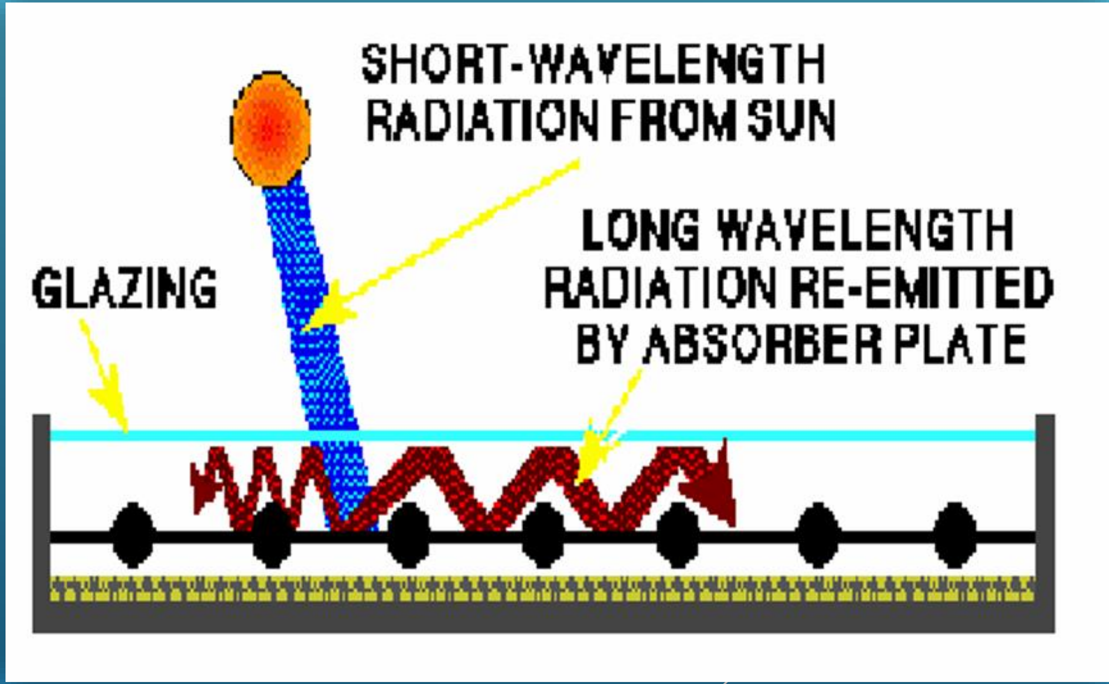
Figure 2. A diagram of a flat plate solar collector.[3]

The solar energy is absorbed from the black surface and supply heat to a fluid which is circulated in the pipes or the channels. The heat is transferred to a process connected to the collector or it is stored. Flat-plate collectors supply heat at generally low temperatures up to about a maximum temperature of 90°C, and typically at a mean temperature of 70°C.

This plate heats up, transferring the heat to either water or air that is held between the glazing and absorber plate. Sometimes these absorber plates are painted with special coatings designed to absorb and retain heat better than traditional black paint. These plates are usually made out of metal that is a good conductor - usually copper or aluminum.




SUN HEATS
FLUID AS IT
FLOWS
THROUGH
TUBES
COOL
FLUID
IN
WARM
FLUID
OUT


SHORT-WAVELENGTH
RADIATION FROM SUN
LONG WAVELENGTH
RADIATION RE-EMITTED
BY ABSORBER PLATE
GLAZING

Evacuated Tube Collectors

This type of solar collector uses a series of evacuated tubes to heat water for use. These tubes utilize a vacuum, or evacuated space, to capture the suns energy while minimizing the loss of heat to the surroundings.

They have an inner metal tube which acts as the absorber plate, which is connected to a heat pipe to carry the heat collected from the Sun to the water. This heat pipe is essentially a pipe where the fluid contents are under a very particular pressure.

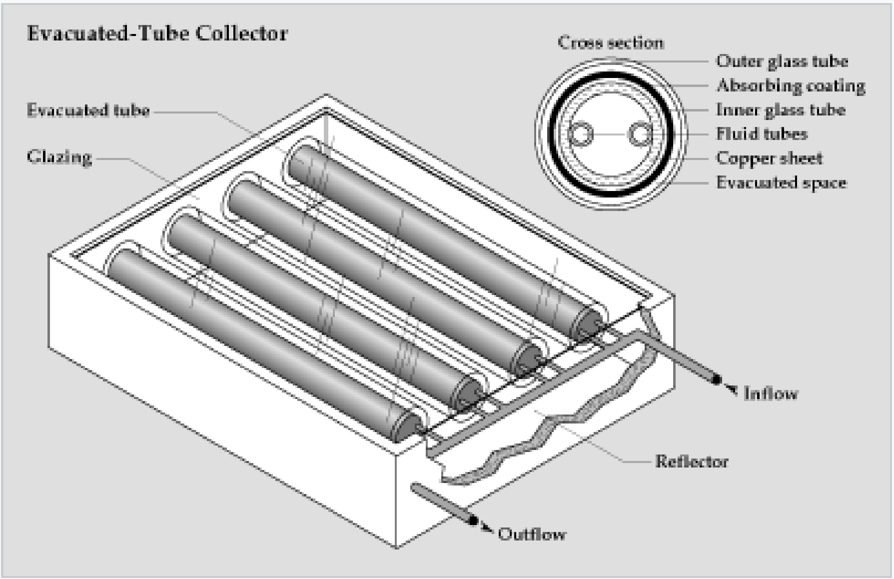
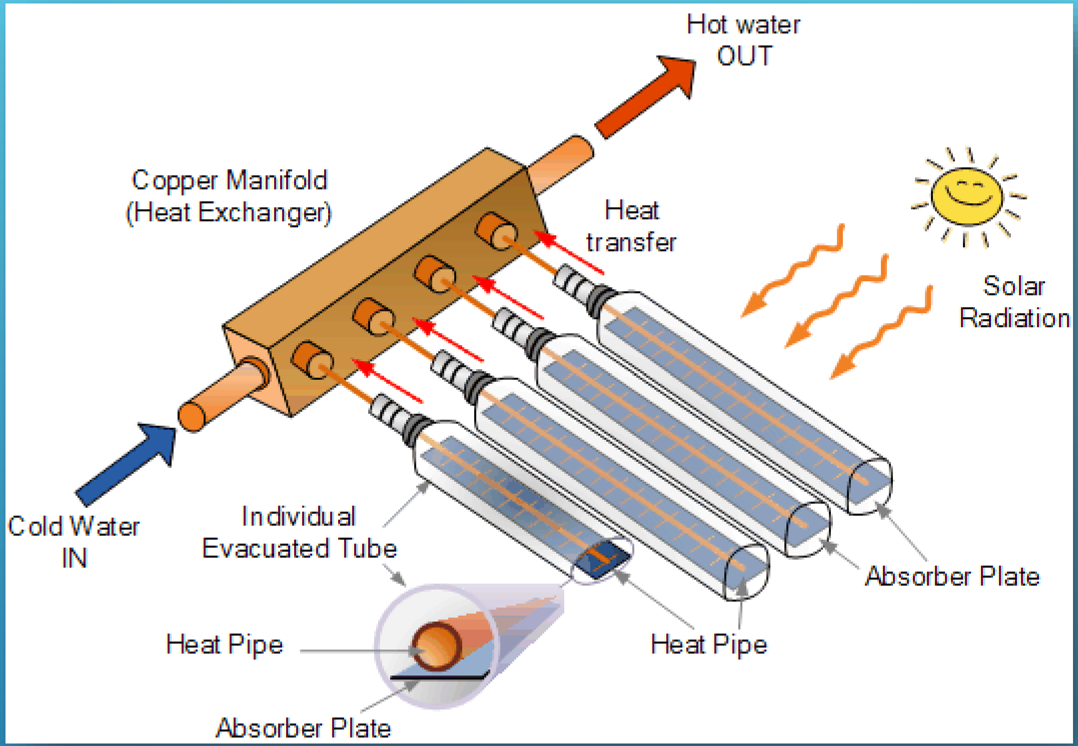
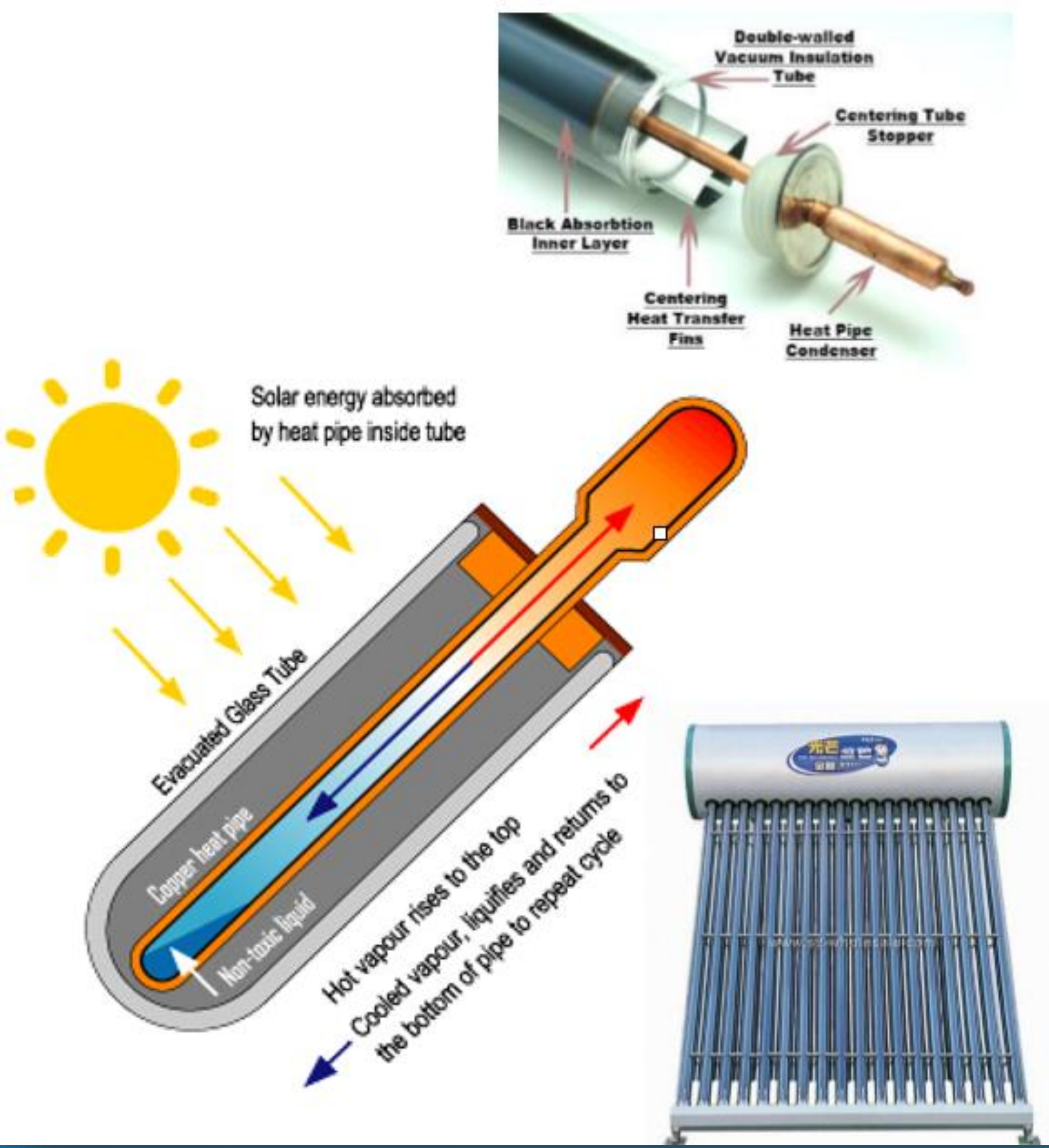


Figure 3. A diagram of an evacuated tube solar collector.[5]


Hot water
OUT
Copper Manifold
(Heat Exchanger)
Heat
transfer
Solar
Radiation
Cold Water
IN
Individual
Evacuated Tube
Absorber Plate
Heat Pipe
Heat Pipe
Absorber Plate


Double-walled
Vacuum Insulation
Tube
Centering Tube
Stopper
Black Absorbtion
Inner Layer
Centering
Heat Transfer
Fins
Heat Pipe
Condenser
Solar energy absorbed
by heat pipe inside tube
Evacuated Glass Tube
Copper heat pipe
Non-toxic liquid
Hot vapour rises to the top
Cooled vapour, liquifies and returns to
the bottom of pipe to repeat cycle

At this pressure, the "hot" end of the pipe has boiling liquid in it while the "cold" end has condensing vapor. This allows for thermal energy to move more efficiently from one end of the pipe to the other. Once the heat from the Sun moves from the hot end of the heat pipe to the condensing end, the thermal energy is transported into the water being heated for use.

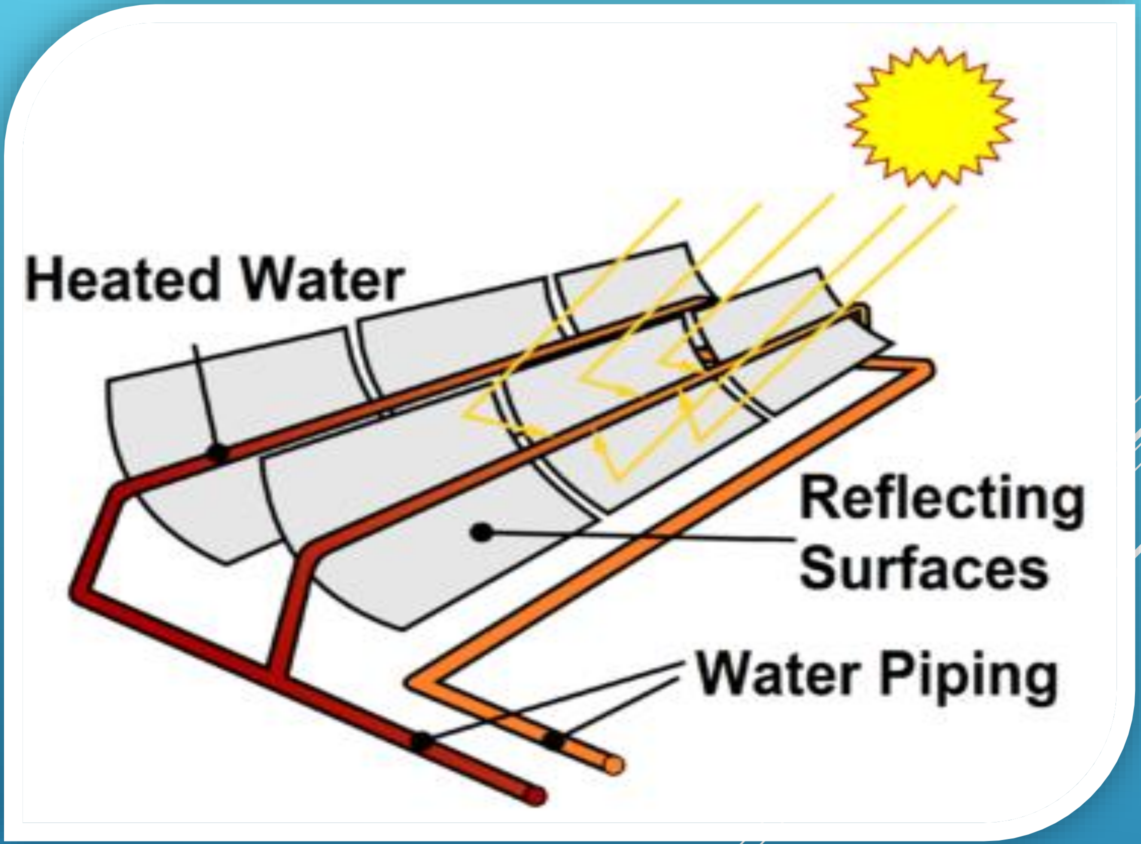
Evacuated tube collectors are flat devises which consist of cylindrical absorbing surfaces or tubes with internal fins installed in an evacuated tube to reduce the convection losses. They produce temperatures of 80°C up to 120°C.

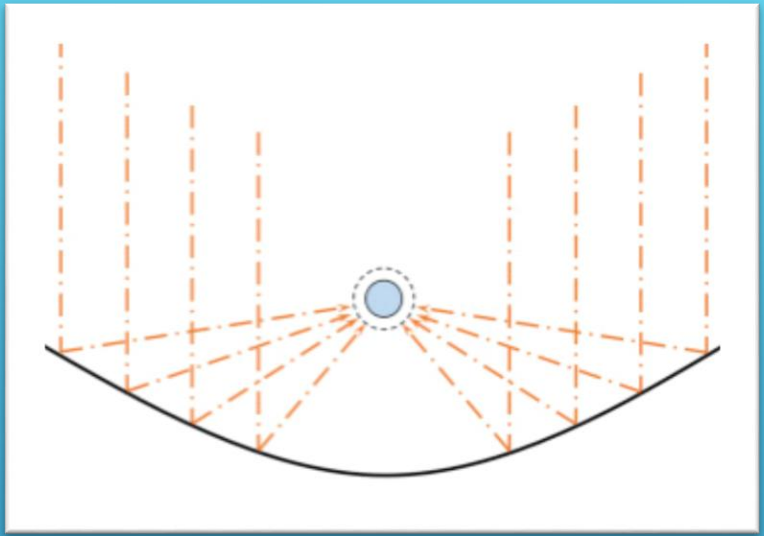
Concentrating Solar Collectors

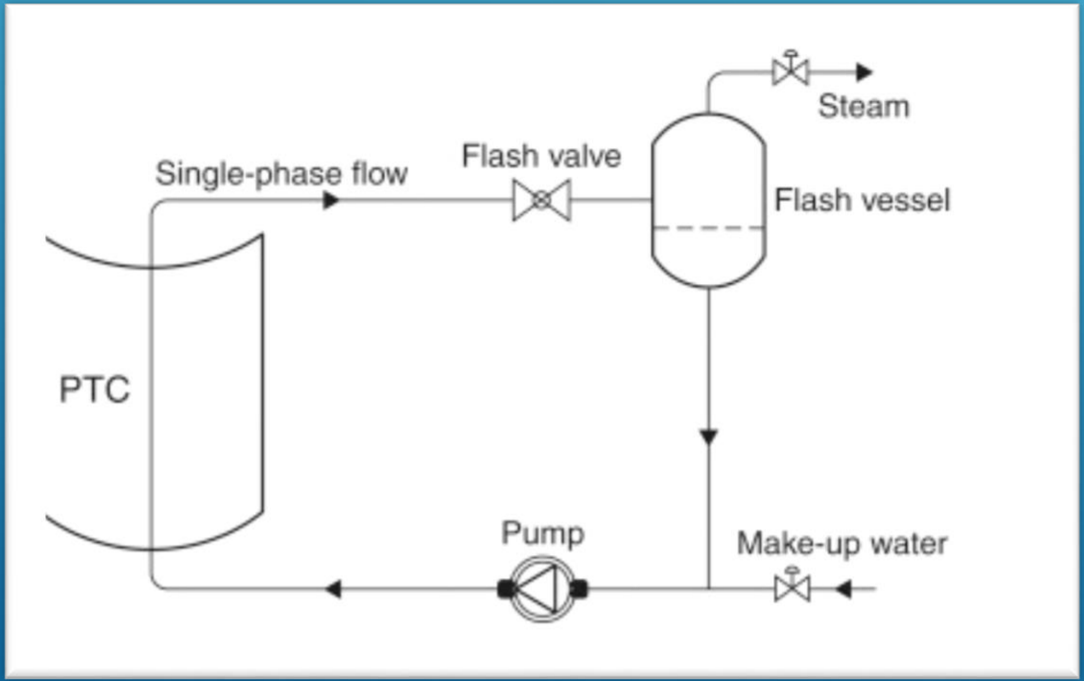
These collectors, sometimes known as parabolic troughs, use highly reflective materials to collect and concentrate the heat energy from solar radiation.

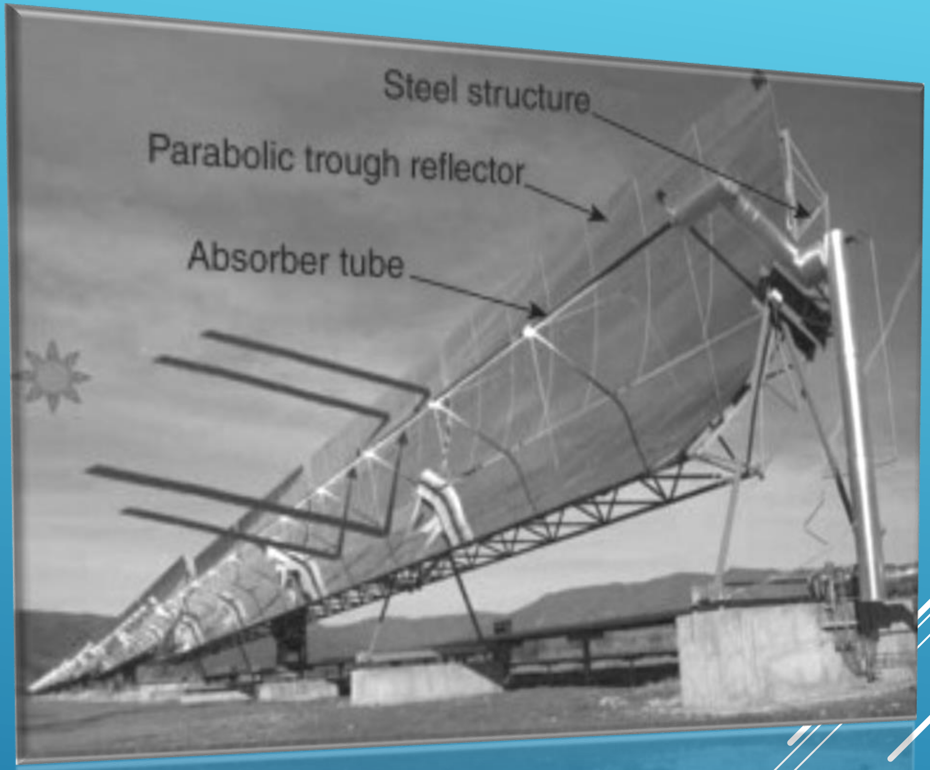
A pipe that carries water is placed in the center of this trough so that sunlight collected by the reflective material is focused onto the pipe, heating the contents.

These are very high powered collectors and are thus generally used to generate steam for Solar thermal power plants and are not used in residential applications.





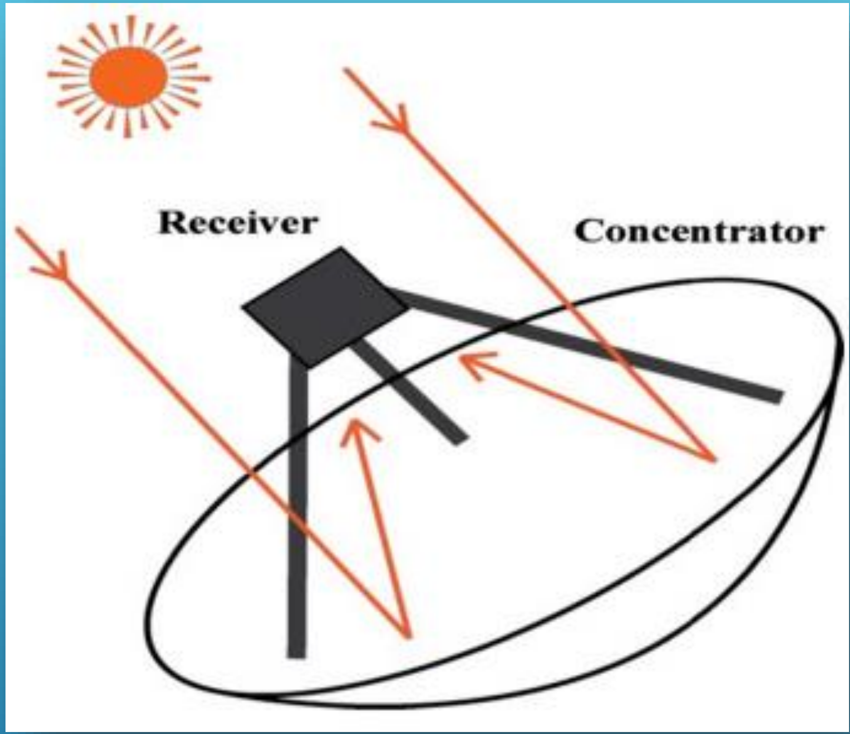

Steam
Flash valve
Single-phase flow
Flash vessel
PTC
Pump
Make-up water


Steel structure
Parabolic trough reflector
Absorber tube

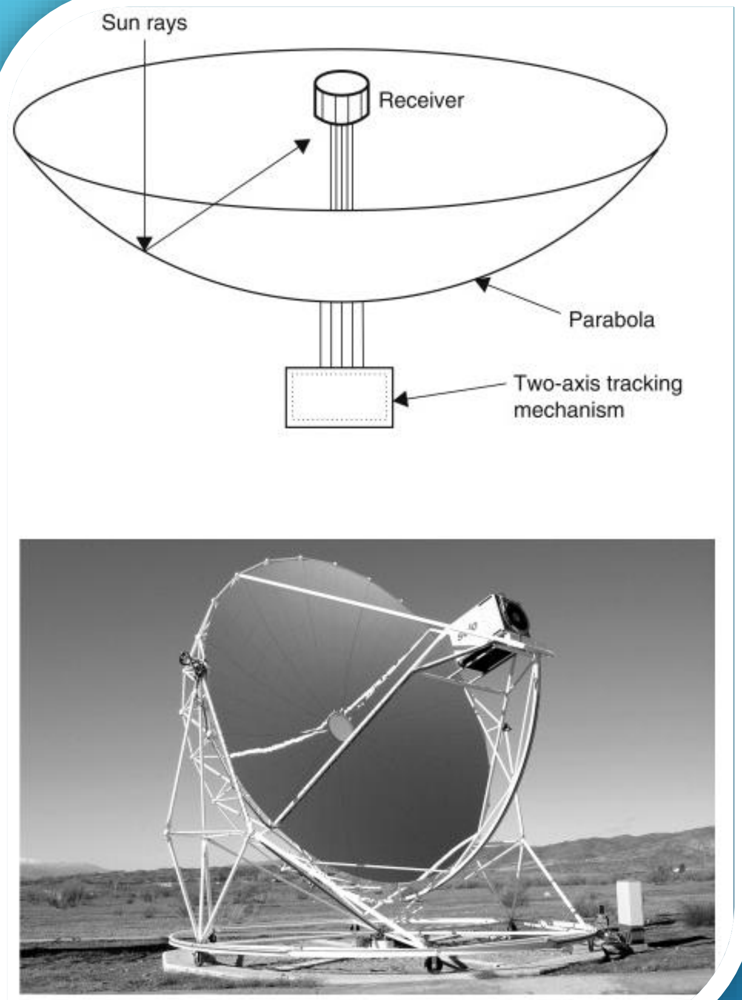
Parabolic Dish Collectors:

These collectors are large parabolic dishes composed of some reflective material that focus the Sun's energy onto a single point. Although very effective at collecting sunlight, they must actively track the Sun across the sky to be of any value. These dishes can work alone or be combined into an array to gather even more energy from the Sun.

They produce either hot water under pressure or high-temperature steam. The temperatures produced are between ~375°C and 2000°C.



These collectors consist of a set of parabolic dish–shaped mirrors



A parabolic dish reflector (PDR) 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 fully track the sun to reflect the beam into the thermal receiver.

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

Note: Concentration ratio is defined as the aperture area divided by the receiver/absorber area of the collector.

Solar Energy Applications And Type Of Collectors Used

Application	System	Collector
Industrial process heat		
Industrial air and water systems	Active	FPC, CPC ETC
Steam generation systems	Active	PTC, LFR
Solar desalination		
Solar stills	Passive	-
Multi-stage flash (MSF)	Active	FPC, CPC ETC
Multiple effect boiling (MEB)	Active	FPC, CPC ETC
Vapour compression (VC)	Active	FPC, CPC ETC
Solar thermal power systems		
Parabolic trough collector systems	Active	PTC
Parabolic tower systems	Active	HFC
Parabolic dish systems	Active	PDR
Solar furnaces	Active	HFC, PDR
Solar chemistry systems	Active	CPC, PTC, LFR

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