SOLAR ENERGY

Sun and energy

In order to investigate the conversion of sun energy into photovoltaic energy and thermal energy it is essential to look at the amount of solar energy available on earth surface.

The sun is an atomic globe of gas having a radius 100 times that of our earth. Its surface to center temperature varies from 6000^0 to 15 million ^{0}K at the center. A thermonuclear holocaust fusing 3,630,000 tons of solar hydrogen into helium each second hurls out this incredible energy.

At the solar surface the radiation energy density is 8 KW/CM^2. The mean solar radiation in outer atmosphere of the earth at normal incidence is 1.35 KW/M^2 with the variable losses namely absorption, scattering, reflection, refraction, grazing angle and blockage in the transit of solar radiation from out space to earth's surface, the solar energy on the earth varies in the range of 0-1 KW/M^2.

Solar energy spectrum and solar insolation

The sun's surface is at a temperature of about 6000^0K and a huge amount of energy is radiating from its surface. The earth is receiving a fraction of the energy after travelling through the atmosphere. Above earth's atmosphere the spectral radiance curve i.e. the amount of energy radiated per unit area per second in a unit wavelength interval or commonly known as irradiance W_λ plotted against wavelength λ corresponds approximately to the spectral radiance curve of a black body at 5900^0K. According to Planck's radiance equation, the spectral radiance W_λ of a blackbody source at a temperature T_S is given by

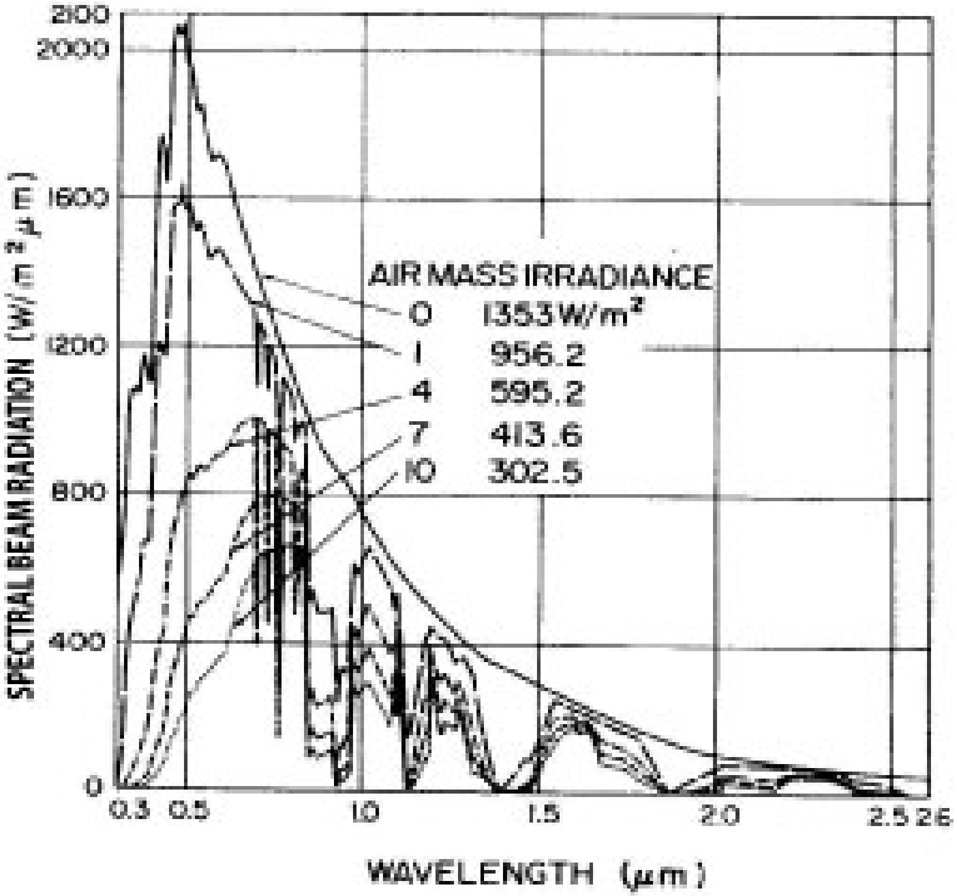
$$W_\lambda = C_1\lambda^{-5}[\exp(C_2/\lambda T_s) - 1]^{-1}, \quad \text{where}$$

C_1 = first radiation constant = $2\pi hc^2$
h = Planck's constant
k = Boltzmann constant
c = Velocity of light
C_2 = Second radiation constant = $h c / k$

Like any other radiant energy source, the sun emits photons of all wave lengths from $\lambda \rightarrow 0$ to $\lambda \rightarrow \infty$. The peak of the spectral radiance curve is around 0.5 μm. There is hardly any irradiance for $\lambda \geq 2.5$ μm. Fig.1 shows the spectral radiance curve of a black body at 5762^0K. The total energy received per unit area per second in the earth's outer atmosphere is

$$\int_o W_\lambda \, . \, d\lambda = 1.35 \text{ KW/M}^2$$

Fig.1 also shows the spectral radiance curve above the earth's atmosphere.



The solar energy that reaches the earth's surface is modified considerable by the atmosphere. The atmospheric conditions that effect the solar insulation on earth are:

- Atmospheric gases
- Aqueous vapors
- Dust

Utilization of solar energy.

Solar energy is a very large, inexhaustible source of energy. The power from the sun intercepted by the earth is approximately 1.8 x10^{11} MW, which are many thousands of times larger than the present consumption rate on the earth of all commercial energy sources. Thus in principle, solar energy could supply all the present and future energy needs of the world on a continuing basis. This makes it one of the most promising of the non conventional sources.

In addition to its size, solar energy has two other factors in its favour :

- Firstly unlike fossil fuels and nuclear power, it is an environmentally clean source of energy.
- Secondly it is free and available in adequate quantities in almost all parts of the world.

However, there are many problems associated with its uses:

- The main problem is that it is a dilute source of energy. Even in the hottest regions on earth, solar radiation the available rarely exceeds 1KW/m^2 and the total radiation over a day is at best ~ 7.0 KW/m^2. So large collecting areas are required in many applications.
- Second problem is that solar energy is intermittent, thus one needs to store energy when available. The need for storage adds to the cost of the system.

A broad classification of the various methods of solar energy utilization is given below

Solar energy utilization

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Direct Methods Indirect Method

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Thermal Photovoltaic

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Water Power Wind Biomass Wave energy Ocean temperature deference

Principle of solar thermal conversion and solar collector

The principle of the conversion of solar energy into thermal energy is to expose a black surface to solar radiation so that radiation is absorbed. A part of the absorbed radiation is then transferred to a fluid like air or water.

The device through which heat energy from sun is collected in an absorber and then transferred to the fluid is called a solar collector. This is the most important type of solar collector, because it is simple in design, having no moving parts and requires little maintenance. It can be used for applications in temperature range from 40^0C to about 100^0C.

Flat plate collectors

A flat plate can absorb both direct and diffuse solar radiation; therefore, it is partially effective even on cloudy days when there is no direct radiation.

Flat plate solar collector may be divided into two main classes based on the type of heat transfer fluid used.

a) Liquid heating collectors are used for heating water and non-freezing aqueous solution and occasionally non-aqueous heat transfer fluids.

b) Air or Gas heating collectors are employed as solar air heater.

The principal difference between the two types is the design of the passages for the heat transfer fluid.

Components of Flat plate collectors

The majority of the flat plate collectors have five main components:

1. The absorber plate, normally metallic or a metallic black surface.
2. A transparent cover, which may be one or more sheets of glass or transmitting plastic film or sheet.
3. Tubes, fins, passages, or channels are integrated with the collector absorber plate or connected to it, which carry water, air or other fluid.
4. Insulation, which is provided at the back and side to minimize the heat losses
5. The casing or container which encloses the other components and protects them from the weather.

A liquid Flat Plate Solar collector.

A schematic diagram of a liquid flat plate collector is given below :

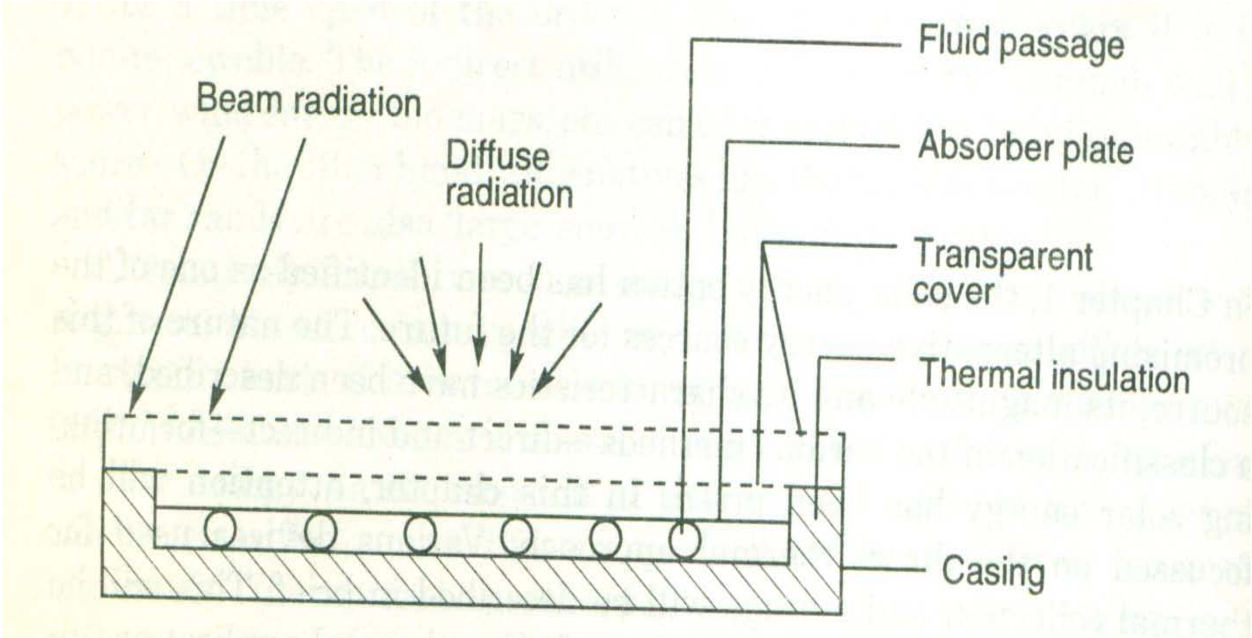

Fig. 2.1 Liquid Flat-plate Collector

It is the plate and tube type collector. It is basically consists of a flat surface with high absorptivity for solar radiation, called the absorbing surface. Typically a metal plate, usually, copper, steel or aluminium sheet with copper tubing in thermal contact with the plates.

Solar radiation falls through transparent cover and is absorbed in the absorber plate. The absorbed radiation is partly transferred to the liquid flowing through tubes which are fixed to the absorber plate. This energy transfer is the useful gain. The remaining part of the radiation absorbed in the absorber plate is lost by convection and re-radiation to the surroundings from the top surface, and by conduction through the bank and edges. The transparent cover helps in reducing the losses by convection and re-radiation. While the thermal insulation on the back and edges help in reducing the conduction heat loss. The liquid most commonly used is water. A liquid flat plate collector is usually held tilted in affixed position on a supporting structure, facing south if located in the northern hemisphere.

Heat Balance Equation.

Under steady conditions the useful heat delivered by a solar collector is equal to the energy absorbed in the metal surface minus the heat losses from the surface directly and indirectly to the surroundings. The principle can be stated in the relationship:

$$Q_u = A_c \, [HR \, (\tau . \alpha) - U_L \, (T_p - T_a)]$$

Where,

Q_u is the useful energy delivered by the collector, Watts or kcal/hr.

A_c is the collector area, m^2 .

HR is the solar energy received on the upper surface of the slopping collector structure, W/m or kcal/hr m^2

H is the rate of incident beam of diffuse radiation on a unit area of the surface of any orientation.

R is the factor to convert beam or diffuse radiation to that on the Plane of the collector.

τ is the Transmittivity, fraction of the solar radiation that reaches the absorbing surface.

α is the absorptivity, fraction of the solar energy reaching the surface that is absorbed.

U_L is the overall heat loss coefficient.

T_p is the average temperature upper surface of the absorber plate.

T_a is the atmospheric temperature.

The absorption of solar radiation and Heat losses

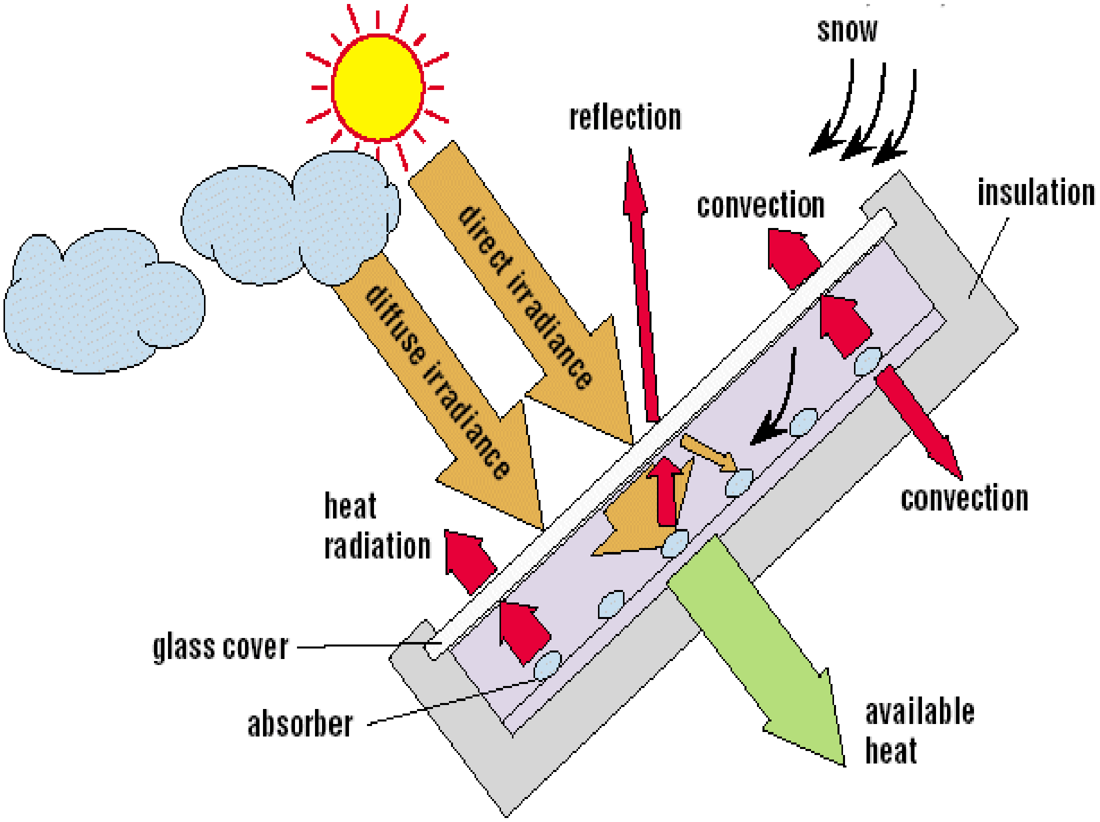

FIGURE 1. Processes at a flat-plate collector

A flat-plate solar collector usually has a non- selective or a selective black plate with one or two glass covers a few centimeters above the black plate, and a well insulated back. The length of the plate is typically about 2m. Edge effects are usually small.

- Solar irradiance $\mathbf{I}_{in}$ incident on the cover glass

$$\mathbf{I}_{in} = \mathbf{I}_b \cos \theta + \mathbf{I}_{d},$$

Where, I_b is the beam solar irradiance, θ is the angle of incidence, and I_d is the diffuse irradiance.

- For one glass cover the solar irradiance on the black plate is

$$\tau(\theta).\ \mathbf{I}_b \cos\theta + \tau_m \mathbf{I}_{d},$$

Where τ_m is the mean value of $\tau(\theta)$.

The solar radiation flux $\mathbf{Q}_{abs}$ absorbed by the black plate is given by

$$\mathbf{Q}_{abs} = \tau(\theta).\ \boldsymbol{\alpha}(\theta)\ \mathbf{I}_b \cos\theta + (\tau.\boldsymbol{\alpha})_m\ \mathbf{I}_{d},$$

Heat Losses

Let at thermal equilibrium T_p, T_c and T_a are the absorber plate, cover glass and ambient temperature respectively.

- i) Heat loss by conduction through the back insulation

  $h_{pa}(T_p - T_a)$ ……………… (1)

  where h_{pa} is the heat transfer coefficient for conduction.

- ii) Heat loss from plate to the cover glass by convection

  $h_{pc}(T_p - T_c)$ …………… (2)

  Where h_{pc} is the heat transfer coefficient of convection.

- iii) Heat loss by radiation between the black plate and the glass cover

  $$[\sigma.(T_p^4 - T_c^4)] / [\varepsilon_{p-1} + \varepsilon_{c-1} - 1] = \varepsilon_{pc}.\sigma(T_p^4 - T_c^4) \quad (3)$$

where σ is the Stefan-Boltzman constant $56.7\times10^{-9}\text{W/m}^2\text{K}^4$.

ε_p and ε_c emissivity of plate and cover glass respectively.

- iv) Thus the total heat loss Q_{pa} from the black plate can be written as

  $$Q_{pa} = h_{pa}(T_p - T_a) + h_{pc}(T_p - T_c) + \varepsilon_{pc}.\ \sigma(T_p^4 - T_c^4) \quad (4)$$

- v) The heat loss from the glass cover to the surroundings

$$Q_{ca} = h_{ca}.(T_c - T_a) + \varepsilon_{pc}.\ \sigma\ T_c^4 - \varepsilon_{c.}L \qquad \ldots. \quad (5)$$

Where, the first term is heat transfer by convection, the second term is the long wave radiation from glass cover and the third term is the long wave radiation absorb by the glass cover from the sky.

Collector Efficiency in the Steady State

- To find the collector efficiency it is necessary to calculate the temperatures T_p and T_c from the radiation fluxes and the ambient temperature Ta.

- Assume a value for Q_{ca} equation (5) may be solved for T_c. Now it can be shown that

$$Q_{ca} = h_{pc}\ (T_p - T_c) + \varepsilon_{pc}\ \sigma\ (T_{pc}^4 - T_c^4),\ \ldots.. \qquad (6)$$

from the heat balance of the glass cover in the steady state. This equation is solved for T_p. Finally Q_{pa} can be found.

- Let Q_{out} be the heating power output of the collector per unit area, then heat balance for the absorber plate gives

$$Q_{out}, = Q_{abs} - Q_{pa}$$

- Where Q_{abs} depends on $\mathbf{I}_b$, θ, and $\mathbf{I}_d$; and the heat loss rate Q_{pa} is known as a function of T_p.

- The overall efficiency is defined as,

η = (Useful energy collected) / (Energy incident in the plate of the collector)

$= Q_{out}/Q_{in}$

Water Heating Methods

Thermosyphon systems

For storing water overnight or on cloudy days, a storage tank is needed. A very simple way of doing this, making use of gravity is shown in Figure 4 - the thermosyphon system. The principle of the thermosyphon system is that cold water has a higher specific density than warm water, and so being heavier will sink down. Therefore, the collector is always mounted below the water storage tank, so that cold water from the tank reaches the collector via a descending water pipe. If the collector heats up the water, the water rises again and reaches the tank through an ascending water pipe at the upper end of the collector. The cycle of tank–water pipe–collector ensures the water is heated up until it achieves an equilibrium temperature. The consumer can then make use of the hot water from the top of the tank, with any water used being replaced by cold water at the bottom. The collector then heats up the cold water again. Due to higher temperature differences at higher solar irradiances, warm water rises faster than it does at lower irradiances. Therefore, the circulation of water adapts itself almost perfectly to the level of solar irradiance. A thermosyphon system's storage tank must be positioned well above the collector, otherwise the cycle can run backwards during the night and all the water will cool down. Furthermore, the cycle does not work properly at very small height differences. In regions with high solar irradiation and flatroof architecture, storage tanks are usually installed on the roof.

Thermosyphon systems operate very economically as domestic water heating systems, and the principle is simple, needing neither a pump nor a control. However, thermosyphon systems are usually not suitable for large systems, that is, those with more than 10 m² of collector surface. Furthermore, it is difficult to place the tank above the collector in buildings with sloping roofs, and single-circuit thermosyphon systems are only suitable for frost-free regions.

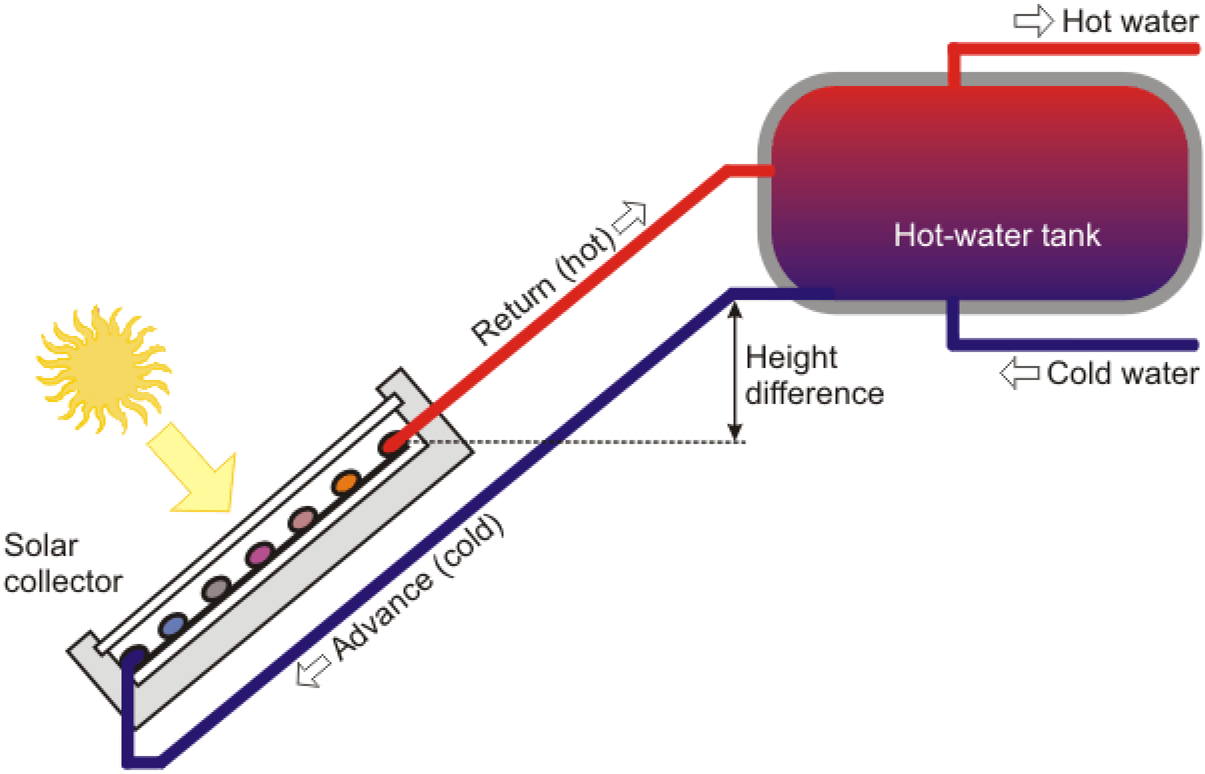

FIGURE 4. A thermosyphon system

Forced-circulation systems

In contrast to thermosyphon systems, an electrical pump can be used to move water through the solar cycle of a system by forced circulation. Collector and storage tank can then be installed independently, and no height difference between tank and collector is necessary. Figure 5 shows a system using forced circulation with a conventional boiler for back-up heating.

Two temperature sensors monitor the temperatures in the solar collector and the storage tank. If the collector temperature is above the tank temperature by a certain amount, the control starts the pump, which moves the heat transfer fluid in the solar cycle; ‘switch-on’ temperature differences are normally between 5°C and 10°C. If the temperature difference decreases below a second threshold, the control switches off the pump again.

In regions where there is a danger of frost, a double-circuit system is usually used. Drinking water is kept inside the storage tank, while the water in the solar cycle is mixed with an antifreeze agent. A heat exchanger transfers the heat of the solar cycle to the storage tank, and keeps the drinking water separate from the antifreeze mixture.

Forced-circulation systems can be used for room heating as well as domestic water heating. In this case, collectors and storage tanks must be much larger than with simple domestic water heating systems, where a collector surface of about 4 m² is sufficient for most households. Larger systems have also been realized successfully with two or more storage tanks.

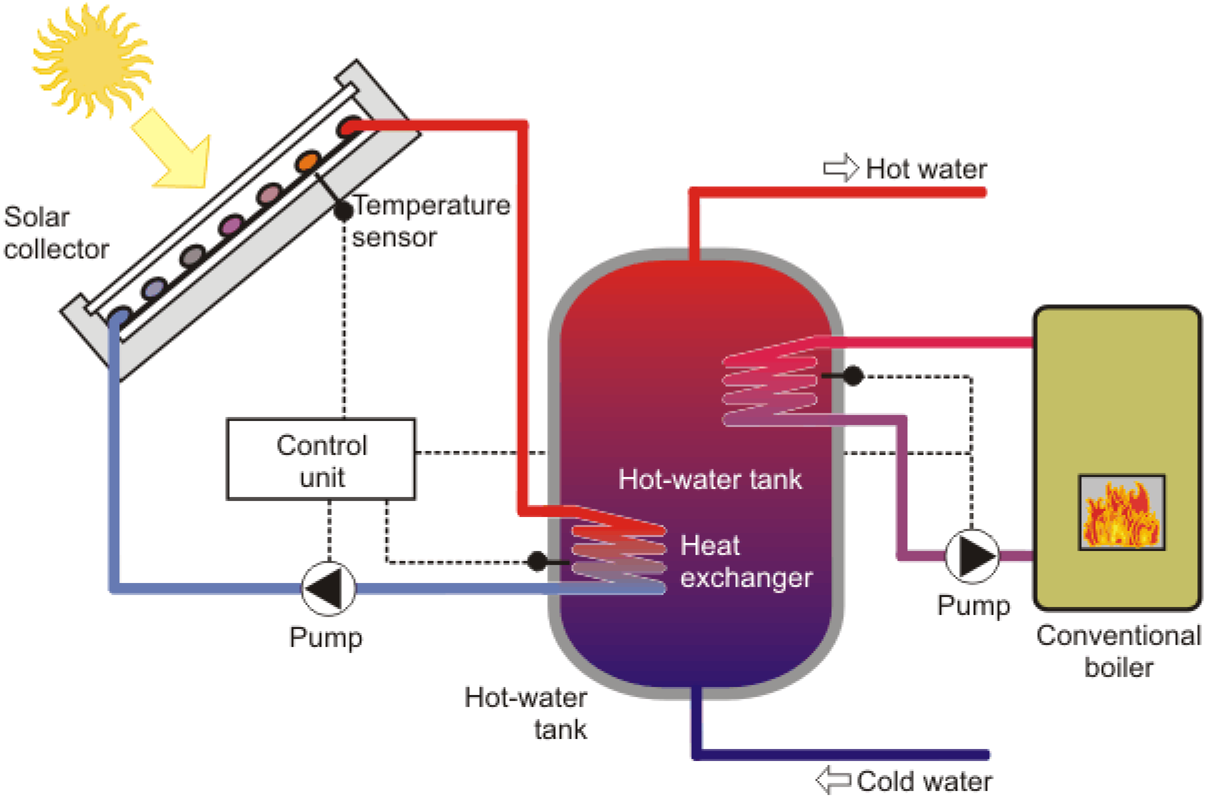

FIGURE 5. A double-cycle system with forced circulation with a conventional boiler for back-up heating