Unit I

Long Answer Questions

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Assignment 1

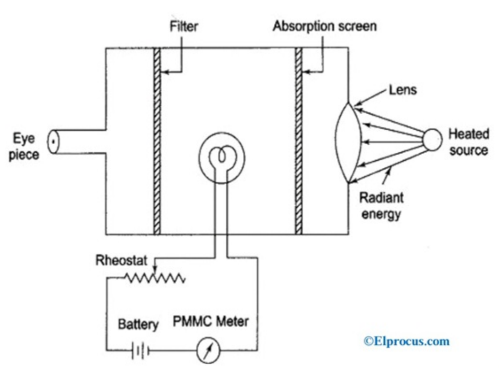
1. **Describe the principle and working of pyrometer and pyrheliometer for direct radiation measurement?.Mention the difference between these two meters.**

Pyrometer

Principle and working: It measures the object's temperature by sensing the heat/radiation emitted from the object. It records the temperature depending upon the intensity of radiation emitted. Pyrometer also is known as an Infrared thermometer or Radiation thermometer or non-contact thermometer.

Types of Pyrometer

2 types. They are 1) Optical Pyrometers 2) Infrared / Radiation pyrometers. **1)Optical Pyrometer:** The temperature of the hot objects measured will depend on the visible light they emit. Optical pyrometers are capable of providing a visual comparison between a calibrated light source and the targeted object's surface. When the temperature of the filament and the object's surface is the same, then the thermal radiation intensity caused due to the filament merges into the targeted object's surface and becomes invisible. When this process happens, the current passing through the filament is converted into a temperature level.



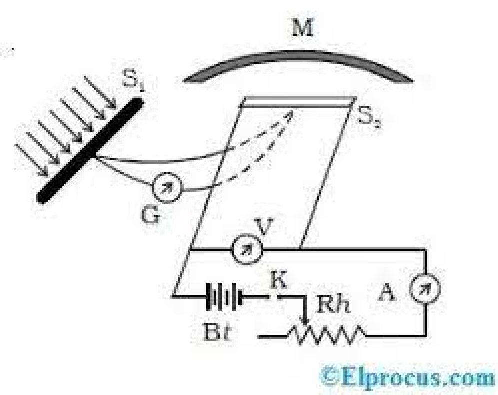


Fig. 1. Pyrometer

Fig. 2 Pyrheliometer

2)Infrared or Radiation Pyrometers: These pyrometers are designed to detect thermal radiation in the infrared region. It measures the temperature of a targeted object from the emitted radiation. This radiation can be directed to a thermocouple to convert into electrical signals.

Pyrheliometer: The pyrheliometer is used to measure the direct beam of solar radiation. This instrument is used with a tracking mechanism to follow the sun continuously. It is responsive to wavelength bands that range from 280 nm to 3000 nm.

Principle & working: The external structure of the Pyrheliometer instrument looks like a telescope. The Pyrheliometer basic structure is shown below. Here the lens can be pointed in the direction of the sun & the solar radiation will flow throughout the lens. The irradiance of solar enters into this device through a crystal quartz window and directly reaches onto a thermopile. So this energy can be changed from heat to an electrical signal that can be recorded. A calibration factor can be applied once changing the mV signal to a corresponding radiant energy flux, and it is calculated in W/m^2 .

The circuit diagram of the pyrheliometer is shown below. It includes two equal strips specified with two strips S1 & S2 with area 'A'. Here, a thermocouple is used where its one junction can be connected to S1 whereas the other is connected to S2. A responsive galvanometer can be connected to the thermocouple. The S2 Strip is connected to an exterior electrical circuit.

Once both the strips are protected from the radiation of solar, then the galvanometer shows no deflection. Now 'S1' strip is exposed to the solar radiation & S2 is protected with a cover like M. When S1 strip gets heat radiations from the sun, then strip temperature will be increased, thus the galvanometer illustrates deflection, both strips are at same temperature. When current is supplied to the S2 strip, the galvanometer shows no deflection. Now, again both the strips are at equal temperature. If the heat radiation amount received per unit area per unit time on S1 strip is 'Q' & its absorption coefficient a, so $VI = QAa$. Here, 'V' is the potential difference & 'I' is the flow of current through it. When heat absorbed is equivalent to the heat generated. By substituting the values of V, I, A and a, the value of 'Q' can be calculated, temperature is measured.

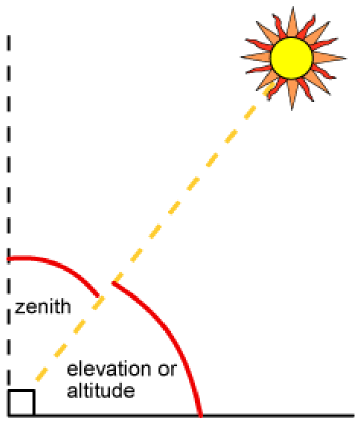
Differences: Pyrometer measures diffuse solar irradiance, while pyrheliometer measures direct sun's irradiance. Pyrometer used the technique of visual comparison between a calibrated light source and the targeted object's surface. Pyrheliometer used to measure direct sun's irradiance with the help of thermopile.

2. Define Solar constant, Zenith angle and air mass. Explain the Spectral distribution of radiation.

Solar constant:

The rate at which the sun's energy is received per unit area at the top of the earth's atmosphere when the sun is at its mean distance from the earth. Its value is 1367 watts per square meter.

Zenith angle:



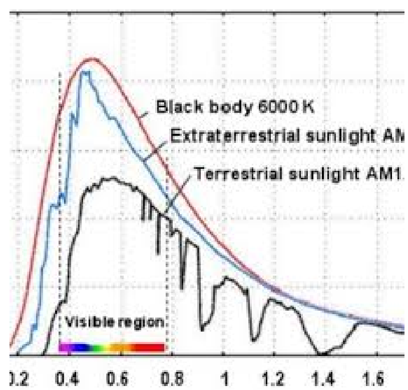


Fig. 3 Zenith angle **Fig. 4 Spectral distribution of Solar radiation**

The zenith angle is the angle between the sun and the vertical. zenith angle = 90° - elevation.

Air mass: The Air Mass is the path length which light takes through the atmosphere normalized to the shortest possible path length (that is, when the sun is directly overhead). The Air Mass quantifies the reduction in the power of light as it passes through the atmosphere and is absorbed by air and dust. The Air Mass is defined as $AM = 1/\cos\theta$, θ is the angle from the vertical or zenith angle, when the SUN is directly over head, AM =1

Spectral distribution of radiation: The distribution of the irradiance as a function of the wavelength is shown in figure.The distribution of radiation can be divided into two regions. Above a wavelength of around 1000 Angstroms the radiation produced by the Sun is 'thermal' in origin - i.e. it arises because the Sun is a hot object. The spectral distribution has a shape known as a black body curve with the peak occurring at around 5000 A. For higher, or lower, wavelengths the radiation produced by the Sun decreases.

Within this range, the region from around 1000 A to 4000 A is the ultraviolet and this radiation is generally absorbed in the atmosphere of the Earth by the ozone layer. 45 percent of the sun's energy comes to us at wavelengths in the visible spectrum. Also, only a little more than 1 percent of the sun's energy at shorter wavelengths (UV and X-solar radiation) and the rest (54 percent) is in the infrared (IR) region.

Short Answers

1.Explain standard time, local apparent time, equation of time.

Local Standard Time The Local Standard Time Meridian (LSTM) is a reference meridian used for a particular time zone and is similar to the Prime Meridian, which is used for Greenwich Mean Time. The (LSTM) is calculated according to the equation: $LSTM=15^0 \Delta T_{UTC}$ where ΔT_{UTC} is the difference of the Local Time (LT) from Universal Coordinated Time (UTC) in hours. ΔT_{UTC} is also equal to the time zone. 15°= 360°/24 hours. For instance, India, UTC +5.30 The longitude of 82°5'E passing through Naini near Allahabad was chosen as the standard meridian for the whole country .

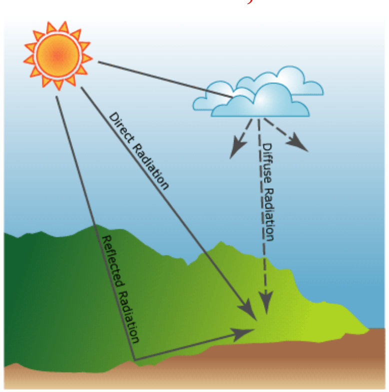
local apparent time Local apparent time is that for the meridian of the observer. Apparent time for any other meridian is designated by name, for example, Greenwich apparent time.

Equation of Time (EoT)

The equation of time (EoT) (in minutes) is an empirical equation that corrects for the eccentricity of the Earth's orbit and the Earth's axial tilt. An approximation 2 accurate to within ½ minute is:

$EoT=9.87\sin(2B)-7.53\cos(B)-1.5\sin(B)$ where $B=360/365(d-81)$ in degrees and d is the number of days since the start of the year.

2. Describe direct, diffuse and total radiations.



The solar radiation that reaches the Earth's surface without being diffused is called direct beam solar radiation. The sum of the diffuse and direct solar radiation is called global solar radiation. Atmospheric conditions can reduce direct beam radiation by 10% on clear, dry days and by 100% during thick, cloudy days.

Unit II Solar Thermal collectors

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Assignment 2

1. **Mention types of thermal collectors. Describe flat plate collector (FPC)-Liquid heating type. Write down energy balance equations and efficiency.**

Solar Thermal collectors are classified into three types. 1) Flat plate collector 2) Evacuated tube collector 3) Concentrated collectors.Solar collectors are the key component of active solar-heating systems. They gather the sun's energy, transform its radiation into heat, then transfer that heat to a fluid (usually water or air). The solar thermal energy can be used in solar water-heating systems, solar pool heaters, and solar space-heating systems.

Flat-plate collectors

Flat-plate collectors are the most common solar collector for solar water-heating systems in homes and solar space heating. A typical flat-plate collector is an insulated metal box with a glass or plastic cover (called the glazing) and a dark-colored absorber plate. These collectors heat liquid or air at temperatures less than 80°C.

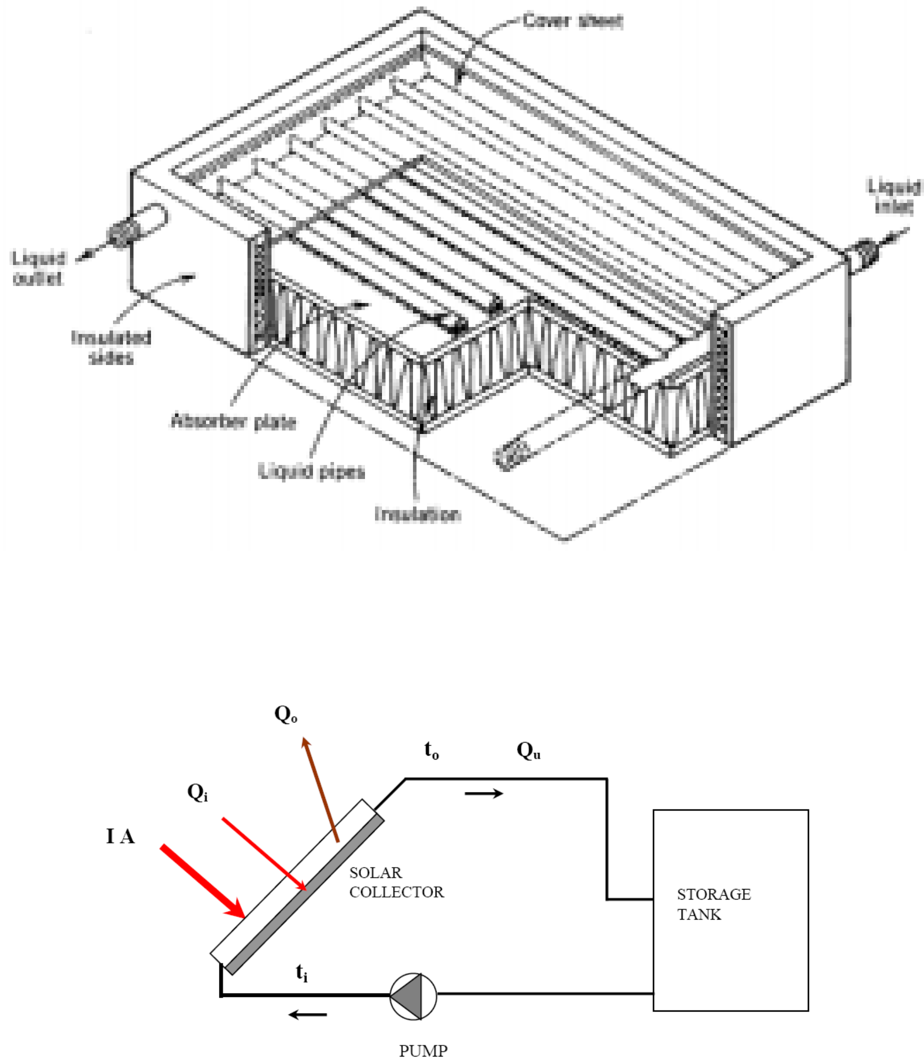
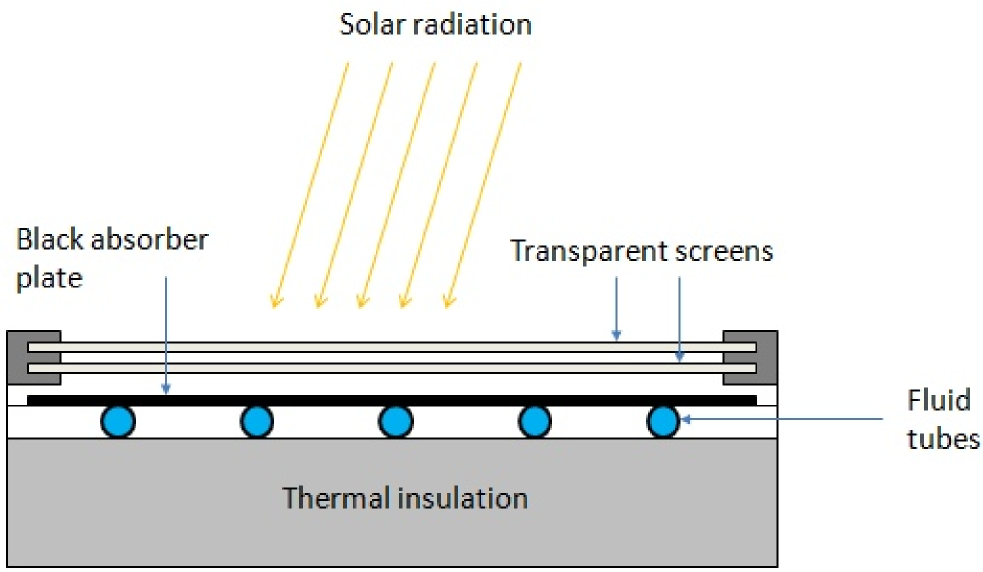


Fig. 1 A typical liquid Flat Plate Collector

Flat-plate collectors are used for residential water heating and hydronic space-heating installations.

T_c collector average temperature, (°C), T_i inlet fluid temperature, (°C), T_a ambient temperature, (°C) , U_L collector overall heat loss coefficient, W/m^2 , Q_i collector heat input, W, Q_u useful energy gain, (W), Q_o heat loss, (W) τ transmission coefficient of glazing , α absorption coefficient of plate, η collector efficiency



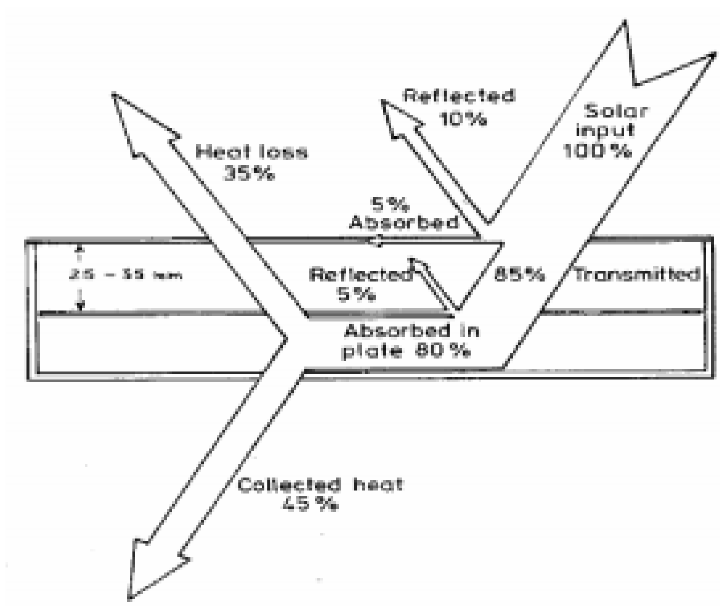


Fig. 2 Heat flow through a Flat Plate solar collector

If I is the intensity of solar radiation, in W/m^2, incident on the aperture plane of the solar collector having a collector surface area of A, (m^2) , then the amount of solar radiation received by the collector is

Q_i = IA ----1

However, as it is shown Figure 3, a part of this radiation is reflected back to the sky, another component is absorbed by the glazing and the rest is transmitted through the glazing and reaches the absorber plate as short wave radiation.
Therefore the conversion factor indicates the percentage of the solar rays penetrating the transparent cover of the collector (transmission) and the percentage being absorbed. Basically, it is the product of the rate of transmission of the cover and the absorption rate of the absorber.

Thus, $Q_i = I(\tau\alpha) \cdot A$ **(2)**

As the collector absorbs heat its temperature is getting higher than that of the surrounding and heat is lost to the atmosphere by convection and radiation. The rate of heat loss (Qo) depends on the collector overall heat transfer coefficient (U_L) and the collector temperature.

$$Q_o = U_L A\ (T_c - T_a) \text{ -------(3)}$$

Thus, the rate of useful energy extracted by the collector (Q_u), expressed as a rate of extraction under steady state conditions, is proportional to the rate of useful energy absorbed by the collector, less the amount lost by the collector to its surroundings.This is expressed as follows:

$$Q_U = Qi - Qo = I(\tau\alpha) \cdot A - U_L A\ (T_c - T_a) \text{ ------4}$$

It is also known that the rate of extraction of heat from the collector may be measured by means of the amount of heat carried away in the fluid passed through it, that is:

$$Q_u = m\ Cp\ (T_o - T_i) \text{ --------5}$$

Equation 4 proves to be somewhat inconvenient because of the difficulty in defining the collector average temperature. It is convenient to define a quantity that relates the actual useful energy gain of a collector to the useful gain if the whole collector surface were at the fluid inlet temperature. This quantity is known as "the collector heat removal factor (F_R)" and is expressed as:

$$F_R = m\ Cp\ (T_O - T_i) / A[I(\tau\alpha) - U_L A (T_c - T_a)] \text{ -------------6}$$

The maximum possible useful energy gain in a solar collector occurs when the whole collector is at the inlet fluid temperature. The actual useful energy gain (Qu), is found by multiplying the collector heat removal factor (F_R) by the maximum possible useful energy gain. This allows the rewriting of equation (4):

$\mathbf{Q_u = F_R\, A[\mathit{I}(\tau\alpha)\text{-}\mathit{U_L A}(\mathit{Tc} - \mathit{Ta})]}$ **------7**

Equation (7) is a widely used relationship for measuring collector energy gain and is generally known as the "Hottel- Whillier-Bliss equation".

Collector efficiency (η) : It is defined as the ratio of the useful energy gain (Qu) to theincident solar energy over a particular time period.

η = Qu / AI

$$\eta = \frac{FR\ A[I(\tau\alpha) - ULA(Tc - Ta)]}{AI}$$

$$\eta = F_R\ \tau\ \alpha\ -\ F_R\ U_L \left(\frac{Ti - Ta}{I}\right)$$

Short Answer Questions

2. Mention the types of Concentrating Solar Systems. Describe Concentrating collector

Types of concentrating collectors

1.Parabolic trough system 2.Parabolic dish system 3.Power tower system 4.Stationary concentrating solar collectors

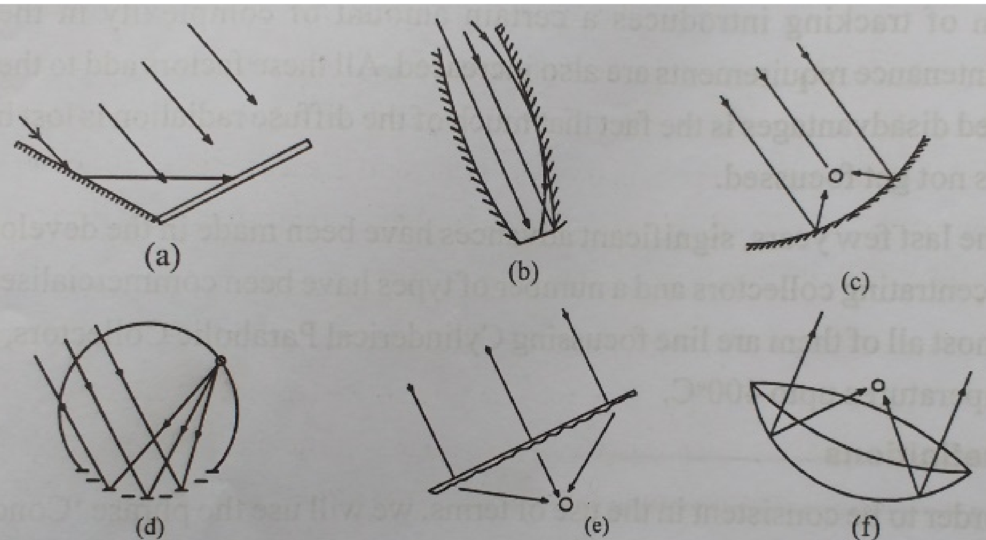
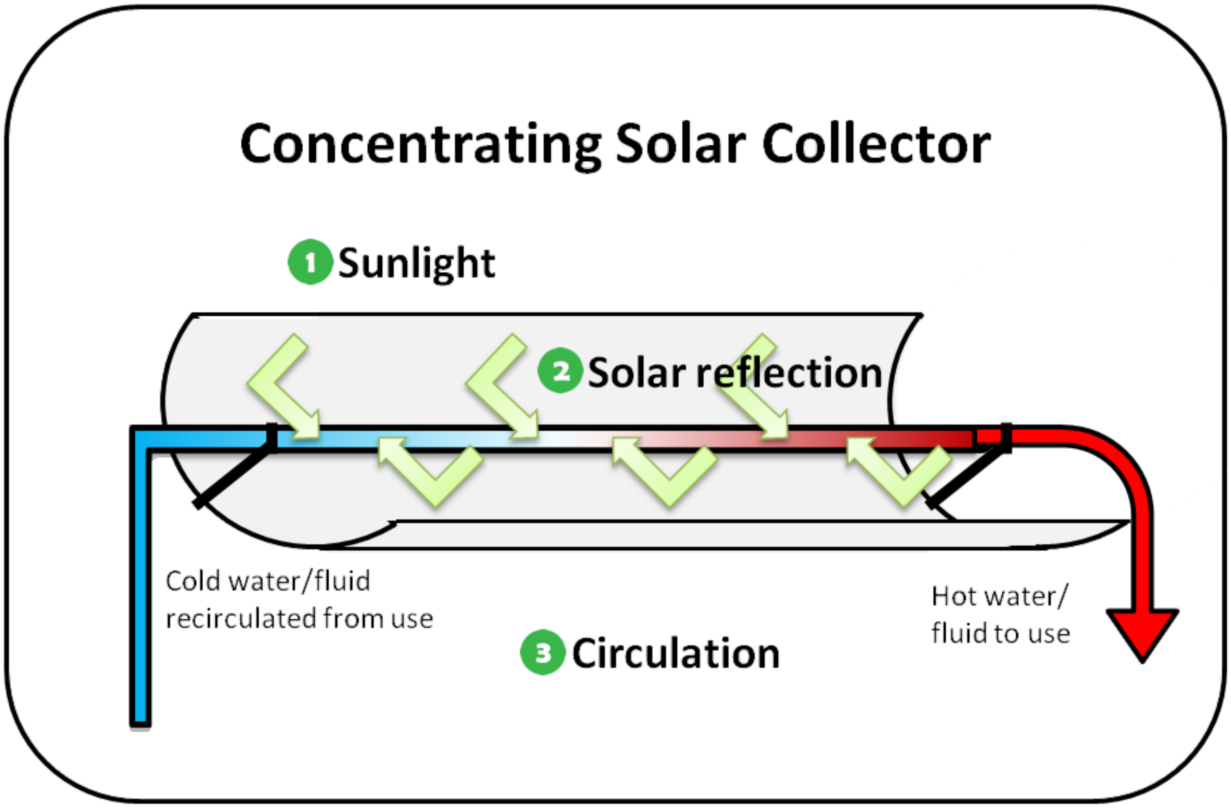


Fig. 4.29 Types of Concentrating Collectors
(a) Flat-Plate Collector with Plane Reflector (b) Compound Parabolic Collector (c) Cylindrical Parabolic Collector (d) Collector with Fixed Circular Concentrator and Moving Receiver (e) Fresnel lens Concentrating Collector (f) Paraboloid Dish Collector.

The concentrating solar power system (CSP) uses lenses or mirrors to focus sunlight into a sharp beam with the help of concentrating solar collectors. This powerful beam is next focused on a small receiver to heat a fluid to a high temperature.The hot fluid is then used to generate steam that drives a steam turbine coupled to an electrical generator. Concentrating solar systems work by reflecting and directing solar energy from a large area onto a small one. Smaller, reflective bowl-shaped arrays can produce water at a few hundred degrees for industrial or agricultural processes or for heating large volumes of water, such as resort swimming pools. Some arrays work with long parabolic troughs that concentrate sunlight onto a pipe running the length of the trough, which carries a heat transfer fluid. Even larger systems use fields of mirrors to reflect sunlight onto a central tower. These types of arrays produce high-pressure steam or other superheated fluids for a range of activities, from heat-intensive chemical processing to electric power generation.



1. Sunlight: Sunlight hits a reflective material (i.e., a mirrored surface), usually in the shape of a trough (shown here) or a dish.
2. Solar reflection: The reflective material redirects the sunlight onto to a single point (for a dish) or a pipe (for a trough).
3. Circulation: Cold water or a special heat transfer fluid circulates through the pipe, absorbing heat.

Concentrating systems are capable of producing enormously hot fluids for a variety of processes, and they can produce a relatively large amount of energy for each dollar invested. However, these systems tend to be much larger and more complex than the other types of solar collectors described above, with a higher total price tag. Thus, concentrating solar technology tends to be most effective for large-scale, high-temperature uses, although lower-temperature uses may still be cost-effective under certain circumstances.