



**JECRC Foundation**



JAIPUR ENGINEERING COLLEGE  
AND RESEARCH CENTRE

# JAIPUR ENGINEERING COLLEGE AND RESEARCH CENTRE

Year & Semester - IV Year & VII Semester  
Subject - Power Generation Sources [7EE6-60.2]  
Unit - III (Solar Energy)  
Presented by - Lalit Kumar Sharma, Department of Mech. Engg.

# VISSION AND MISSION OF INSTITUTE

## Vision:

To become a renowned center of outcome based learning, and work towards academic, professional, cultural and social enrichment of the lives of individuals and communities.

## Mission:

M1: Focus on evaluation of learning outcomes and motivate students to inculcate research aptitude by project based learning.

M2: Identify, based on informed perception of Indian, regional and global needs, areas of focus and provide platform to gain knowledge and solutions.

M3: Offer opportunities for interaction between academia and industry.

M4: Develop human potential to its fullest extent so that intellectually capable and imaginatively gifted leaders can emerge in a range of professions.

# VISSION AND MISSION OF DEPARTMENT

## Vision:

The Mechanical Engineering Department strives to be recognized globally for excellent technical knowledge and to produce quality human resource, which can manage the advance technologies and contribute to society through entrepreneurship and leadership.

## Mission:

- M1: To impart highest quality technical knowledge to the learners to make them globally competitive mechanical engineers.
- M2: To provide the learners ethical guidelines along with excellent academic environment for a long productive career.
- M3: To promote industry-institute linkage.

# CONTENTS (TO BE COVERED)

- Basic concepts and Introduction to Solar Energy
  - Perfect Energy Storm
  - Renewable Energy for Rural Development
  - Renewable Energy Solutions
  - Global Solar Resource

# Perfect Energy Storm

The twenty-first century is forming into the perfect energy storm. Rising energy prices, diminishing energy availability and security, and growing environmental concerns are quickly changing the global energy panorama. Energy and water are the keys to modern life and provide the basis necessary for sustained economic development.

Due to a growing world population and increasing modernization, global energy demand is projected to more than double during the first half of the twenty-first century and to more than triple by the end of the century.

Approximately one-third of the world's population lives in rural regions without access to the electric grid, and about half of these same people live without access to safe and clean water.

Unfortunately, traditional fossil fuel energy use has had serious and growing negative environmental impacts, such as CO<sub>2</sub> emissions, global warming, air pollution, deforestation, and overall global environmental degradation.

# Renewable Energy for Rural Development



# Renewable Energy Solutions

There are many examples of energy: mechanical, electrical, thermal, chemical, magnetic, nuclear, biological, tidal, geothermal, and so on. Renewable energy denotes a clean, nontoxic energy source that cannot be exhausted.

The primary renewable energy sources are the Sun, wind, biomass, tides, waves, and the Earth's heat (geothermal). Solar energy is referred to as renewable and/or sustainable energy because it will be available as long as the Sun continues to shine.

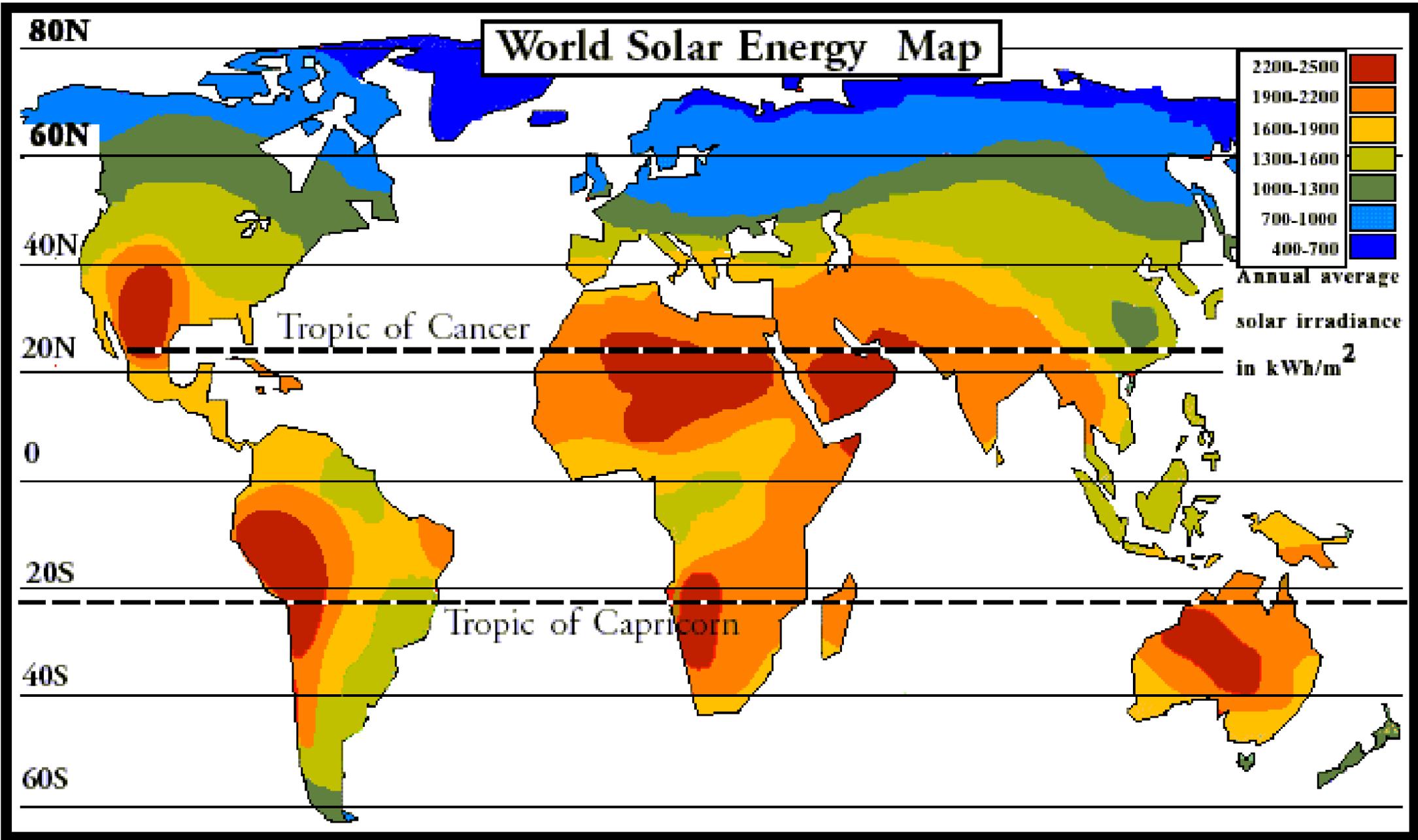
Overall, about 14% of the world's energy comes from biomass—primarily wood and charcoal, but also crop residue and even animal dung for cooking and some heating. This contributes to deforestation and the loss of topsoil in developing countries.

Fossil fuels are stored solar energy from past geological ages (i.e., ancient sunlight).

The advantages of renewable energy are many: sustainability (cannot be depleted), ubiquity (found everywhere across the world in contrast to fossil fuels and minerals), and essentially nonpolluting and carbon free.

The disadvantages of renewable energy are: variability, low density, and generally higher initial cost for conversion hardware.

# Global Solar Resource



# Global Solar Resource

Solar energy is the energy force that sustains life on Earth for all plants, animals, and people. It provides a compelling solution for all societies to meet their needs for clean, abundant sources of energy in the future.

Solar energy is primarily transmitted to the Earth by electromagnetic waves, which can also be represented by particles (photons).

The Earth is essentially a huge solar energy collector receiving large quantities of solar energy that manifest in various forms, such as direct sunlight used for plant photosynthesis, heated air masses causing wind, and evaporation of the oceans resulting as rain, which forms rivers and provides hydropower.

Solar energy can be tapped directly (e.g., PV); indirectly as with wind, biomass, and hydropower; or as fossil biomass fuels such as coal, natural gas, and oil.

As conventional energy prices rise, new and cleaner alternatives will begin to emerge and become economically more competitive.

# Global Solar Resource

Solar radiation is the most important natural energy resource because it drives all environmental processes acting at the surface of the Earth.

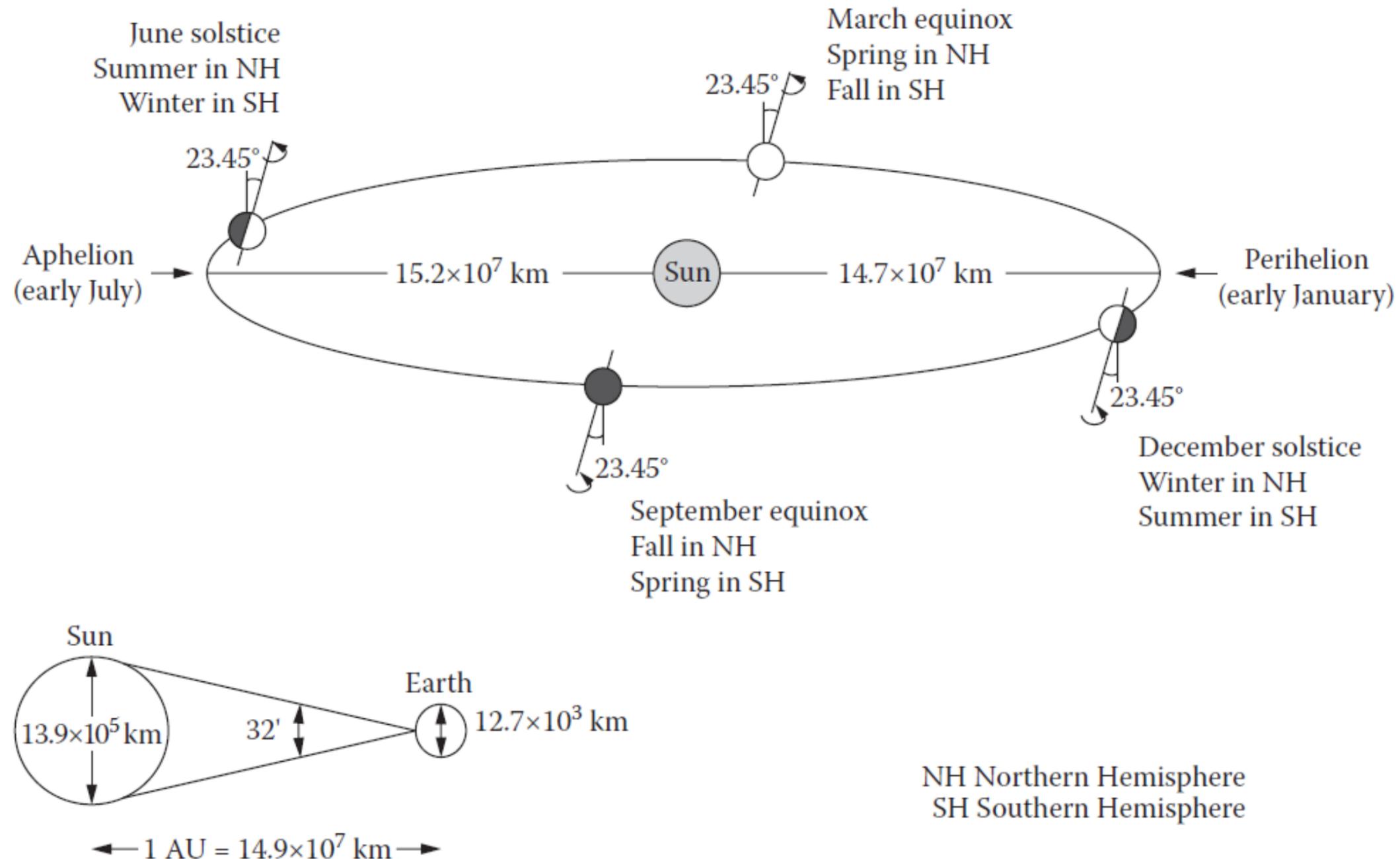
The Sun provides the Earth with an enormous amount of energy.

The energy stored by the oceans helps maintain the temperature of the Earth at an equilibrium level that allows for stability for a broad diversity of life.

Naturally, the Sun has always held the attention of humanity and been the subject of worship by many cultures over the millennia, such as the Egyptians, Incans, Greeks, and Mayans, among many others.

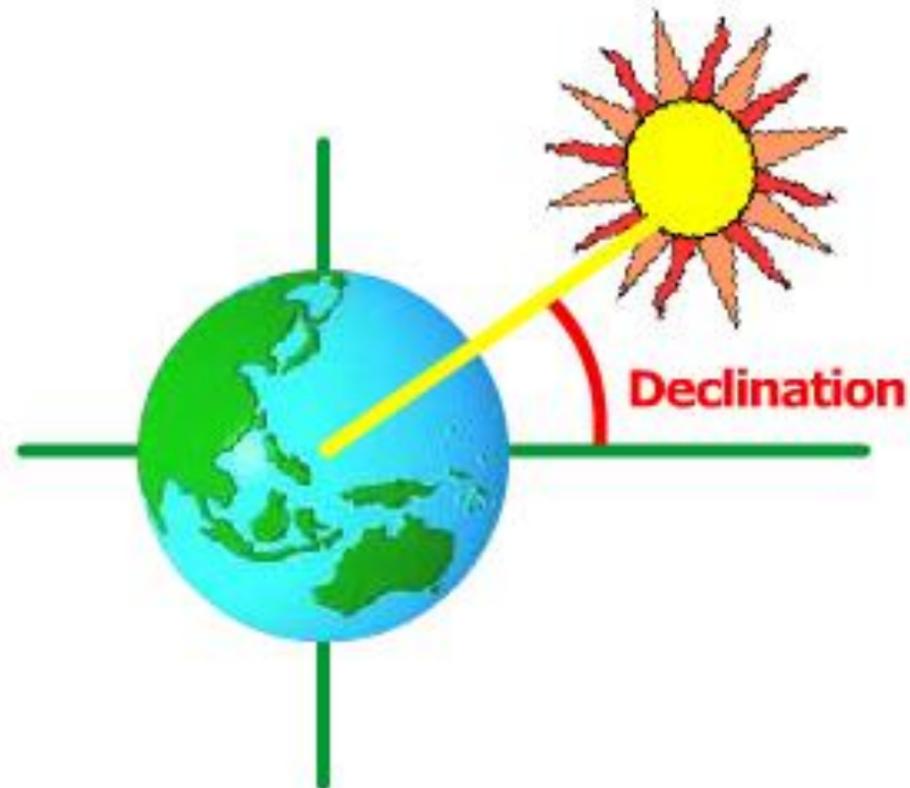
The potential of solar energy to produce heat and electricity to be supplied for our modern economies in a variety of productive activities has been widely demonstrated but not yet widely adopted around the globe due to relatively cheap fossil fuels.

# Sun–Earth Geometric Relationship

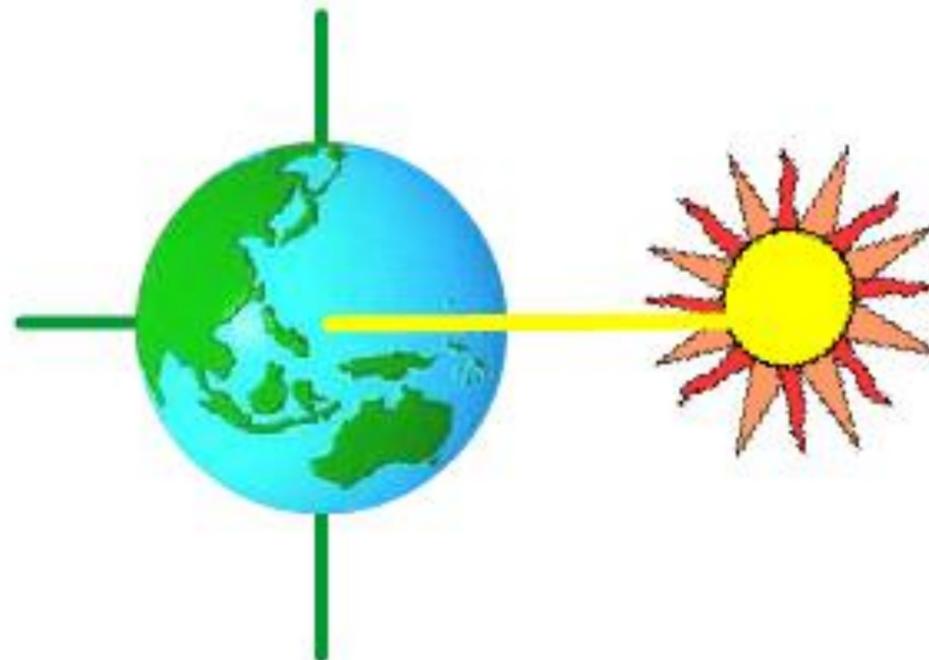


# Sun–Earth Geometric Relationship

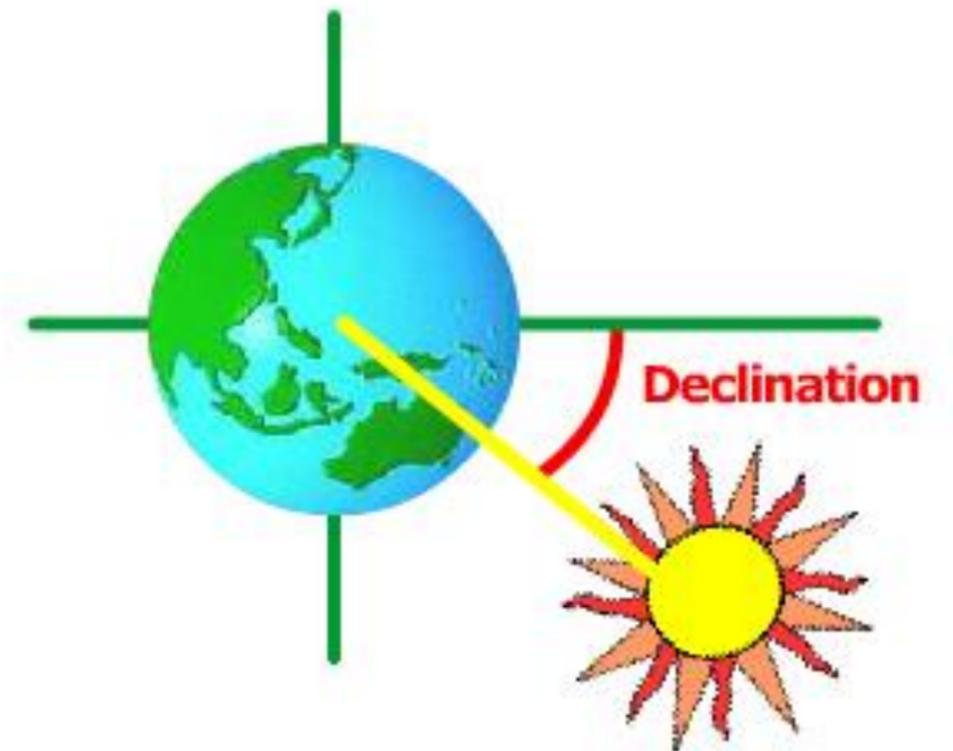
Summer solstice in the northern hemisphere. The declination angle ( $\delta$ ) is at its maximum and is  $23.45^\circ$ .



Spring equinox in the northern hemisphere and autumn equinox in the southern hemisphere. The declination angle ( $\delta$ ) is  $0^\circ$ .



Winter solstice in the northern hemisphere and summer solstice in the southern hemisphere. The declination angle ( $\delta$ ) is  $-23.45^\circ$ .



# Earth–Sun Distance

The Earth has a diameter of  $12.7 \times 10^3$  km, which is approximately 110 times less than the Sun's.

The Earth's orbit's eccentricity is very small, about 0.0167, which causes the elliptical path to be nearly circular.

The elliptical path of the Earth varies from  $14.7 \times 10^7$  km in early January—the closest distance to the Sun, called *perihelion*—to  $15.2 \times 10^7$  km in early July—the farthest distance, called *aphelion*.

The average Earth–Sun distance of  $14.9 \times 10^7$  km is defined as the *astronomical unit (AU)*, which is used for calculating distances within the solar system.

# Earth–Sun Distance

## Declination and Earth–Sun Distance of the Representative Averaged Days for Months

<i>i</i> th day of the month	Month	<i>n</i> for <i>i</i> th day of the month	Julian Day of the year <i>n</i>	Declination $\delta$ in degrees	Earth–Sun distance $E_0$ in AU
17	January	$i$	17	–20.92	1.03
16	February	$31 + i$	47	–12.95	1.02
16	March	$59 + i$	75	–2.42	1.01
15	April	$90 + i$	105	9.41	0.99
15	May	$120 + i$	135	18.79	0.98
11	June	$151 + i$	162	23.09	0.97
17	July	$181 + i$	198	21.18	0.97
16	August	$212 + i$	228	13.45	0.98
15	September	$243 + i$	258	2.22	0.99
15	October	$273 + i$	288	–9.60	1.01
14	November	$304 + i$	318	–18.91	1.02
10	December	$334 + i$	344	–23.05	1.03

# Solar Radiation

Solar radiation from the sun after traveling in space enters the atmosphere at the space–atmosphere interface, where the ionization layer of the atmosphere ends. Afterwards, a certain amount of solar radiation or photons are absorbed by the atmosphere, clouds, and particles in the atmosphere, a certain amount is reflected back into the space, and a certain amount is absorbed by the earth's surface.

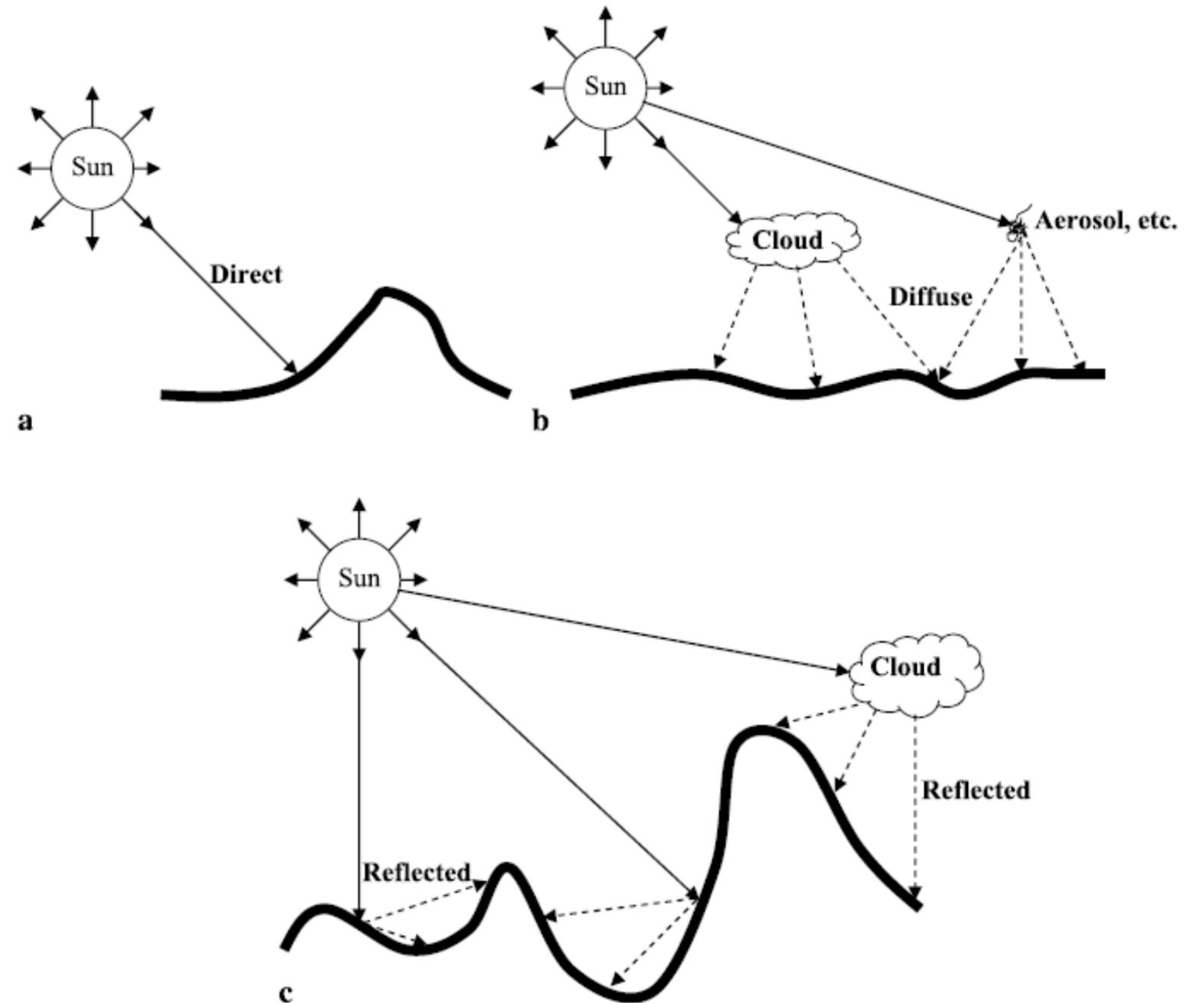
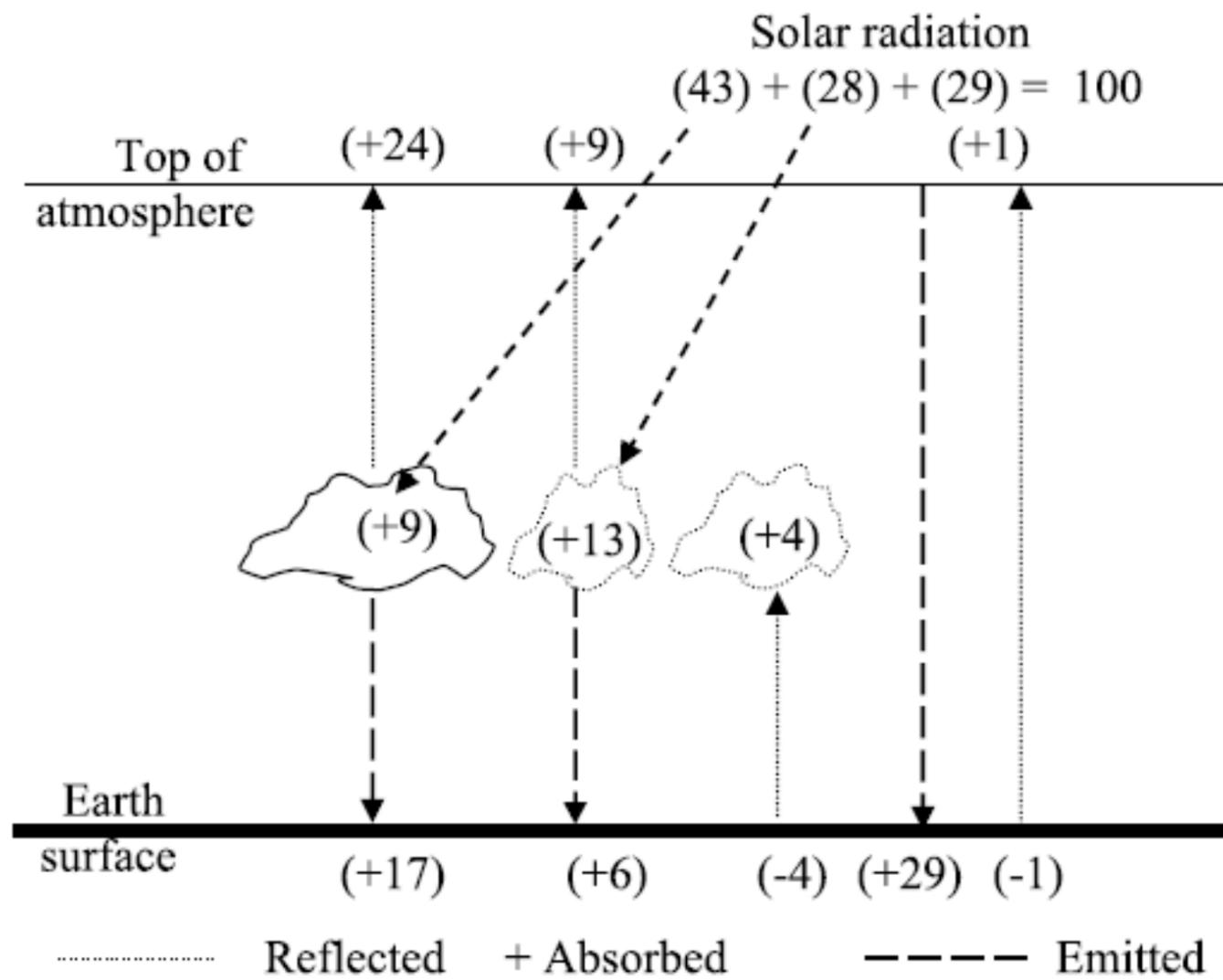
The earth's surface also reflects a certain amount of energy by radiation at different wavelengths due to the earth's surface temperature. About 50% of the total solar radiation remains in the atmosphere and earth's surface. The detailed percentages can be seen in figure.

After the solar radiation enters the earth's atmosphere, it is partially scattered and partially absorbed. The scattered radiation is called *diffuse radiation*.

*Direct solar radiation is that which travels in a straight line from the sun to the earth's surface.*

On the other hand, the radiation arriving on the ground directly in line from the sun is called direct or *beam radiation*.

# Solar Radiation



# Solar Radiation

The output of sun is  $2.8 \times 10^{23}$  KW.

The energy reaching the earth is  $1.5 \times 10^{18}$  KWH/year.

When light travels from outer space to earth, solar energy is lost because of following reasons:

Scattering: The rays collide with particles present in atmosphere

Absorption: Because of water vapor there is absorption

Cloud cover: The light rays are diffused because of clouds.

Reflection: When the light rays hit the mountains present on the earth surface there is reflection.

Climate: Latitude of the location, day (time in the year) also affects the amount of solar energy received by the place.

# Solar Constant

The sun's radiation is subject to many absorbing, diffusing, and reflecting effects within the earth's atmosphere which is about 10 km average thick and, therefore, it is necessary to know the power density, *i. e.*, *watts per meter per minute on the earth's* outer atmosphere and at right angles to the incident radiation.

The density defined in this manner is referred to as the *solar constant*.

*The solar constant and the associated spectrum* immediately outside the earth's atmosphere are determined solely by the nature of the radiating sun and the distance between the earth and the sun.

# Solar Radiation Calculation

Solar irradiance,  $I$  ( $W/m^2$ ), is the rate at which radiant energy is incident on a unit surface.

The incident energy per unit surface is found by integration of irradiance over a specified time, usually an hour or a day.

*Insolation* is a term specifically for solar energy irradiation on surfaces of any orientation.

There are two dimensions to the *energy flux due to the energy of photons and the energy itself*.

Specialists in “solar energy” think in terms of an integrated expression over a certain time interval and have the dimension of energy, J, which is “insolation” as the integrated “irradiance”.

# Insolation

It is a quantity indicating the amount of incident solar power on a unit surface, commonly expressed in units of kW/m<sup>2</sup>.

At the earth's outer atmosphere, the solar insolation on a 1m<sup>2</sup> surface oriented normal to the sun's rays is called SOLAR CONSTANT and its value is 1.37 kW/m<sup>2</sup>.

Due to atmospheric effects, the peak solar insolation incident on a terrestrial surface oriented normal to the sun at noon on a clear day is on the order of 1 kW/m<sup>2</sup>.

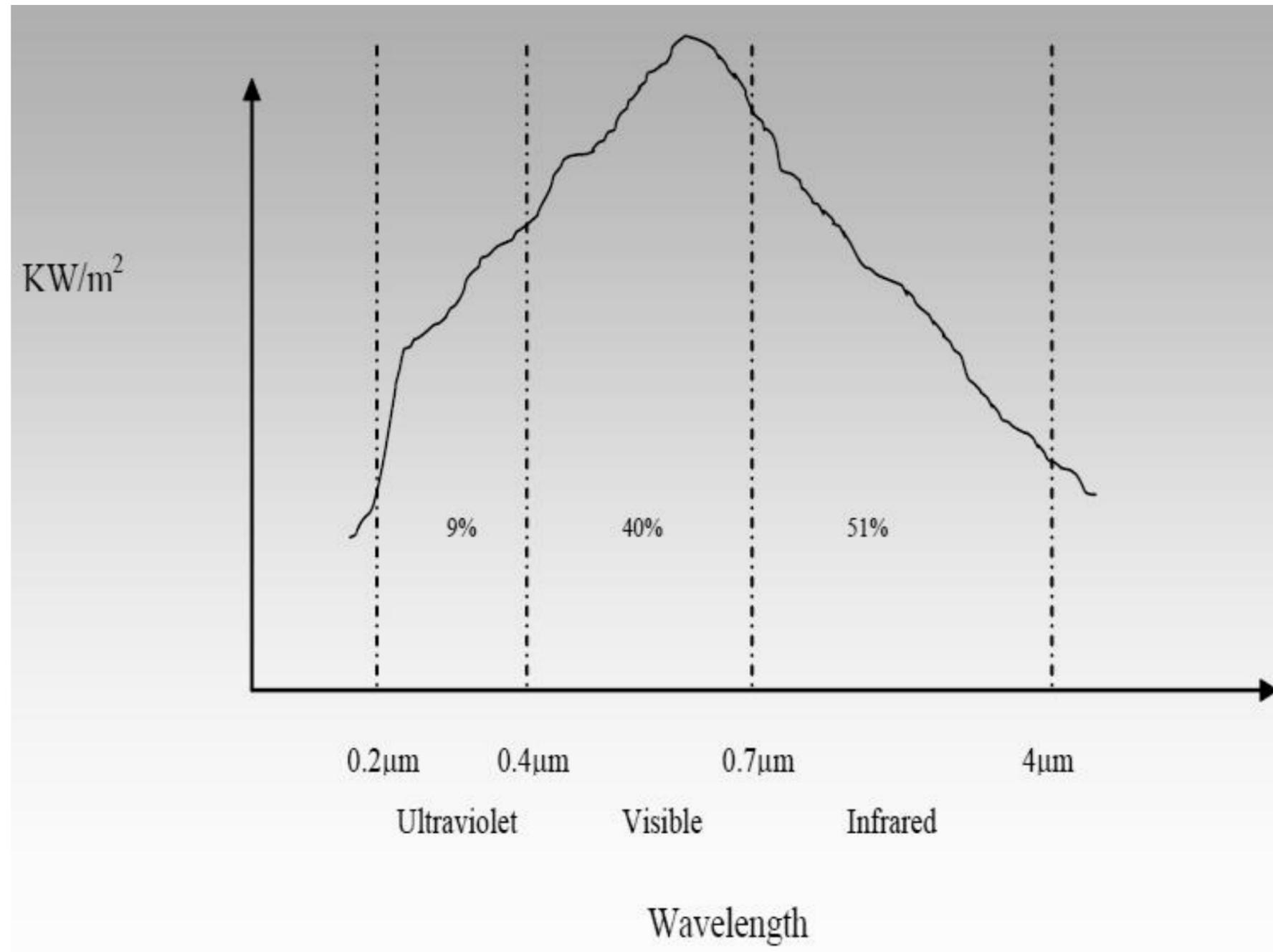
A solar insolation level of 1 kW/m<sup>2</sup> is often called PEAK SUN. Solar insolation is denoted by ' I '.

The graph shown gives the amount of power present in different wavelengths of radiation.

It can be seen from the graph that 50% of solar energy is in the form of thermal energy .

Solar PV captures the energy in visible region. Solar thermal captures energy in infrared region.

# Insolation



# Irradiance

It is an amount of solar energy received on a unit surface expressed in units of kWh/m<sup>2</sup>.

Solar irradiance is essentially the solar insolation (power) integrated with respect to time.

When solar irradiance data is represented on an average daily basis, the value is often called PEAK SUN HOURS (PSH) and can be thought of as the number of equivalent hours/day that solar insolation is at its peak level of 1kW/m<sup>2</sup>.

The worldwide average daily value of solar irradiance on optimally oriented surfaces is approximately 5 kWh/m<sup>2</sup> or 5 PSH. Solar irradiance is denoted by ' H '.

# Radiation Measurement

We know that the atmosphere is made up of ions and other particles including clouds.

When the incident radiation passes through the atmosphere, some radiation penetrates and falls directly on to the panel, some radiation diffuses in atmosphere and travels to the panel and some radiation gets reflected from the surroundings of the panel and reaches the panel, the effect being called albedo effect.

It becomes extremely important to know the amount of energy that has reached the panel through all the paths.

There are several factors on which this energy is dependent. They are as follows:

- Latitude and longitude of the geographical location.
- Climatic conditions such as presence of clouds, water vapor etc.
- Time of the day.
- Time of the year.
- Angle of tilt.
- Collector design.

# Radiation Measurement

Now, let us see how we make use of this information in calculating the solar energy available at the panel. The steps are as follows:

Find the sun position with respect to the location. This is a function of latitude ( $\phi$ ), hour angle ( $\omega$ ) and declination angle ( $\delta$ )

$$\text{SunPosition} = f(\phi, \omega, \delta)$$

Find the available solar energy or irradiance with no atmosphere,  $H_0$ . This is a function of sun position.

$$H_0 = f(\text{SunPosition})$$

Find the solar energy available on horizontal surface with atmospheric effects,  $H_{0A}$ . This is a function of  $H_0$  and clearness index  $K_T$

$$H_{0A} = K_T H_0$$

Find the actual solar energy available at the panel,  $H_t$ . this is a function of  $H_{0A}$  and the tilt factor  $R_D$ .

$$H_t = R_D H_{0A}$$

# Radiation Measurement

All the above mentioned steps can be written as an algorithm so that the moment available data is fed, the actual solar energy available at the panel can be calculated instantly. The algorithm would involve the following equations:

Enter  $\phi$ ,  $\beta$

$N = 1 \rightarrow 365$

$$\delta = 23.45 * \sin [ 2\pi (N - 180) / 365 ]$$

Degrees,  $N = 1$  on jan 1<sup>st</sup>,  $N = 365$  on dec 31<sup>st</sup>

$$\omega_{sr} = \cos^{-1}(-\tan \phi \cdot \tan \delta)$$

$$I_o = I_{sc} \left( 1 + 0.033 \cos \left( \frac{360N}{365} \right) \right) \text{ KW/m}^2$$
$$H_{ot} = \frac{24I_o}{\pi} * (\cos(\phi - \beta) \cos \delta \cos \omega_{sr} + \omega_{sr} \sin(\phi - \beta) \sin \delta)$$

KWh/m<sup>2</sup>/day on a titled surface with no atmospheric effects

# Radiation Measurement

$$H_o = \frac{24I_o}{\pi} * (\cos(\phi)\cos\delta\cos\omega_{sr} + \omega_{sr}\sin(\phi)\sin\delta)$$

KWh / m<sup>2</sup> / day

$$K_T = (\text{curve} \cdot \text{fitting} \cdot \text{data})$$

Clearance index

$$R_D = K_R(1 - K_D) + K_D \left( \frac{1 + \cos\beta}{2} \right) + \rho \left( \frac{1 - \cos\beta}{2} \right)$$

Tilt Factor

where  $\rho$  is the reflection factor which ranges between 0.2 to 0.7.

$$H_t = K_T * R_D * H_o \text{ kWh/m}^2/\text{day}$$

This algorithm can be translated into any of the programming languages like C, C++ or MATLAB. Entering the known parameters, it becomes convenient to find out the solar energy available at any geographical location.

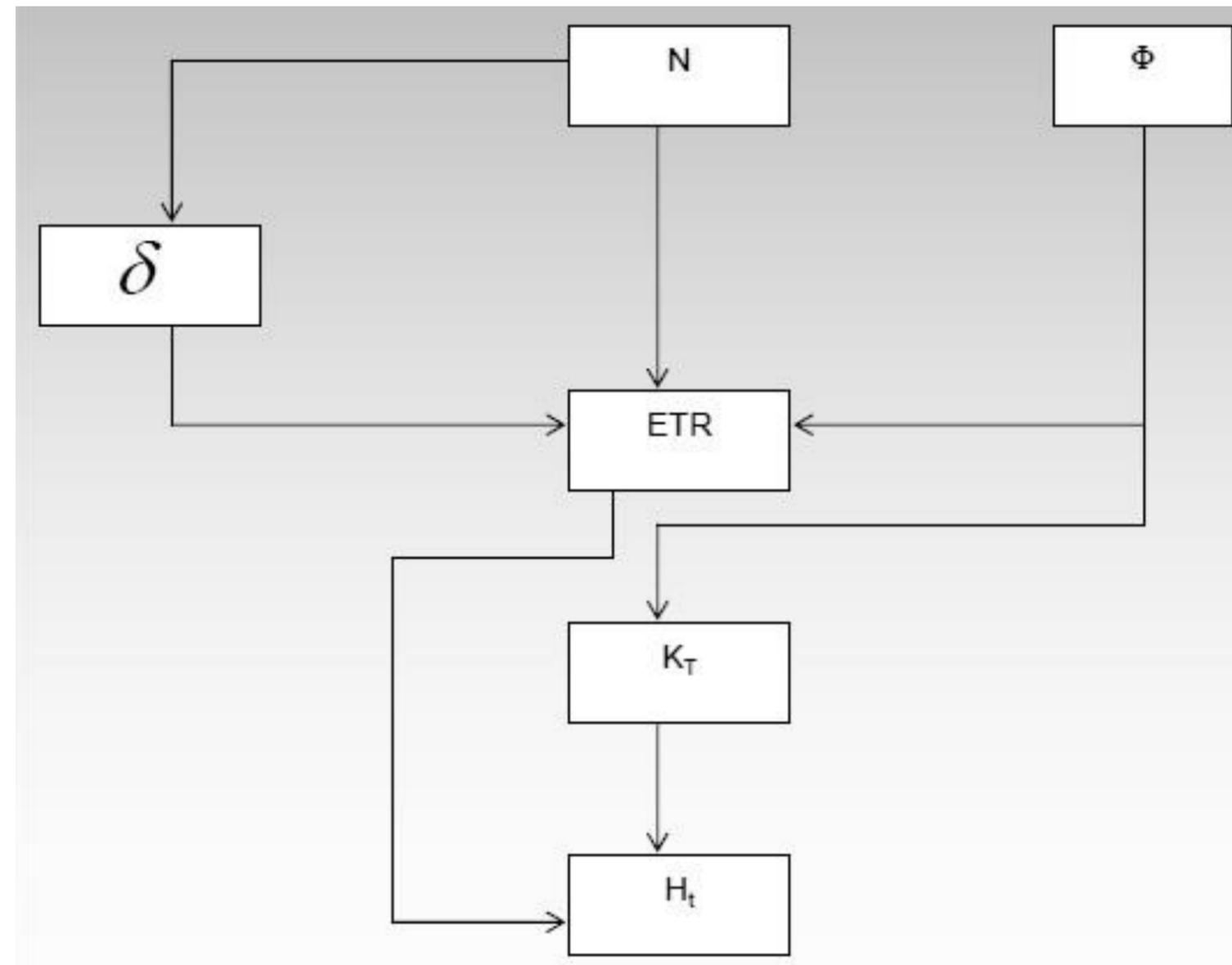
# Insolation at any location

We need to develop an algorithm, which calculates insolation ( $H_t$ ) in kWh/m<sup>2</sup> at any place, once we input the following parameters:

- Day of the year ( $N$ )
- Latitude of the location ( $\varphi$ )
- Tilt angle ( $\beta$ )
- Angle of declination ( $\delta$ )
- Clearness Index ( $K_T$ )
- Reflection co-efficient (varies from 0.2 to 0.7)

# Insolation at any location

Following flow chart gives an idea for developing the algorithm:



# Insolation at any location

We can see that once  $\delta$ ,  $N$  and  $\phi$  are input, Extra Terrestrial Radiation (ETR) can be determined.  $\Delta$ , the declination angle of the sun is assumed to be the same every year and  $\delta = 0$  in March 21<sup>st</sup>. Following Fourier series can be used to calculate  $\delta$ :

$$\delta = A_0 + A_1 \cos t + A_2 \cos 2t + A_3 \cos 3t + B_1 \sin t + B_2 \sin 2t + B_3 \sin 3t$$

where  $t = \frac{360}{365}(N - 80)$  degrees      $A_0, A_1 \dots B_3 = ?$

ETR can be calculated from the following expression:

$$ETR = 24 \cdot k \cdot I_{SC} (\cos \phi \cos \delta \sin \omega_{sr} + \omega_{sr} \sin \phi \sin \delta) \text{ kWh/m}^2$$

where  $k = \left[ 1 + 0.033 \cos \left( \frac{360 N}{365} \right) \right]$

$I_{SC}$  = mean solar constant = 1.37 kW/m<sup>2</sup>

$\phi$  = latitude in degrees/radians

$\delta$  = declination angle in degrees/radians

$\omega_{sr}$  = hour angle at sunrise in degrees/radians =  $\cos^{-1}(-\tan \phi \tan \delta)$

The next parameter that needs to be known is  $K_T$ , the clearness index.

It is one of the most important and difficult factors to be determined since it depends on atmospheric conditions such as absorption, pressure, cloud-cover at the place etc., which are not constant at a given place.

# Insolation at any location

However, a model for  $K_T$  could be developed based on the irradiance level (H) measured at different places and using the relationship  $K_T = H/ETR$ .

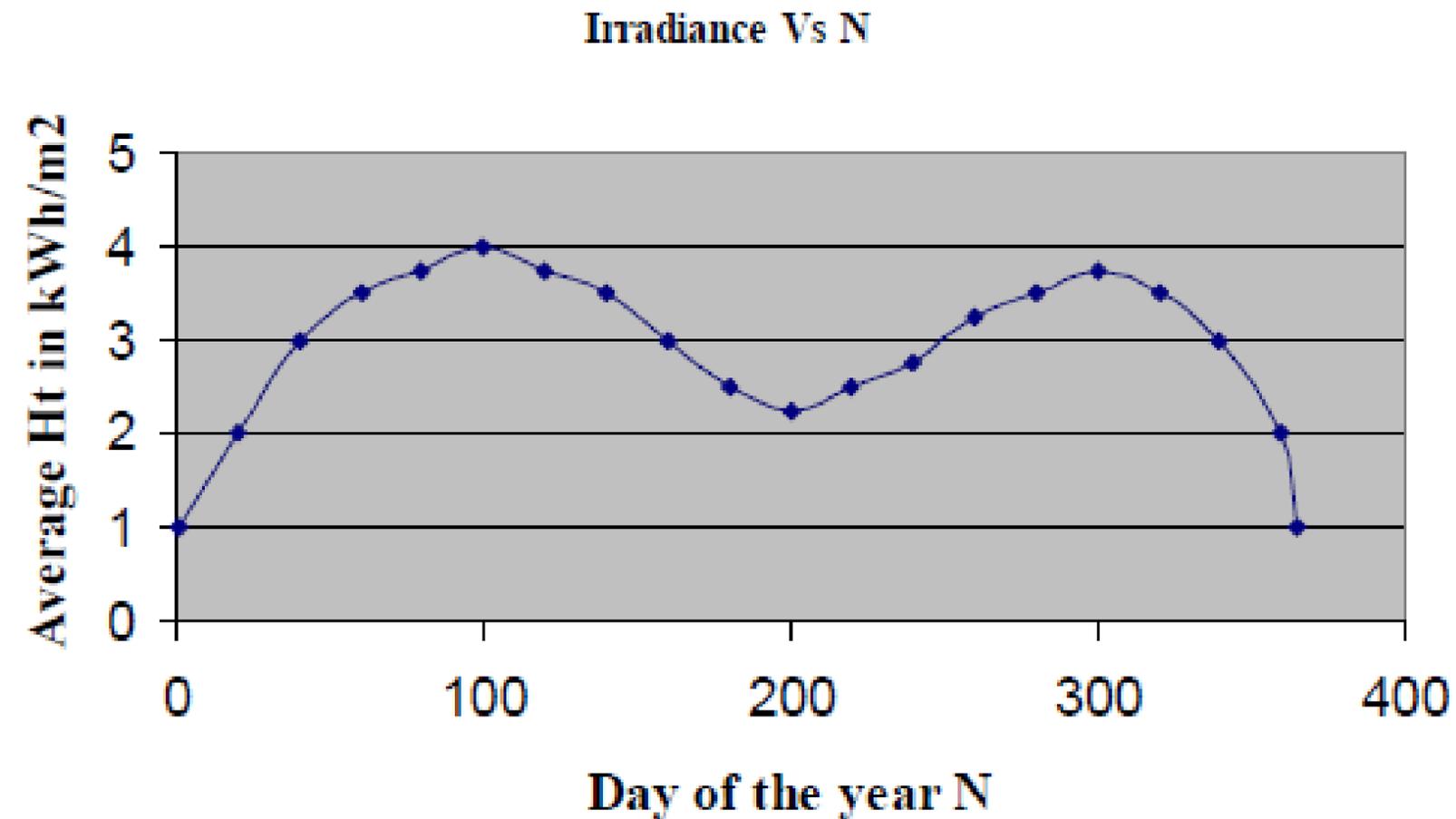
$K_T$  was initially modeled using linear polynomial regression and multiple regression techniques.

Since the results obtained with these models were not very accurate, a model was developed using Fourier series techniques of curve fitting since  $K_T$  is a periodic function of period one year.

We have seen earlier that the irradiance in  $\text{kWh/m}^2$  can be calculated for any location by inputting latitude of the location, declination angle, day number of the year for a given tilt angle using algorithm.

# Insolation at any location

The plot of irradiance as a function of the year is shown in the following figure



We can see that the level varies with the day of the year. It may reach a peak at some day of the year and reach a bottom on some other day of the year. The peaks and valleys are the direct result of the amount of irradiance reaching the earth. This is a graph that gives us the irradiance level over one year period.

# Heat Transfer Concepts

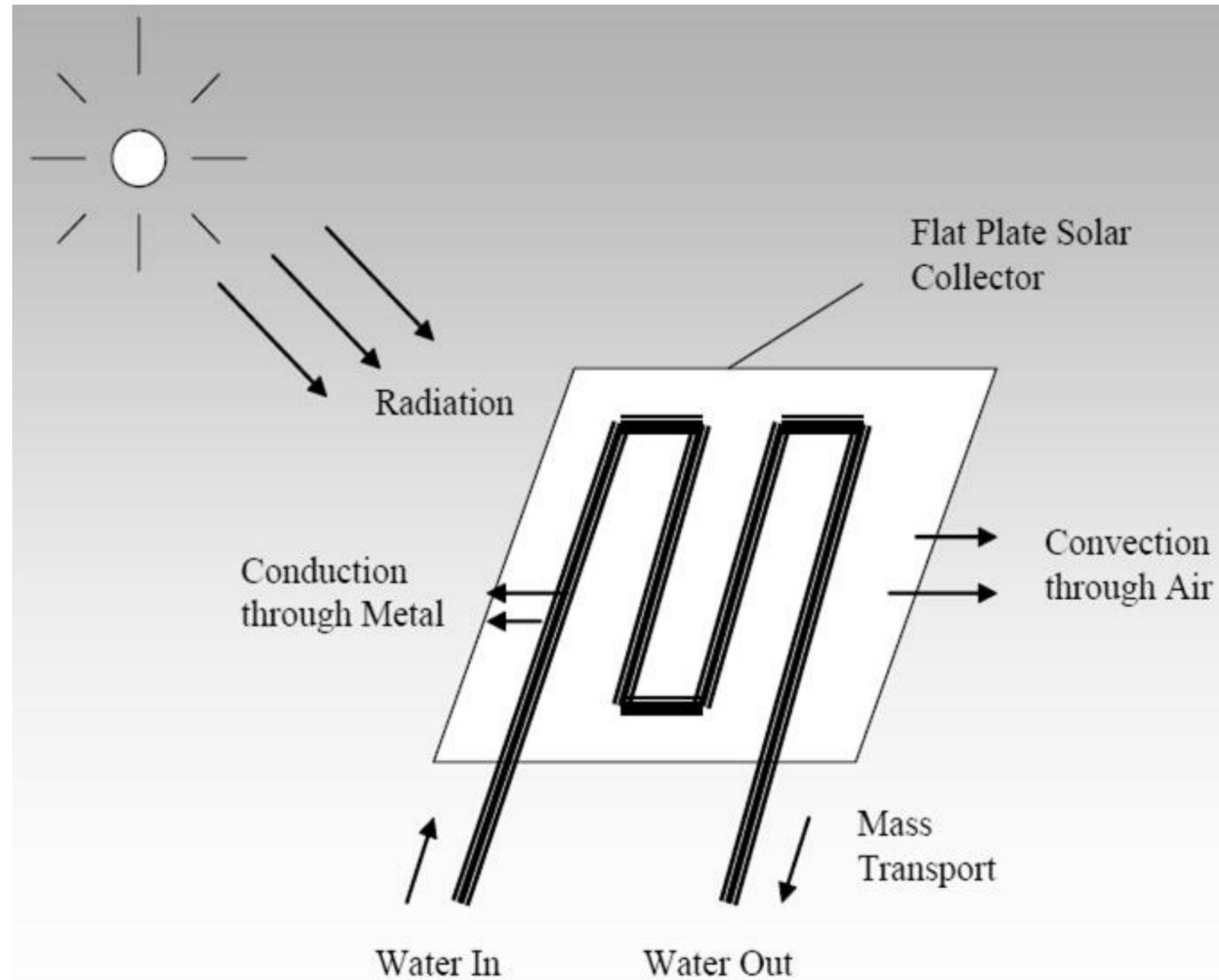
The important terminology one needs to know to understand the heat transfer mechanism is the following:

- Radiation
- Conduction
- Convection
- Mass transport

To understand the meaning of each of these terms, let us take an example.

Let us consider a typical flat plate solar collector that is used in solar water heater system and shown in the following figure.

# Heat Transfer Concepts



# Heat Transfer Concepts

In the above figure it can be seen that the heat is transferred from Sun to the flat plate solar collector by radiation.

Radiation is the process of heat transfer from source to the target directly.

The plate gets heated and transfers part of the heat to the copper tubes carrying water by conduction .

Conduction is a process of heat transfer between two metals or solids. Part of the heat from the plate gets lost due to convection of heat.

# Heat Transfer Concepts

Convection is a process of heat transfer from solids to the surroundings via fluids. The heat transferred to the copper tube gets eventually transferred to the water flowing through the tubes by mass transport.

Mass transport is a process of heat transfer similar to convection with little difference.

Convection is an uncontrolled process where as mass transport is a controlled process where the discharge rate of the fluid can be controlled.

It is important to note at this point that the above-mentioned heat transfer processes are all dependent on the properties of materials.

# Applications

## Solar thermal power plants

The two main types of solar thermal power plants are

- Concentrating Solar Power (CSP) plants.
- Solar Chimneys

# Applications

## Concentrating Solar Power (CSP) plants

- ❑ Solar thermal power plants generally use reflectors to concentrate sunlight into a heat absorber.
- ❑ Such power plants are known as Concentrating Solar Power (CSP) plants.
- ❑ Concentrating solar power plants produce electric power by converting the sun's energy into high-temperature heat using various mirror configurations.
- ❑ The heat is then channeled through a conventional generator.
- ❑ The plants consist of two parts, one that collects solar energy and converts it to heat, and another that converts heat energy to electricity.

# Applications

## Concentrating Solar Power (CSP) plants

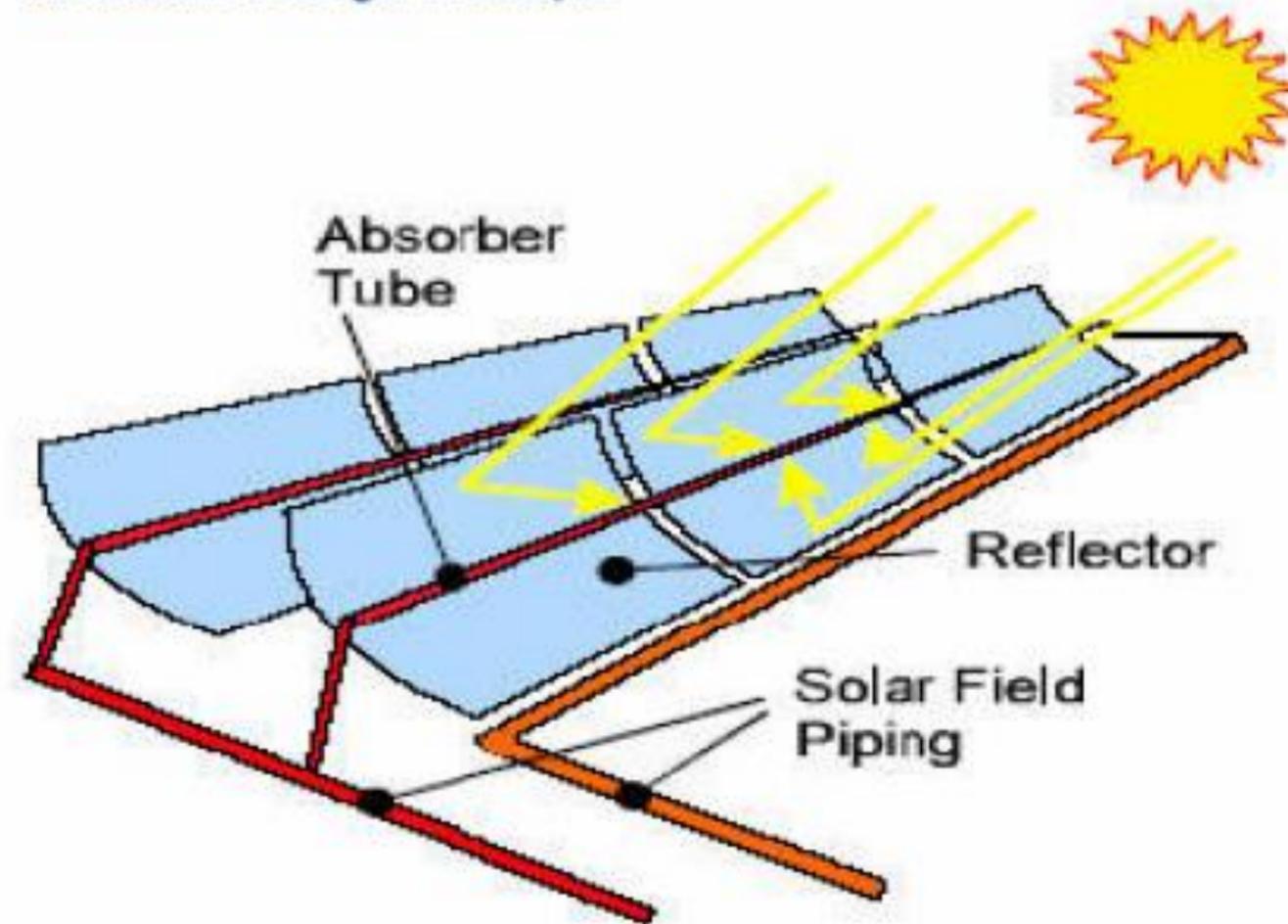
- ❑ Concentrating solar power systems can be sized for village power (10 kilowatts) or grid-connected applications (up to 100 megawatts).
- ❑ Some systems use thermal storage during cloudy periods or at night.
- ❑ There are four CSP technologies being promoted internationally.
- ❑ For each of these, there exists various design variations or different configurations.
- ❑ The amount of power generated by a concentrating solar power plant depends on the amount of direct sunlight.
- ❑ Like concentrating photovoltaic concentrators, these technologies use only direct-beam sunlight, rather than diffuse solar radiation.

# Types of CSP plants

## Parabolic Trough Systems

- The sun's energy is concentrated by parabolically curved, trough-shaped reflectors onto a receiver pipe running along the inside of the curved surface.

Parabolic Trough Principle



# Types of CSP plants

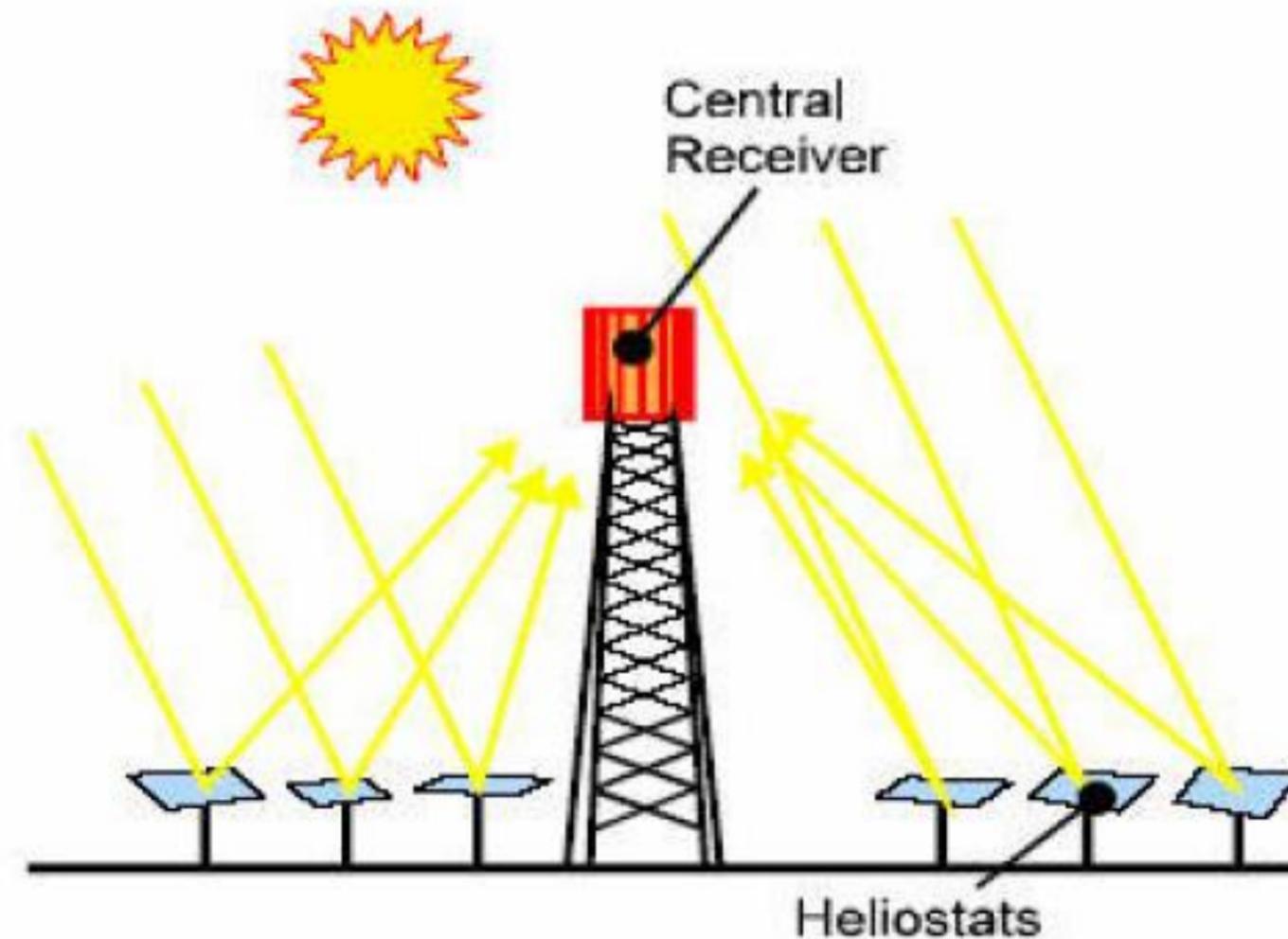
## Parabolic Trough Systems

- This energy heats oil flowing through the pipe and the heat energy is then used to generate electricity in a conventional steam generator.
- A collector field comprises many troughs in parallel rows aligned on a north-south axis.
- This configuration enables the single-axis troughs to track the sun from east to west during the day to ensure that the sun is continuously focused on the receiver pipes.
- Individual trough systems currently can generate about 80 megawatts of electricity .
- Another option under investigation is the approximation of the parabolic troughs by segmented mirrors according to the principle of Fresnel.

# Types of CSP plants

## Power Tower Systems

- A power tower converts sunshine into clean electricity for the electricity grids.



# Types of CSP plants

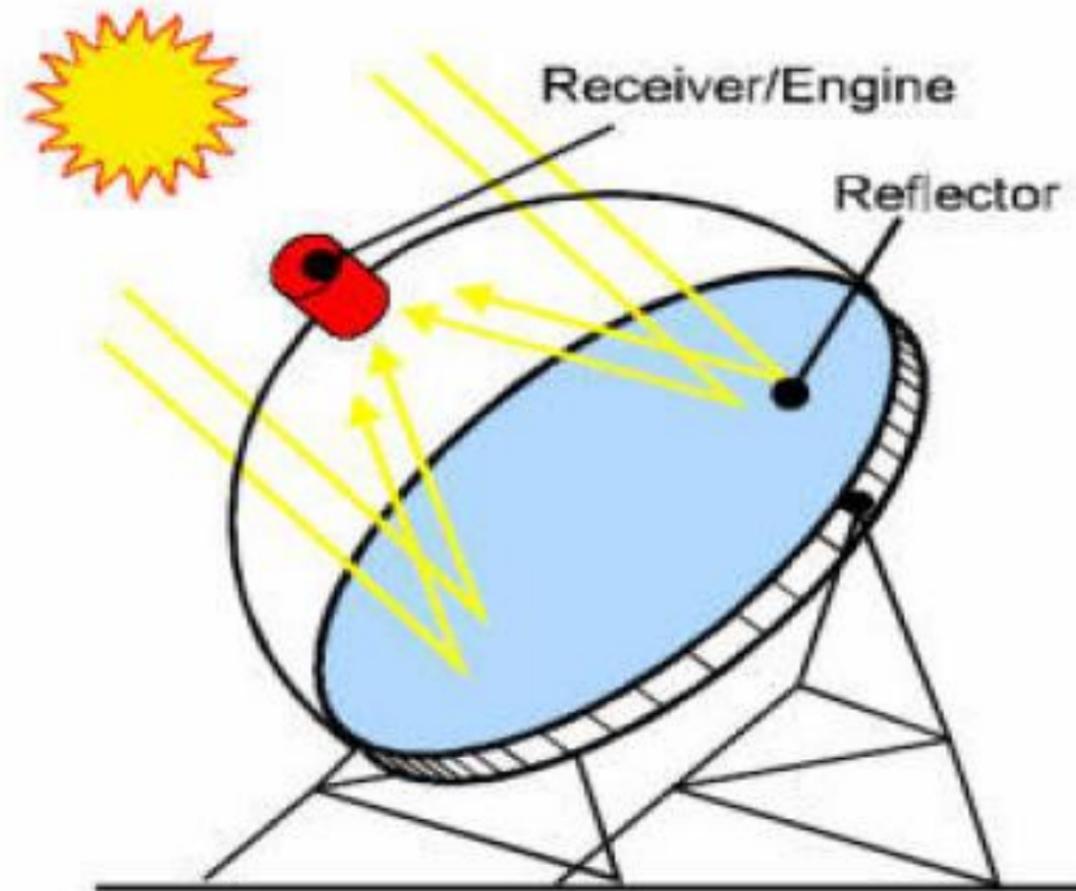
## Power Tower Systems

- The technology utilizes many large, sun-tracking mirrors (heliostats) to focus sunlight on a receiver at the top of a tower.
- A heat transfer fluid heated in the receiver is used to generate steam, which, in turn, is used in a conventional turbine-generator to produce electricity.
- Early power towers (such as the Solar One plant) utilized steam as the heat transfer fluid; current designs (including Solar Two, shown in fig) utilize molten nitrate salt because of its superior heat transfer and energy storage capabilities.
- Individual commercial plants will be sized to produce anywhere from 50 to 200 MW of electricity.

# Types of CSP plants

## Parabolic Dish Systems

- Parabolic dish systems consist of a parabolic-shaped point focus concentrator in the form of a dish that reflects solar radiation on to a receiver mounted at the focal point.



# Types of CSP plants

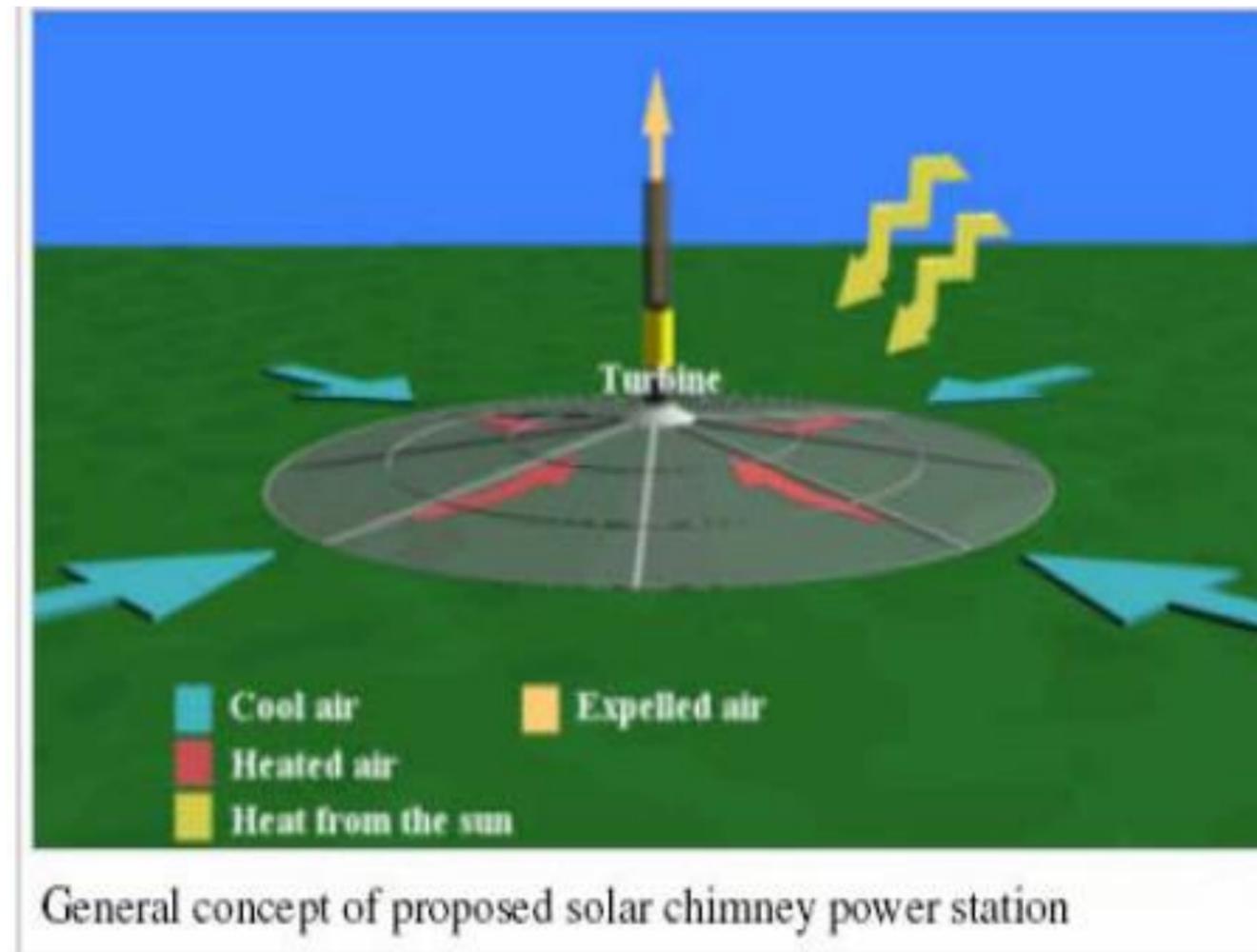
## Parabolic Dish Systems

- These concentrators are mounted on a structure with a two-axis tracking system to follow the sun.
- The collected heat is typically utilized directly by a heat engine mounted on the receiver moving with the dish structure.
- Stirling and Brayton cycle engines are currently favored for power conversion.
- Projects of modular systems have been realized with total capacities up to 5 MW.
- The modules have max sizes of 50 kW and have achieved peak efficiencies up to 30% net.

# Types of CSP plants

## Solar chimney

- A solar chimney is a solar thermal power plant where air passes under a very large agricultural glass house (between 2 and 30 kilometers in diameter).



# Types of CSP plants

## Solar chimney

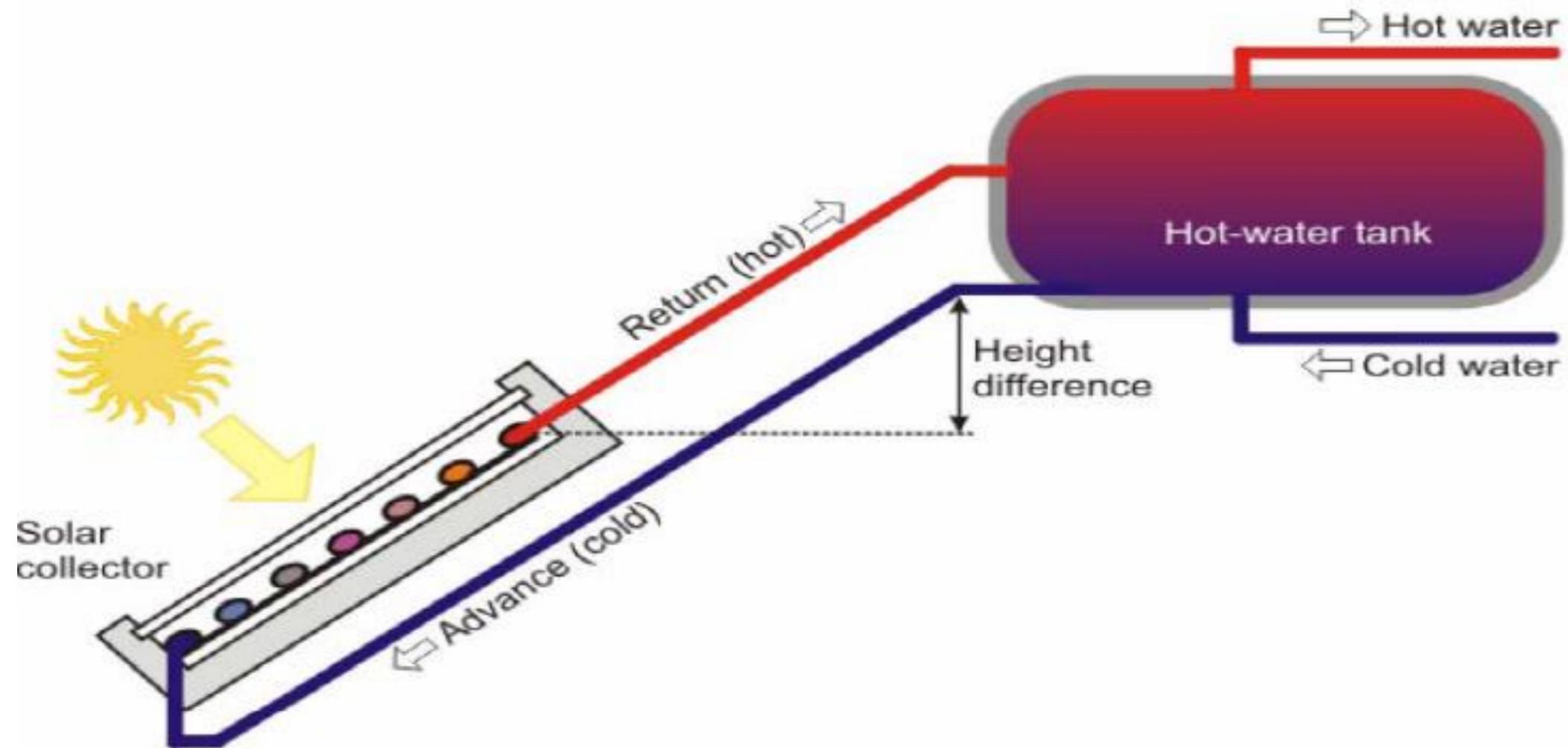
- The air is heated by the sun and channeled upwards towards a convection tower.
- It then rises naturally and is used to drive turbines, which generate electricity.
  
- A **solar chimney** is an apparatus for harnessing solar energy by convection of heated air.
- In its simplest form, it simply consists of a black-painted chimney.
- During the daytime, solar energy heats the chimney and thereby heats the air within it, resulting in an updraft of air within the chimney.
  
- The suction this creates at the chimney base can also be used to ventilate, and thereby cool, the building below .
- In most parts of the world, it is easier to harness wind power for such ventilation, but on hot windless days such a chimney can provide ventilation where there would otherwise be none.
- This principle has been proposed for electric power generation, using a large greenhouse at the base rather than relying on heating of the chimney itself.
- The main problem with this approach is the relatively small difference in temperature between the highest and lowest temperatures in the system.

# Water heating

- ❑ Water heating is required in most countries of the world for both domestic and commercial use.
- ❑ The simplest solar water heater is a piece of black plastic pipe, filled with water, and laid in the sun for the water to heat up.
- ❑ Simple solar water heaters usually comprise a series of pipes, which are painted black, sitting inside an insulated box fronted with a glass panel. This is known as a solar collector.
- ❑ The fluid to be heated passes through the collector and into a tank for storage.
- ❑ The fluid can be cycled through the tank several times to raise the heat of the fluid to the required temperature.

# Water heating

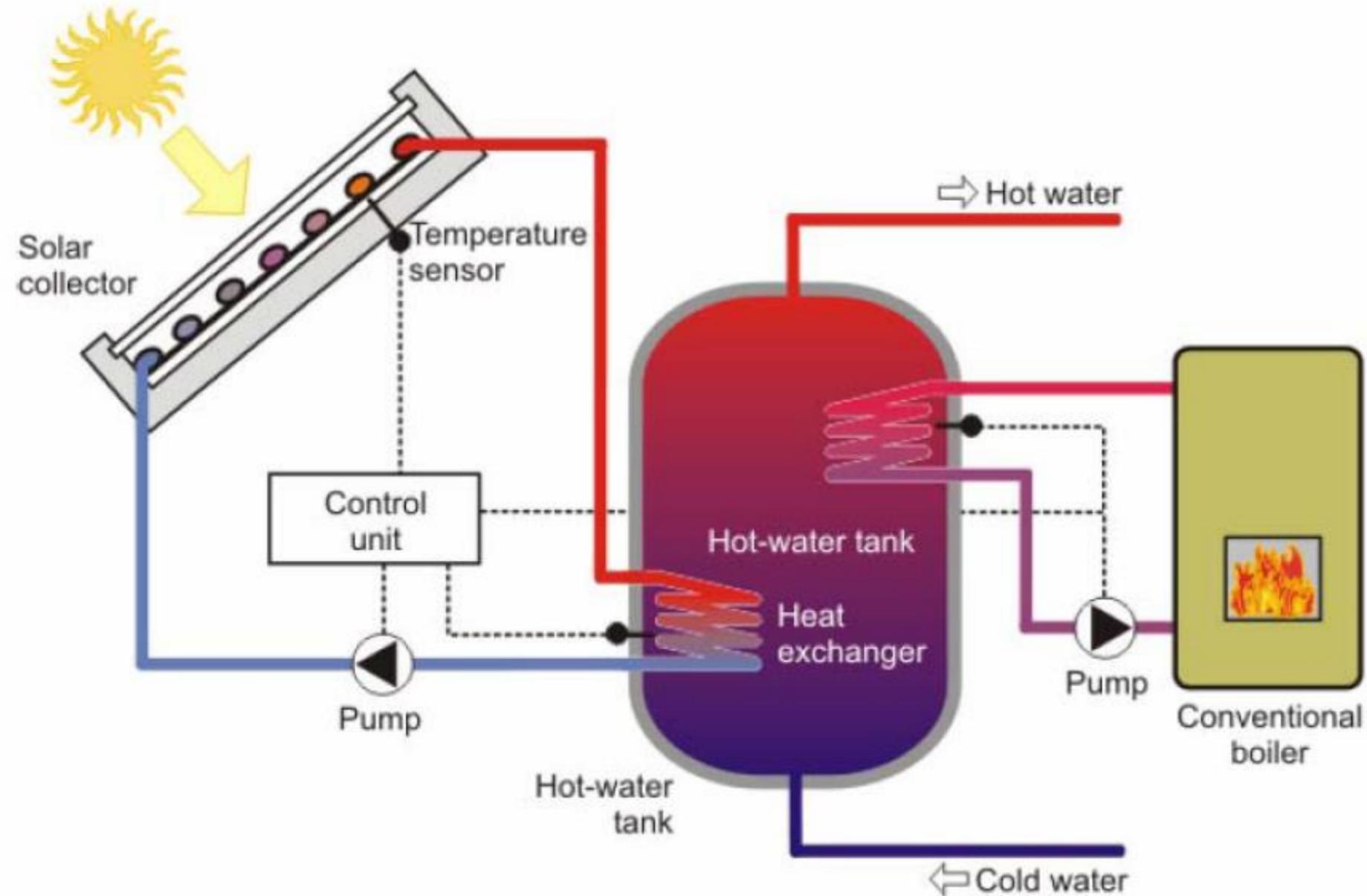
The *thermosyphon system* (see fig) makes use of the natural tendency of hot water to rise above cold water.



# Water heating

- The tank in such a system is always placed above the top of the collector and as water is heated in the collector it rises and is replaced by cold water from the bottom of the tank.
- This cycle will continue until the temperature of the water in the tank is equal to that of the panel.
- A one-way valve is usually fitted in the system to prevent the reverse occurring at night when the temperature drops.
- As hot water is drawn off for use, fresh cold water is fed into the system from the mains.
- As most solar collectors are fitted on the roofs of houses, this system is not always convenient, as it is difficult to site the tank above the collector, in which case the system will need a pump to circulate the water.
- ***Pumped solar water heaters use a pumping device to drive the water through the collector.***
- The advantage of this system is that the storage tank can be sited below the collector.
- The disadvantage of course is that electricity is required to drive the pump.
- Often the fluid circulating in the collector will be treated with an anti-corrosive and /or anti-freeze chemical.
- In this case a heat exchanger is required to transfer the heat to the consumers hot water supply.

# Water heating

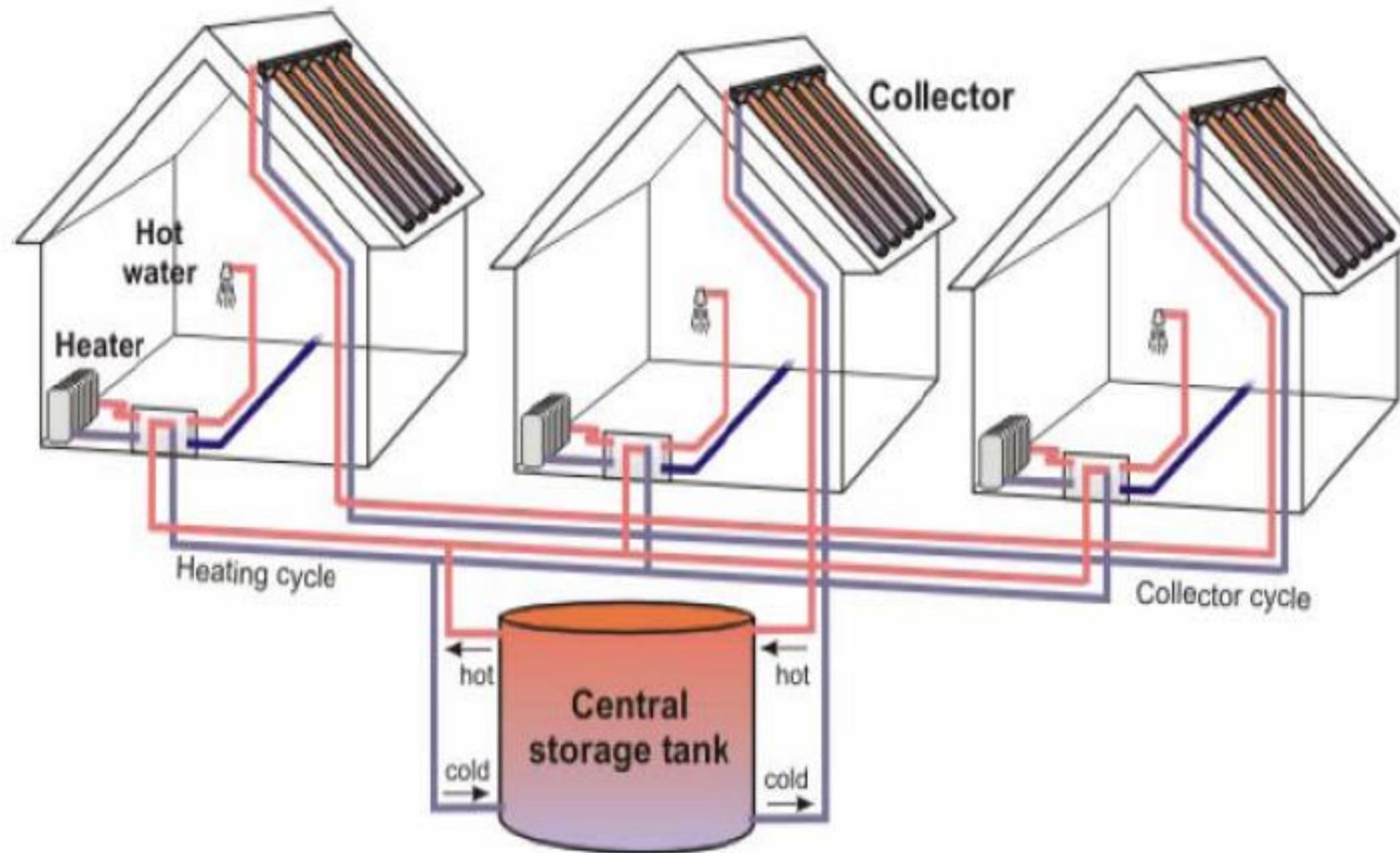


**FIGURE.** A double-cycle system with forced circulation with a conventional boiler for back-up heating

# Solar District Heating

- If an entire housing estate should be fitted with solar systems, one solution is a solar district heating system (see Figure).
- The collectors are either distributed on the houses, or replaced by a large, central solar collector.
- The collectors then heat up a big central storage tank, from which much of the heat is distributed back to the houses.
- The surface-to-volume ratio of a central storage tank is much better than that for distributed storage systems, so the storage losses are much lower, and even permit seasonal heat storage.
- Solar district heating is also an option if room heating is to be covered by solar energy.

# Solar District Heating



# Solar District Heating

## Cost Benefits of solar water heating system

- The most cost-effective way to install a solar geyser is to integrate the collector assembly, cold-water supply and piping with the design of a new house under construction.
- Solar geysers can easily be installed in group houses and apartments, especially during construction, if adequate provisions are made for piping, collector assembly and cold-water supply. Proper load matching is required to ensure that the capacity of the system installed is optimized to meet the daily hot water needs of the end-user.
- Current prices of domestic SWHs are around Rest. 20,000 for a 100 litres per day system.

# Solar Dryer

- ❑ Controlled drying is required for various crops and products, such as grain, coffee, tobacco, fruits vegetables and fish.
- ❑ Their quality can be enhanced if the drying is properly carried out.
- ❑ Solar thermal technology can be used to assist with the drying of such products.
- ❑ Solar drying is in practice since the time imp-memorable for preservation of food and agriculture crops.
- ❑ This was done particularly by open sun drying under open the sky.
- ❑ In open air Solar drying the heat is supplied by direct absorption of solar radiation by material being dried.

# Solar Dryer

## **Solar dryer is a very useful device for**

- Agriculture crop drying
- Food processing industries for dehydration of fruits, potatoes, onions and other vegetables,
- Dairy industries for production of milk powder, casein etc.
- Seasoning of wood and timber.
- Textile industries for drying of textile materials.

## **This process has several disadvantages**

Disadvantages of mechanical and artificial drying:

- Spoilage of product due to adverse climatic condition like rain, wind etc
- Loss of material due to birds and animals
- Deterioration of the material by decomposition, insects and fungus growth
- Highly energy intensive and expensive.
- Solar dryer make use of solar radiation, ambient temperature, relative humidity.
- Heated air is passed naturally or mechanically circulated to remove moisture from material placed in side the enclosure.

# Solar Dryer

## Working of solar dryer

- The main principle of operation is to raise the heat of the product, which is usually held within a compartment or box, while at the same time passing air through the compartment to remove moisture.
- The flow of air is often promoted using the 'stack' effect which takes advantage of the fact that hot air rises and can therefore be drawn upwards through a chimney, while drawing in cooler air from below. Alternatively a fan can be used.
- The size and shape of the compartment varies depending on the product and the scale of the drying system.
- Large systems can use large barns while smaller systems may have a few trays in a small wooden housing.
- Solar crop drying technologies can help reduce environmental degradation caused by the use of fuel wood or fossil fuels for crop drying and can also help to reduce the costs associated with these fuels and hence the cost of the product.

The principal types of solar dryers are enumerated below.

- Solar cabinet dryer.
- Solar green house dryers.
- Indirect solar dryer.

# Solar Distillation/De-salination

## Solar Stills

- ❑ Solar still is a device to desalinate impure water like brackish or saline water.
- ❑ It a simple device to get potable/fresh distilled water from impure water, using solar energy as fuel, for its various applications in domestic, industrial and academic sectors .
- ❑ A solar still consist of shallow triangular basin made up of Fiber Reinforced Plastic (FRP).
- ❑ Bottom of the basin is painted black so as to absorb solar heat effectively.
- ❑ Top of the basin is covered with transparent glass tilt fitted so that maximum solar radiation can be transmitted in to the still.

# Solar Distillation/De-salination

## Solar Stills

- Edges of the glass are sealed with the basin using tar tape so that the entire basin becomes airtight.
- Entire assembly is placed on a structure made of MS angle. Out let is connected with a storage container.

Solar Stills have got major advantages over other conventional Distillation / water purification /de-mineralization systems as follows:

- Produces pure water
- No prime movers required
- No conventional energy required
- No skilled operator required
- Local manufacturing/repairing
- Low investment
- Can purify highly saline water (even sea water)

# Solar Distillation/De-salination

## Working of Solar Stills

- Working of solar still is based on simple scientific principle of Evaporation and condensation.
- Brackish or saline water is filled instill basin, which is painted black at the bottom.
- Solar radiation received at the surface is absorbed effectively by the blacken surface and heat is transferred to the water in the basin.
- Temperature of the water increases that increases rate of evaporation.
- Water vapor formed by evaporation rises upward and condenses on the inner surface of the cover glass, which is relatively cold.
- Condensed water vapor trickles down into troughs from there it is collected in to the storage container.

# Solar box cooker

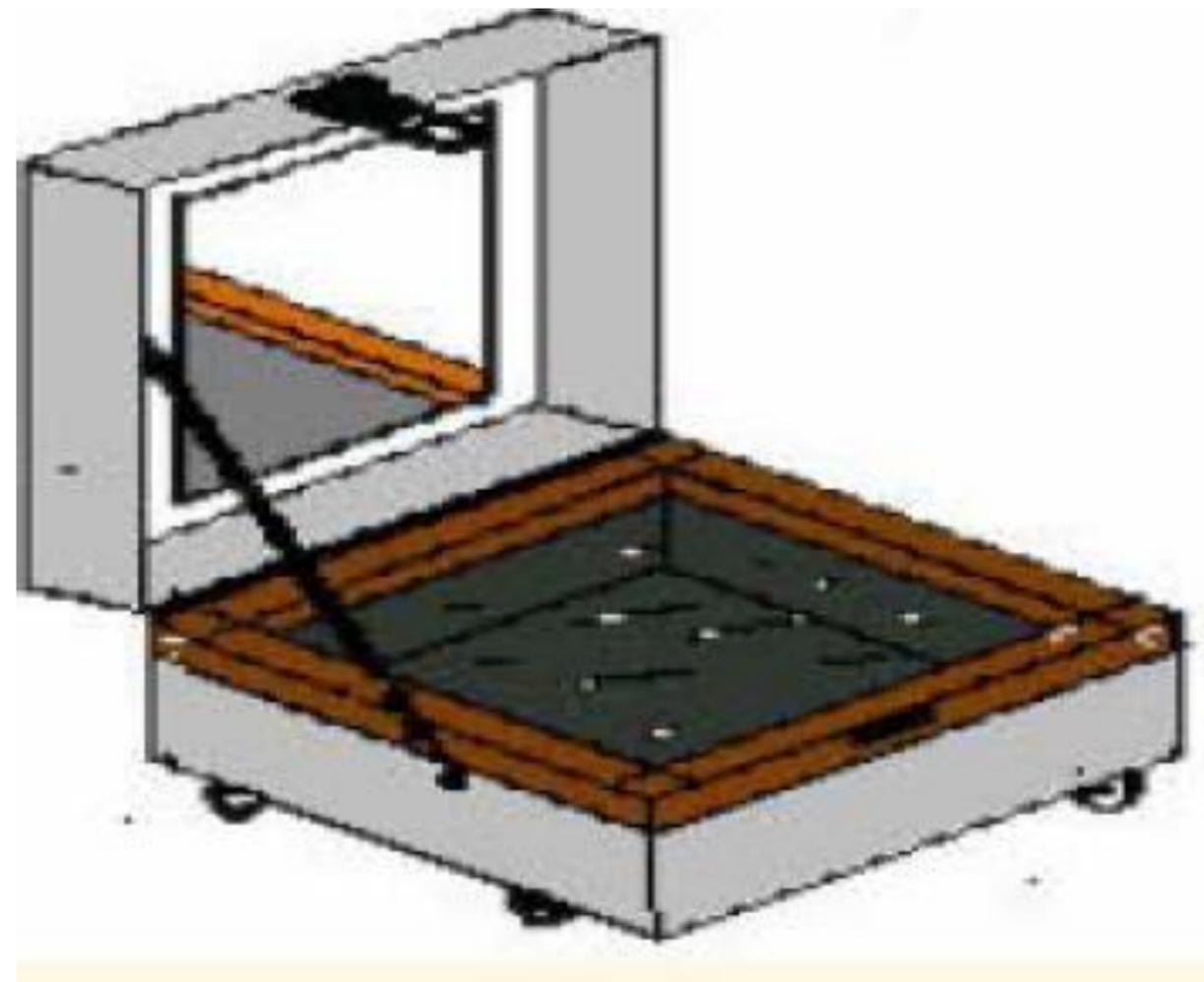
- A **solar box cooker** is an insulated transparent-topped box with a reflective lid.
- It is designed to capture solar power and keep its interior warm.
- The major parts of a solar cooker are enumerated below.
- Important Parts of Solar Cooker:
  1. **Outer Box:** The outer box of a solar cooker is generally made of G.I. or aluminum sheet or fiber reinforced plastic.
  2. **Inner Cooking Box (Tray):** This is made from aluminum sheet. The inner cooking box is slightly smaller than the outer box. It is coated with black paint so as to easily absorb solar radiation and transfer the heat to the cooking pots.

# Solar box cooker

- 3. Double Glass Lid:** A double glass lid covers the inner box or tray. This cover is slightly larger than the inner box. The two glass sheets are fixed in an aluminum frame with a spacing of 2 centimeters between the two glasses.
  - This space contains air which insulates and prevents heat escaping from inside. A rubber strip is affixed on the edges of the frame to prevent any heat leakage.
- 4. Thermal Insulator:** The space between the outer box and inner tray including bottom of the tray is packed with insulating material such as glass wool pads to reduce heat losses from the cooker.
  - This insulating material should be free from volatile materials.
- 5. Mirror:** Mirror is used in a solar cooker to increase the radiation input on the absorbing space and is fixed on the inner side of the main cover of the box. Sunlight falling on the mirror gets reflected from it and enters into the tray through the double glass lid.
  - This radiation is in addition to the radiation entering the box directly and helps to quicken the cooking process by raising the inside temperature of the cooker.
- 6. Containers:** The cooking containers (with cover) are generally made of aluminum or stainless steel.
  - These pots are also painted black on the outer surface so that they also absorb solar radiation directly.

# Solar box cooker

- *Horace de Assure, a Swiss naturalist, invented solar cookers as early as 1767.*



- We can cook a large number of items, like pulses, rice, cheer etc.

# Solar box cooker

- The time taken to cook will depend upon the type of the food, time of the day and solar intensity.
  
- The time taken to cook some of the dishes in a solar cooker is as follows:
  - Rice (45 minutes to one hour),
  - Vegetables (about one to two hours),
  - Black gram and Raja (about two hours),
  - Cake (one hour).

# SOLAR THERMAL ELECTRIC POWER SYSTEMS



**Distributed collectors**

# SOLAR THERMAL ELECTRIC POWER SYSTEMS



**Power tower**

# SOLAR THERMAL ELECTRIC POWER SYSTEMS

Collectors with concentrators can achieve temperatures large enough ( $\geq 700^\circ\text{C}$ ) to operate a heat engine at reasonable efficiency, which can be used to generate electricity. However, there are considerable engineering difficulties in building a single tracking bowl with a diameter exceeding 30 m. A single bowl of that size could receive at most a peak thermal power of  $\pi(15\text{m}^2) (1\text{kWm}^{-2}) = 700\text{kW}$ , with subsequent electricity generation of perhaps 200 kW. This would be useful for a small local electricity network, but not for established utility networks.

# SOLAR THERMAL ELECTRIC POWER SYSTEMS

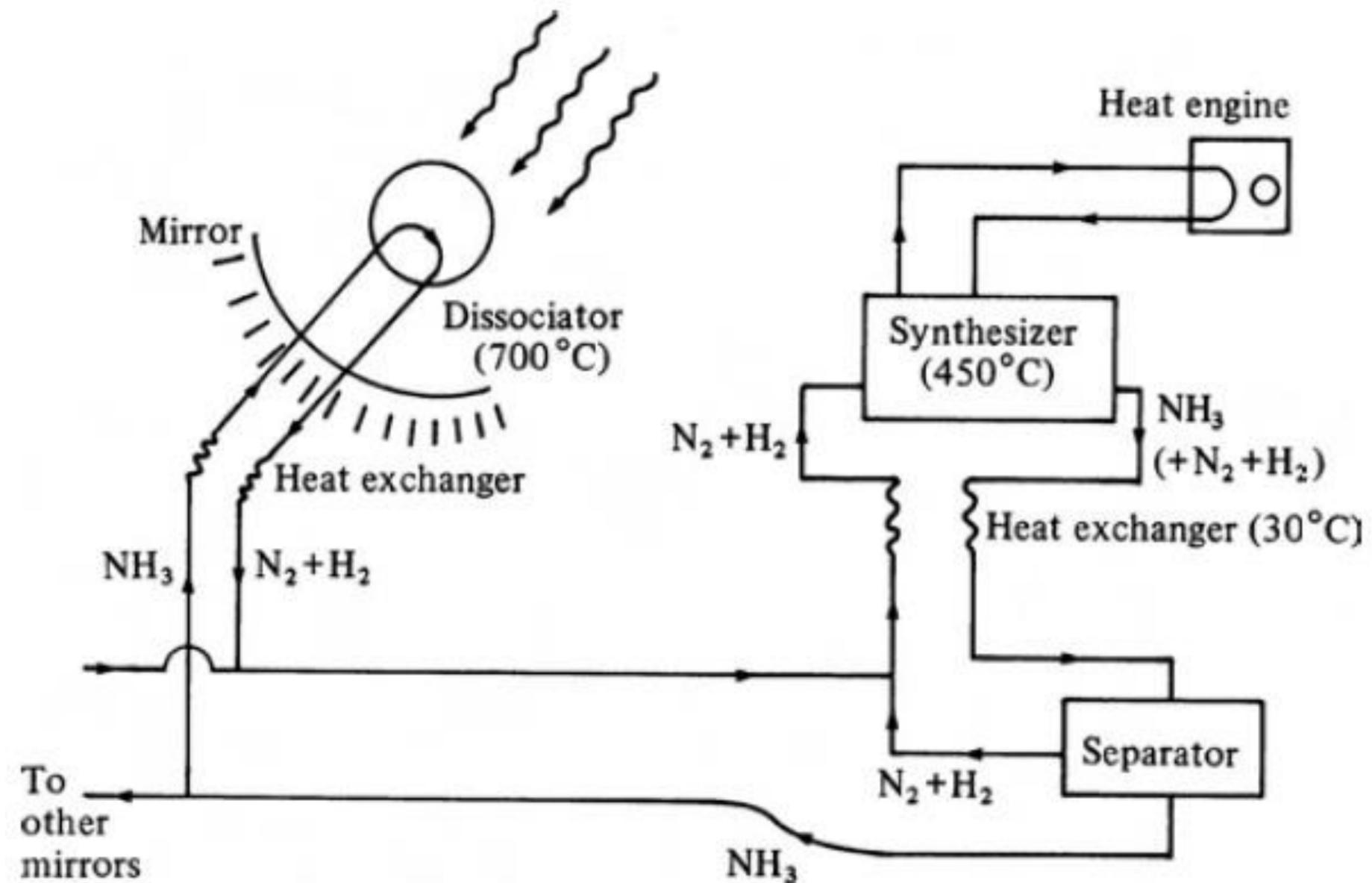


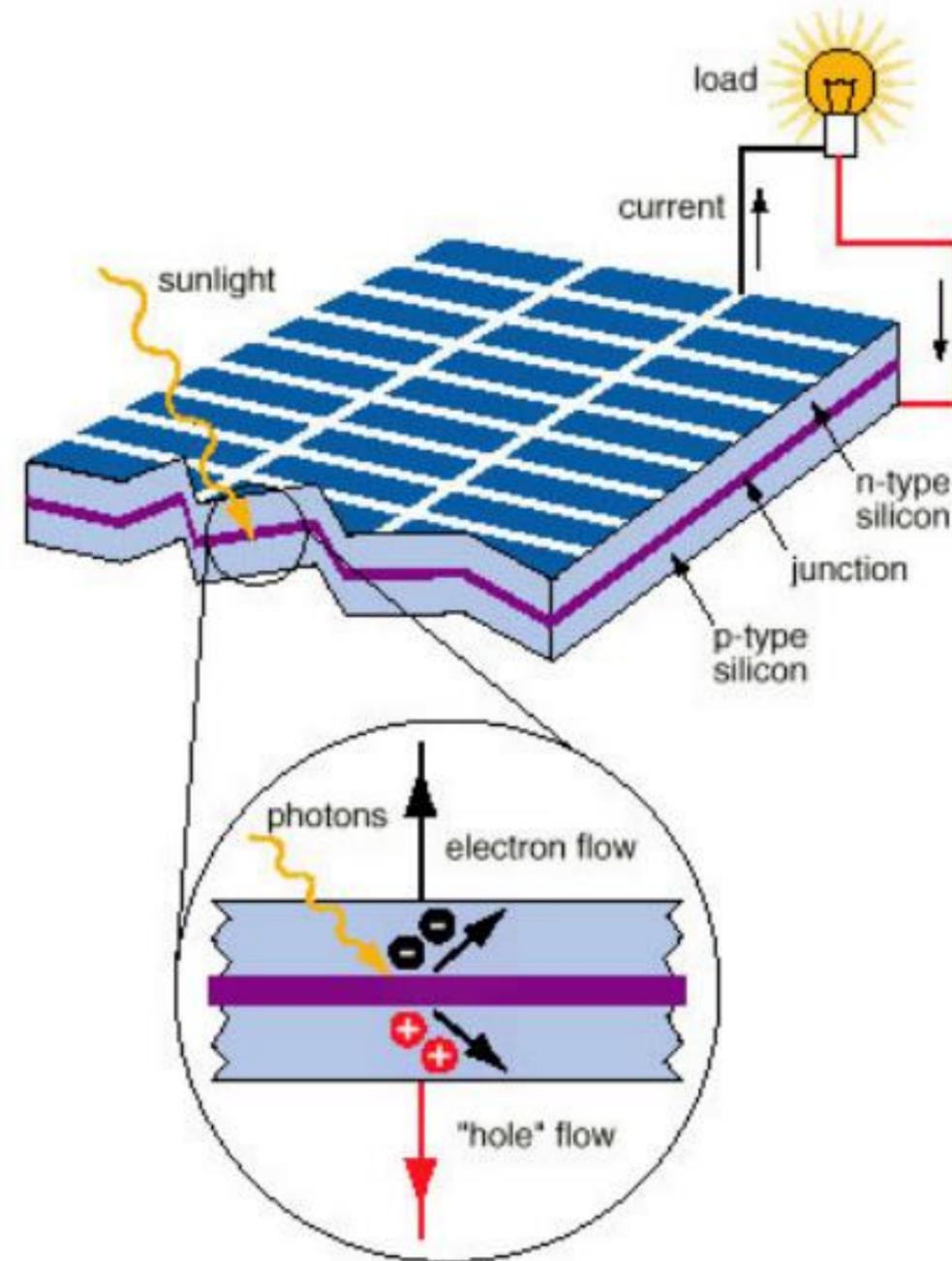
Fig. Dissociation and synthesis of ammonia as a storage medium for solar energy.

# Solar photo voltaic conversion

- Photovoltaic (PV) systems convert light energy directly into electricity.
- Commonly known as “solar cells.”
- The simplest systems power the small calculators we use every day. More complicated systems will provide a large portion of the electricity in the near future.
- PV represents one of the most promising means of maintaining our energy intensive standard of living while not contributing to global warming and pollution.

**Sunlight is composed of photons, or bundles of radiant energy. When photons strike a PV cell, they may be reflected or absorbed (transmitted through the cell). Only the absorbed photons generate electricity. When the photons are absorbed, the energy of the photons is transferred to electrons in the atoms of the solar cell.**

# Solar photo voltaic conversion



# PV applications

- 1. Stand-alone application**
- 2. Balance of system components**
- 3. Grid-connected systems**

# PV applications



*Figure 7.27* A typical stand-alone application of photovoltaics: powering a railway signal box in a remote area of Australia. [Photo by courtesy of BP Solar.]

# PV applications



# PV applications



*Figure 7.29* Examples of grid-connected photovoltaic installations. (a) An office building at the University of Melbourne, Australia, with an envelope of PVs on its north-facing wall. This building also includes many other features of 'sustainable design' – see Section 6.3. [Photo courtesy of University of Melbourne.] (b) A service station in Australia with PVs on its roof. Note the juxtaposition of renewable and non-renewable energy sources. [Photo by courtesy of BP Solar.]

# Hybrid systems

- In hybrid energy systems more than a single source of energy supplies the electricity.
- Wind and Solar compliment one another

# Hybrid systems



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you!*