ME 476
Solar Energy

UNIT FOUR
SOLAR COLLECTORS
Flat Plate Collectors

Outline

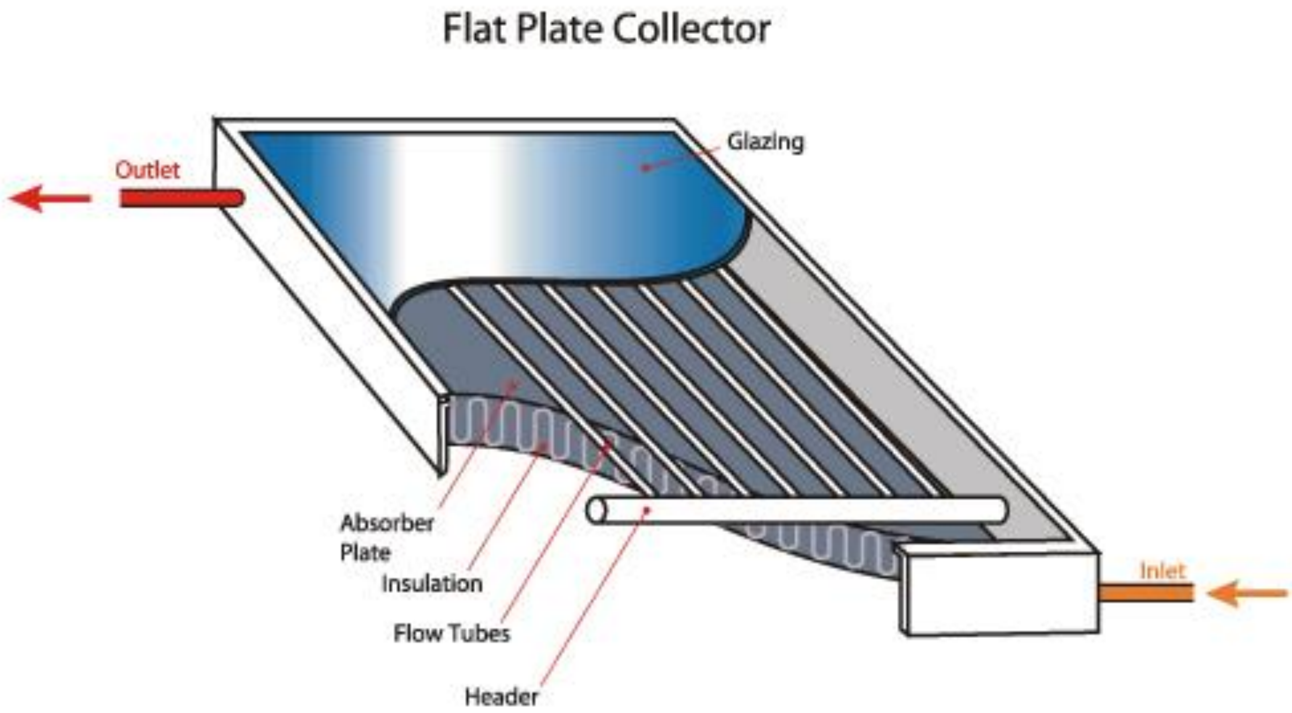
- What are flat plate collectors?
- Types of flat plate collectors
- Applications of flat plate collectors
- Thermal analysis of flat plate collectors

What Are Flat Plate Collectors?

- A flat plate collector is a heat exchanger that uses solar irradiation to heat a working fluid.
- The working fluid is usually liquid or air.
- The collector is a black surface that is placed at a convenient path of the sun.
- In flat plate collectors there is no optical concentration of sunlight and they are generally stationary.
- The outlet temperature capability is below 100 °C

What Are Flat Plate Collectors?

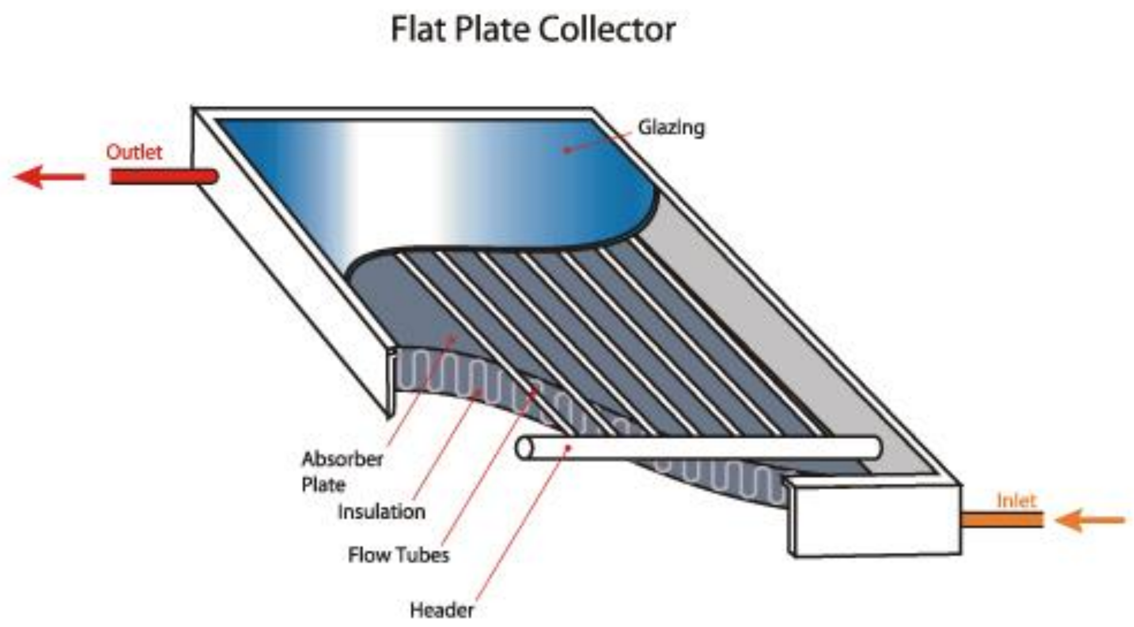
- A typical flat plate collector is a metal box with a glass or plastic cover (called glazing) on top and a dark-colored absorber plate on the bottom.
- The sides and bottom of the collector are usually insulated to minimize heat loss.



Components of Flat Plate Collectors?

ABSORBER PLATE

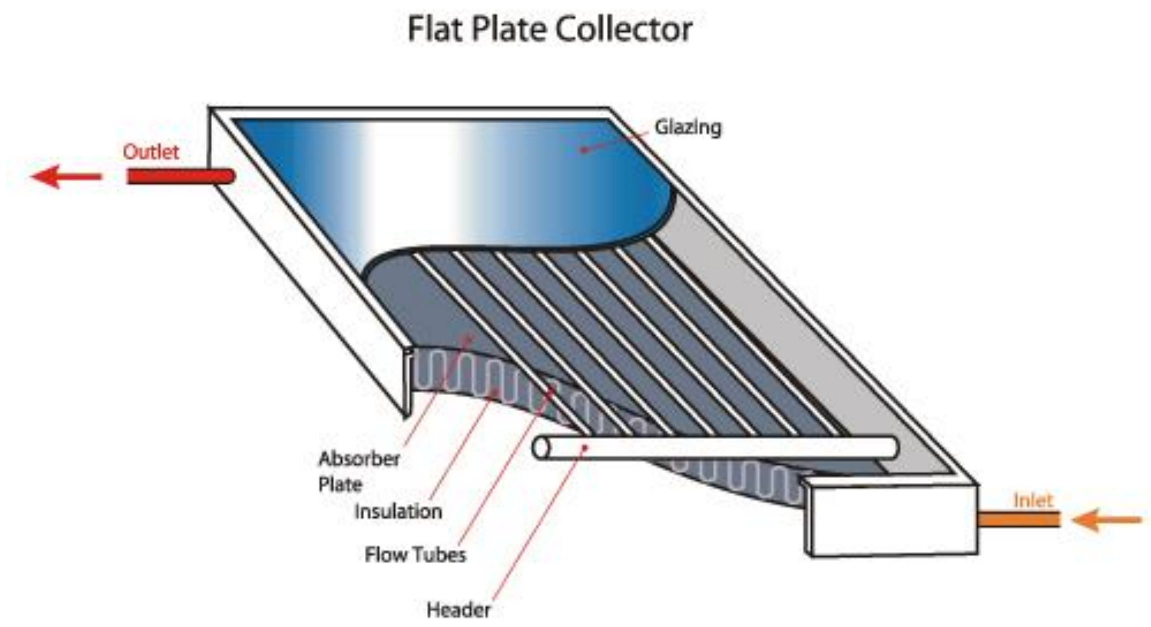
- The plate is usually made of copper, steel, or plastic.
- The surface is covered with a black material of high absorptance.
- A selective coating can be used to maximize the absorptance of solar energy and minimizes the radiation emitted by plate.



Components of Flat Plate Collectors?

FLOW PASSAGES

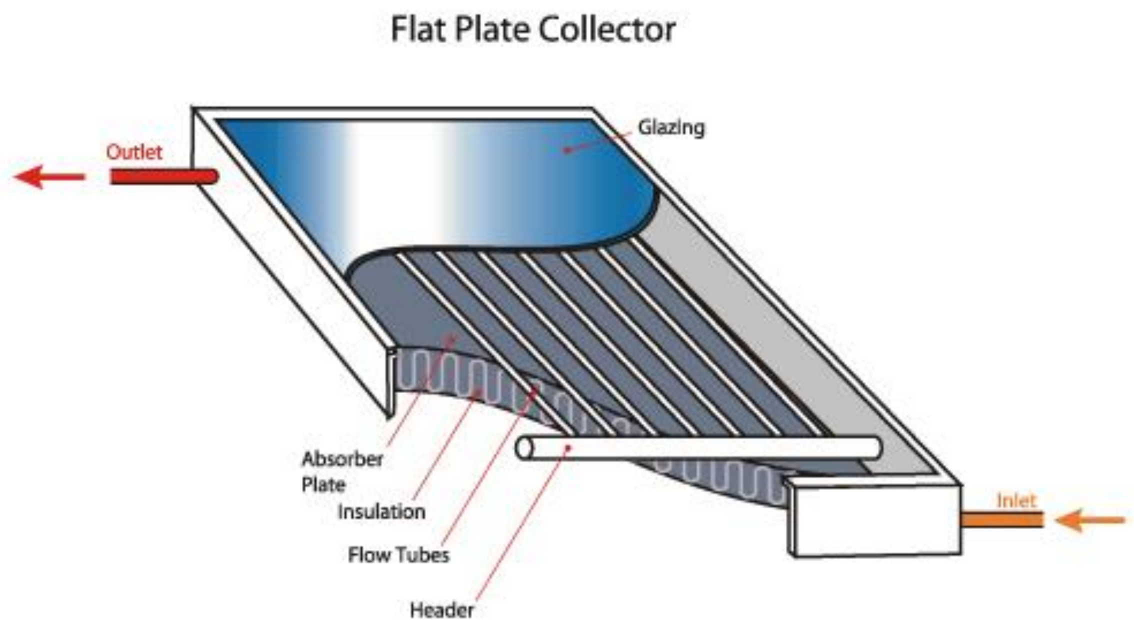
- The flow passages carry the working fluid through the collector.
- If the working fluid is a liquid, the flow passage is usually a tube that is attached to, or is a part of absorber plate.
- If the working fluid is air, the flow passages can have different configurations.



Components of Flat Plate Collectors?

COVER PLATE (GLAZING)

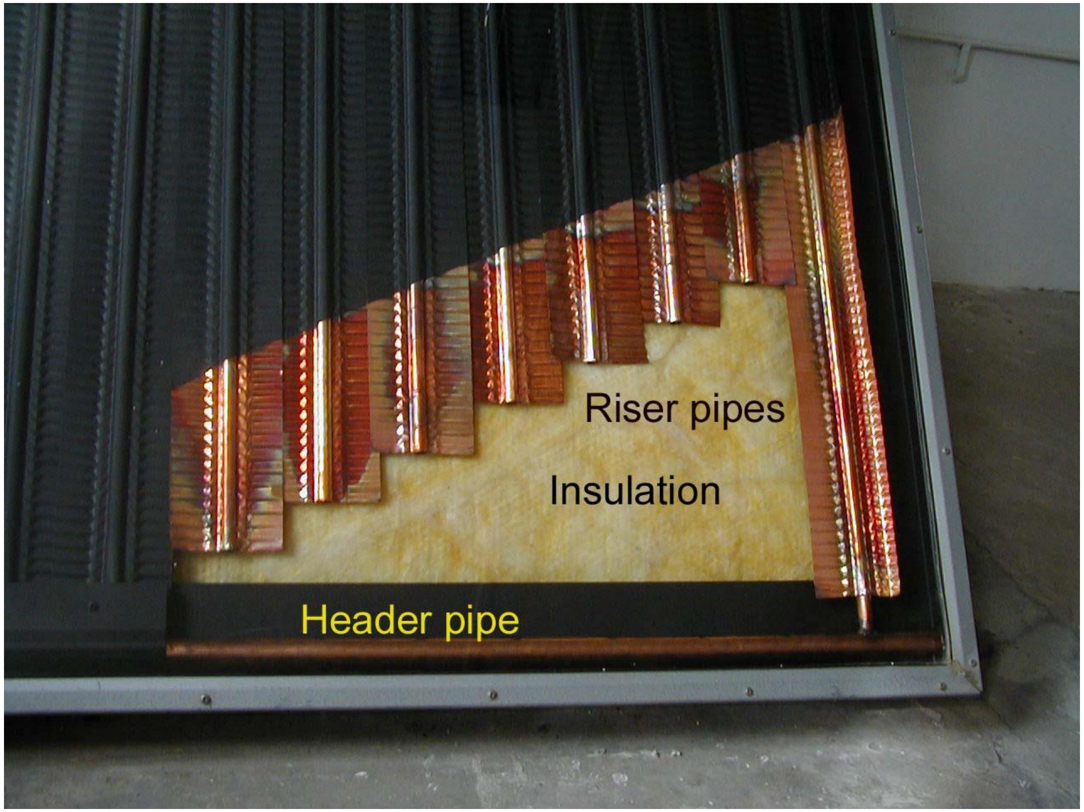
- To reduce convective and radiative heat losses from the absorber, one or two transparent covers (glazing) are generally placed above the absorber plate.
- They usually be made from glass or plastic.



Components of Flat Plate Collectors?

INSULATION

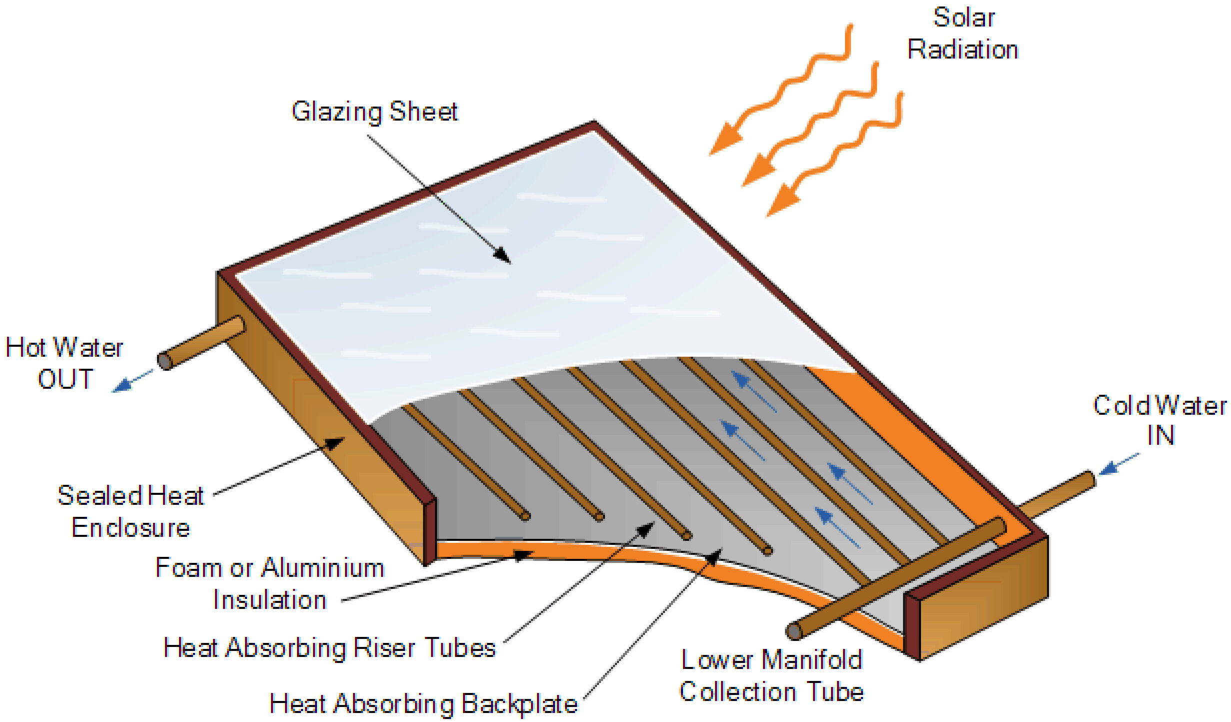
- These are some materials such as fiberglass and they are placed at the back and sides of the collector to reduce heat losses.



Components of Flat Plate Collectors?

ENCLOSURE

- A box that encloses the collector to:
  - **Hold all the components together**
  - **Protect them from weather**
  - **Facilitate installation on a roof or appropriate frame.**



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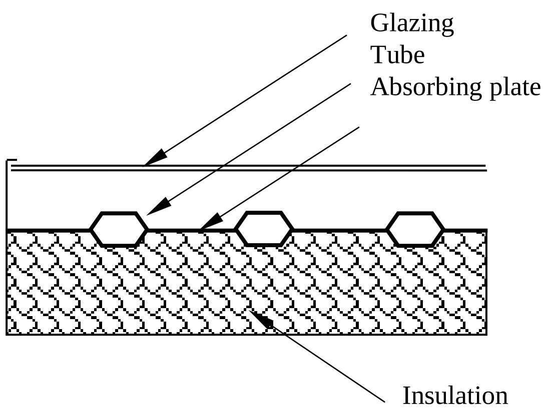
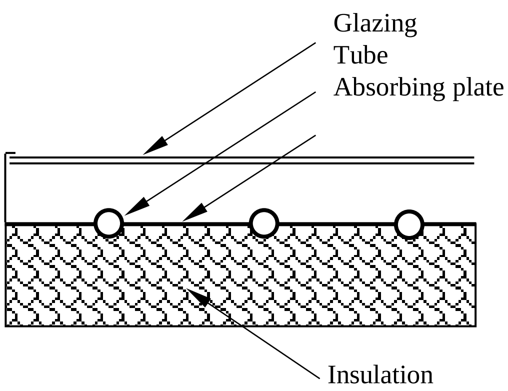
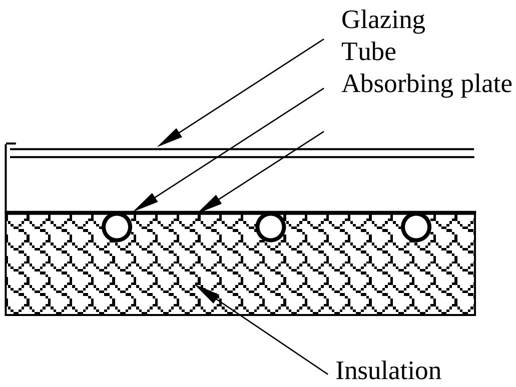
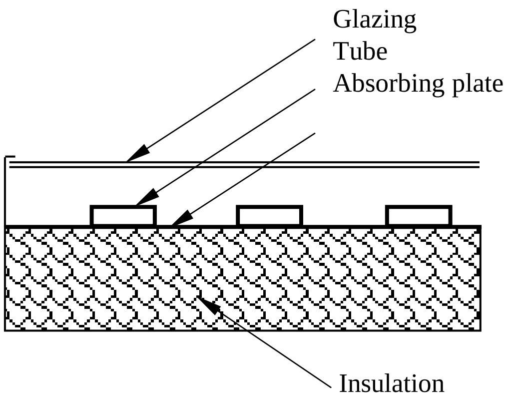
Types of Flat Plate Collectors

WATER SYSTEMS



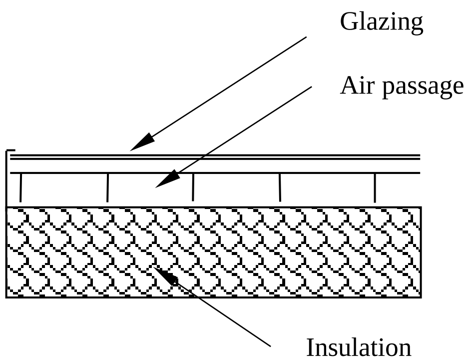


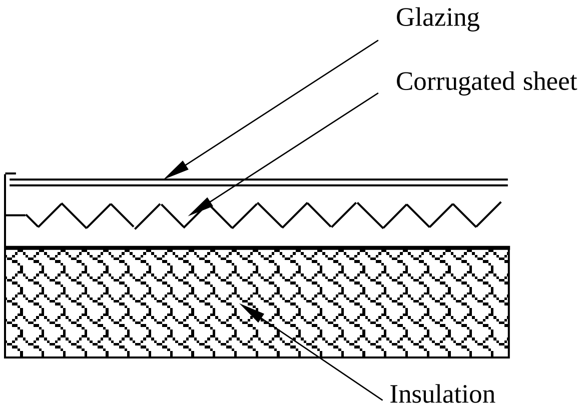


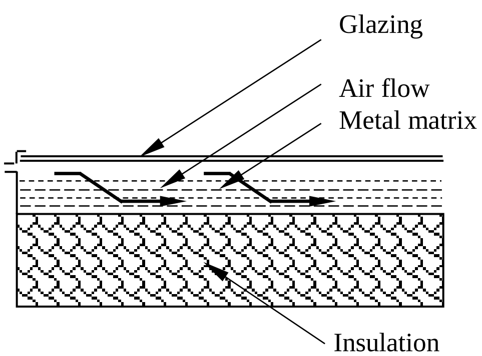


Types of Flat Plate Collectors

AIR SYSTEMS







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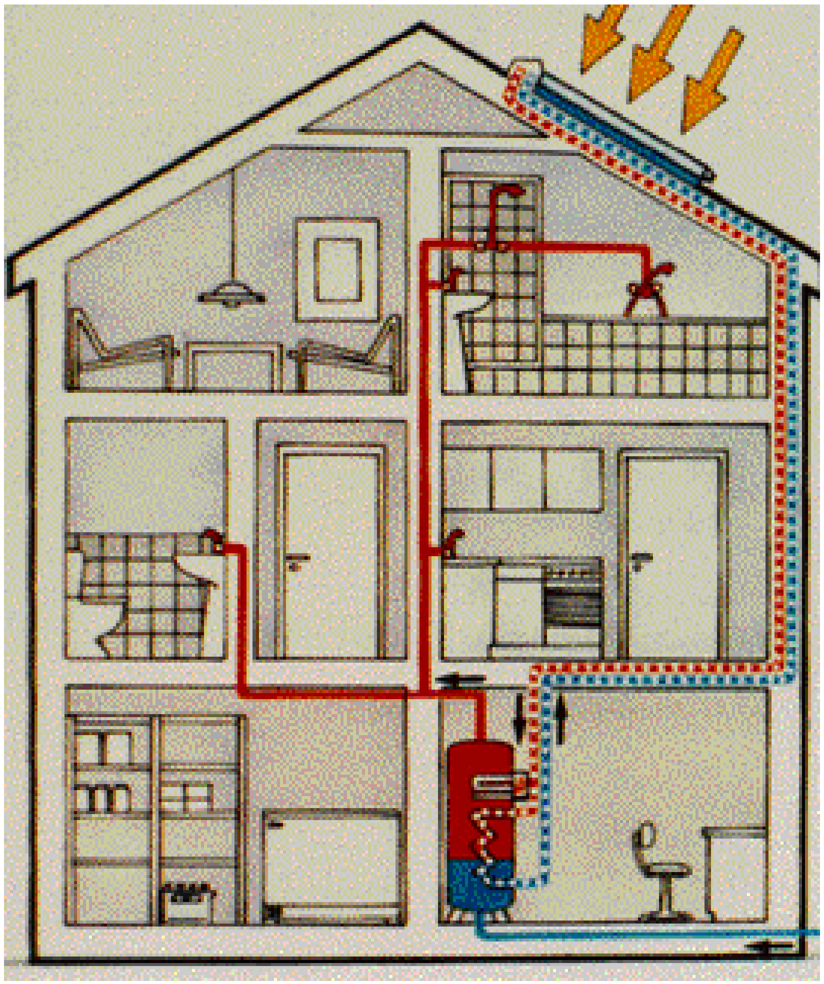
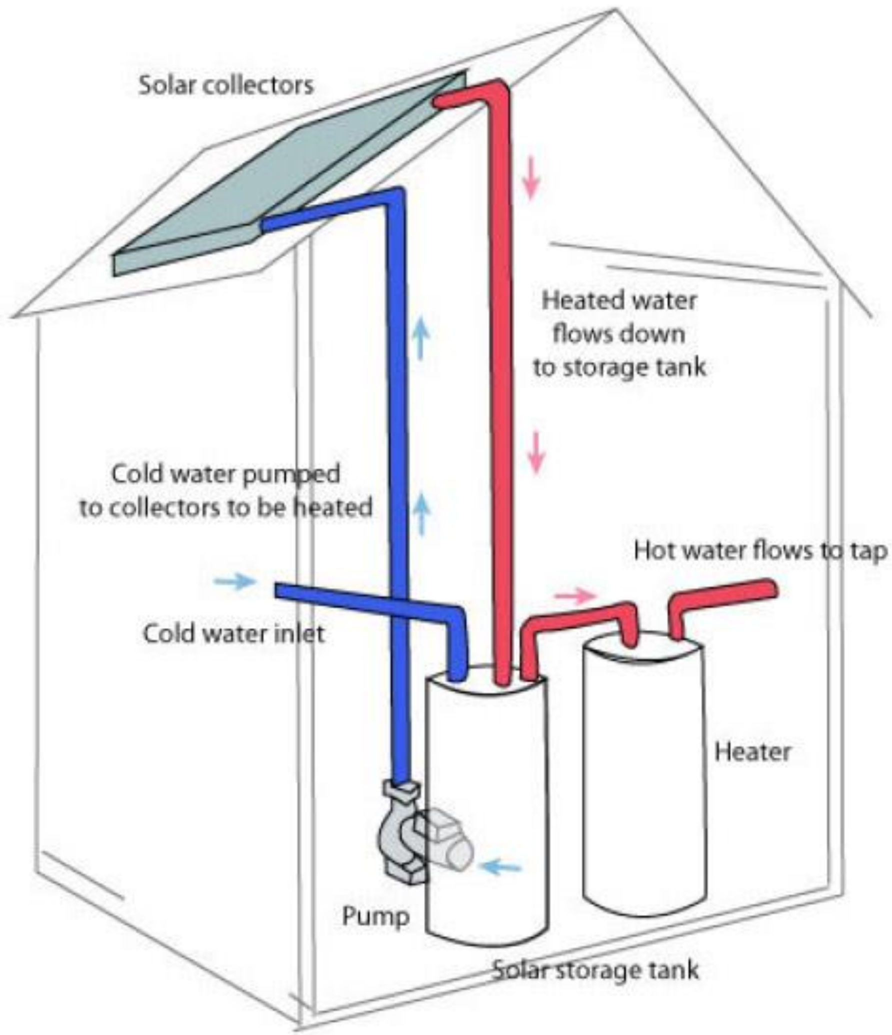
Applications of Flat Plate Collectors

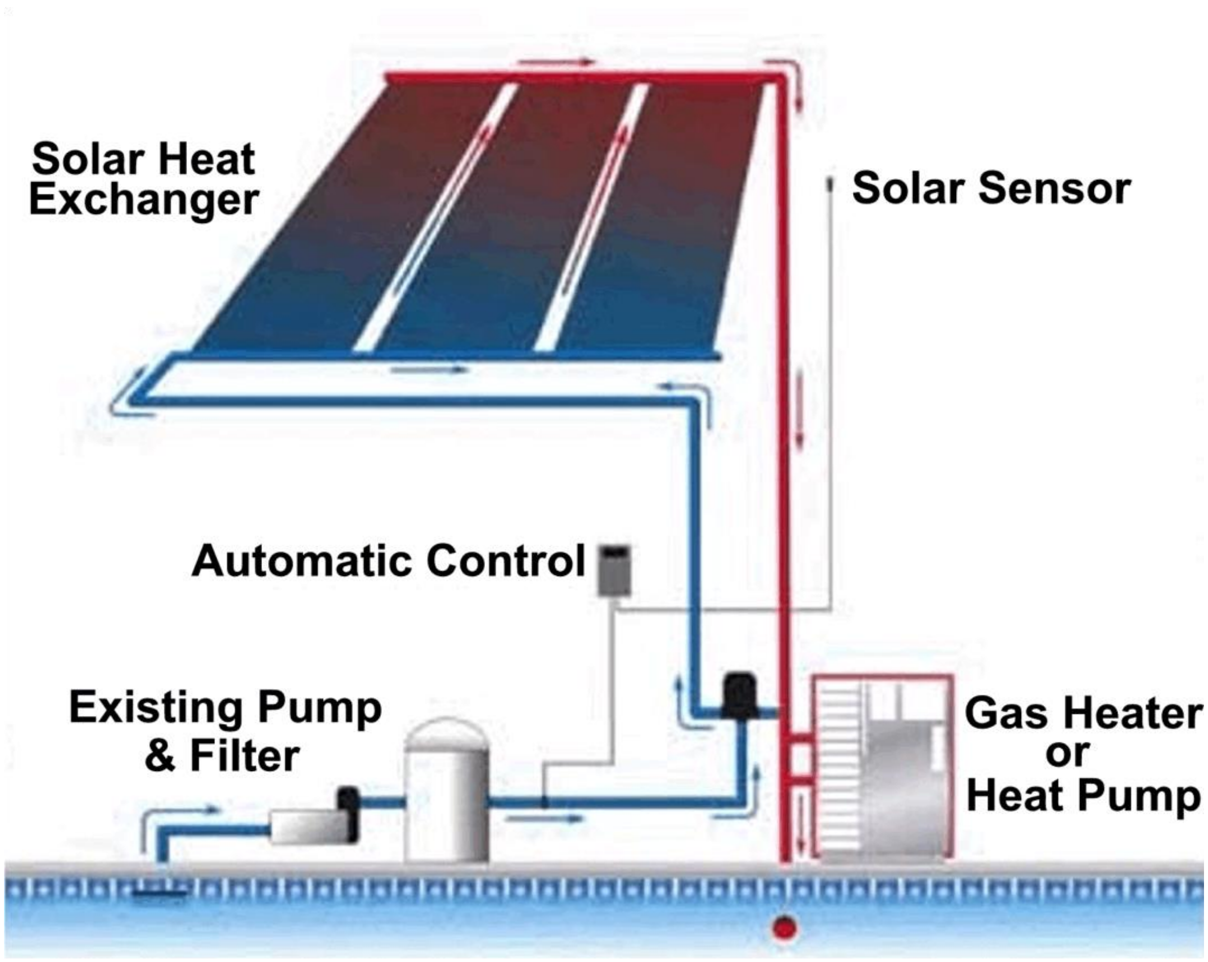
DOMESTIC HOT WATER





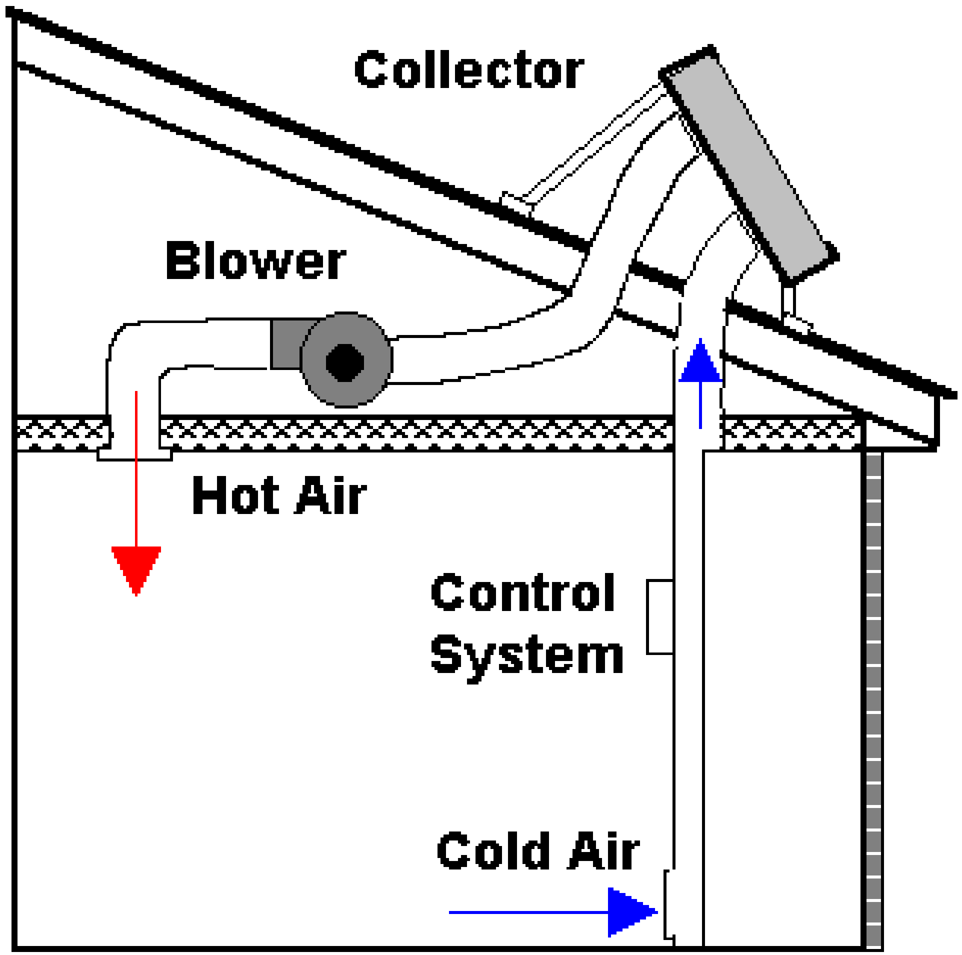
Applications of Flat Plate Collectors

WATER HEATING



Applications of Flat Plate Collectors

SPACE HEATING



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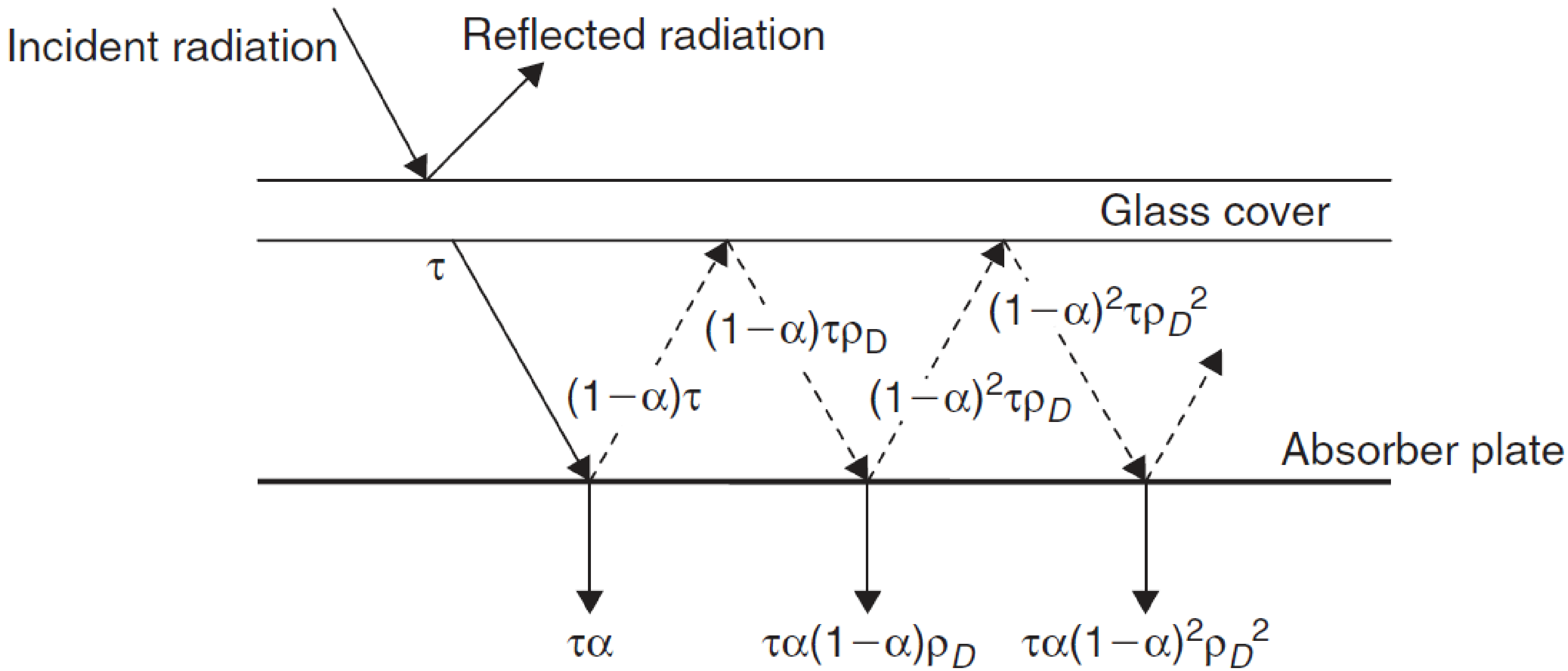
Energy Absorbed by a Flat Plate Collector

- The irradiation incident on a collector (G_t) is not all absorbed.
- Once the irradiation penetrates the glass cover, part of it is absorbed by the collector, but another part is reflected back diffusely to the glass cover.
- The glass cover then reflects diffusely to the absorber, and so on.

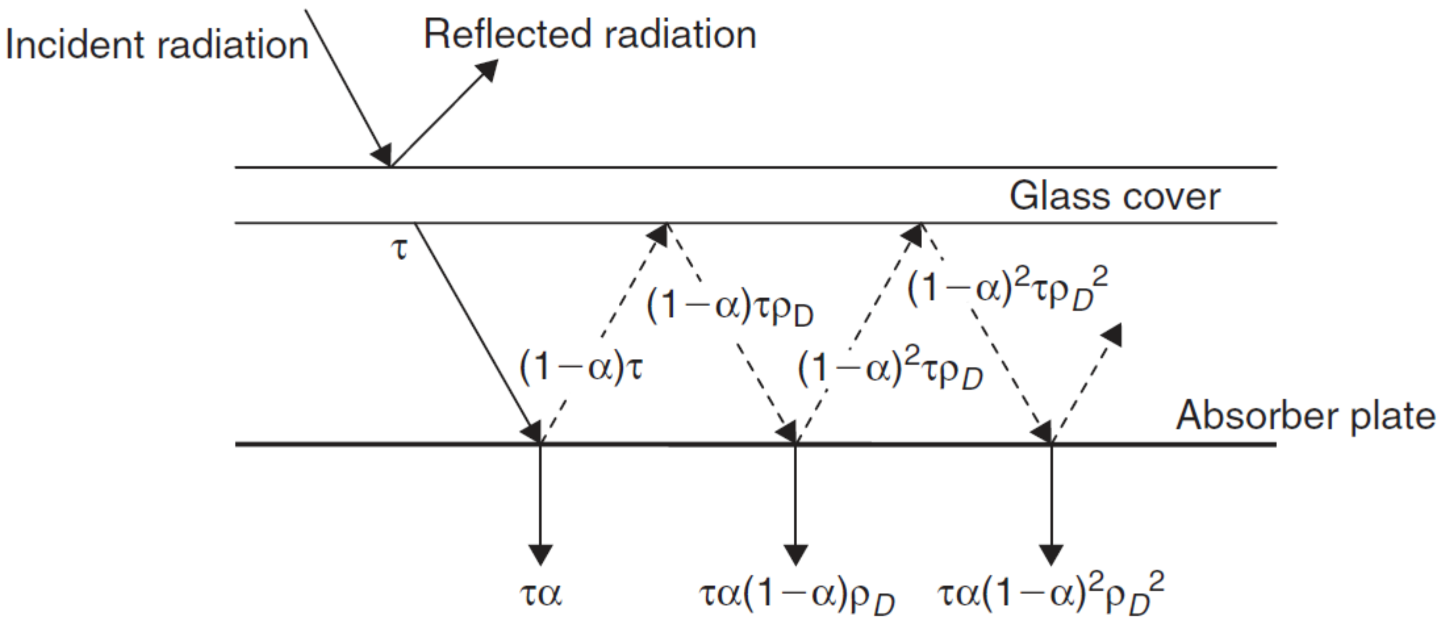


Energy Absorbed by a Flat Plate Collector

- The net energy absorbed by the collector can be expressed in terms of a quantity called $(\tau\alpha)$.
- Theoretically, the net energy absorbed by the collector per unit area is:

$$S = G_t\,(\tau\alpha)_{av}$$

Where $(\tau\alpha)_{av}$ is the average value of $(\tau\alpha)$



Energy Gain of a Flat Plate Collector

- The useful energy gain of a flat plate collector is given by:

  $Q_u = S \times A_c - Q_{loss}$

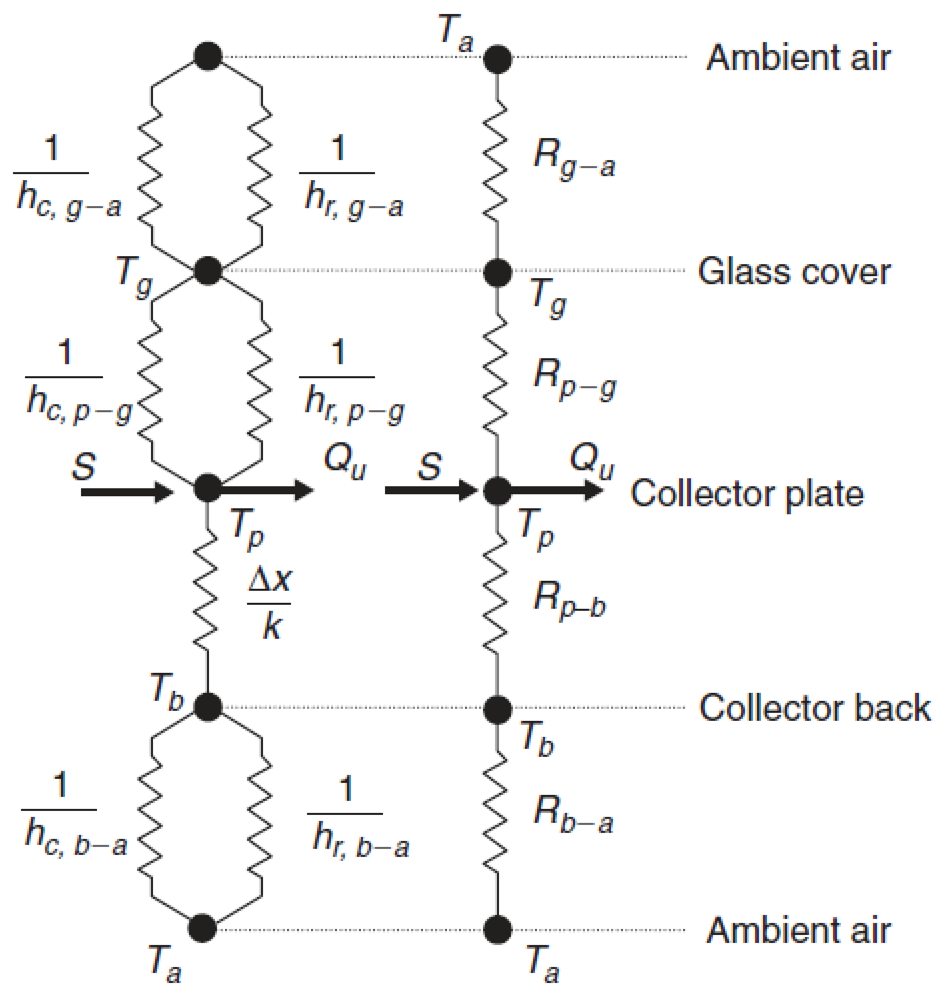
- Q_{loss} can be due to energy loss through:
  - **Top of the collector**
  - **Bottom of collector**
  - **Edges of collector**

- Q_{loss} can be expressed as: $Q_{loss} = U_L\, A_c\, (T_p - T_a)$

  where,
  - **T_p: mean temperature of the absorber plate**
  - **T_a: ambient temperature**
  - **U_L: overall heat transfer coefficient based on collector area**

Energy Loss of a Flat Plate Collector

- U_L consists of U_t (top), U_b (bottom), and U_e (edges)

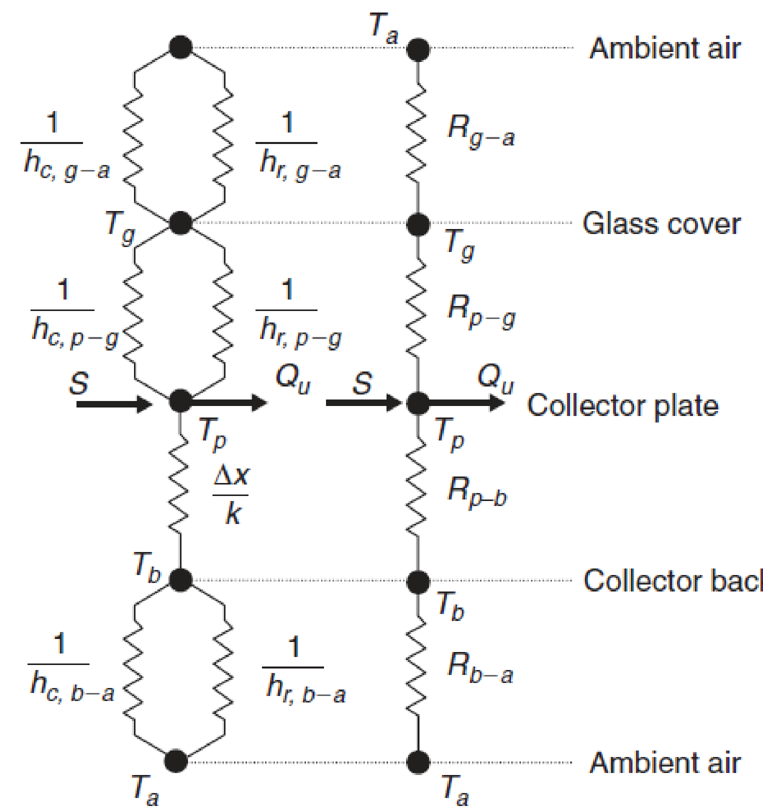


(a) Heat transfer network (b) Resistance network

Energy Loss of a Flat Plate Collector

U_t involves the calculation of:

- $h_{c,p\text{-}g}$: convective heat transfer coefficient between plate and glazing
- $h_{r,p\text{-}g}$: radiative heat transfer coefficient between plate and glazing
- $h_{c,g\text{-}a}$: convective heat transfer coefficient between glazing and ambient air
- $h_{r,g\text{-}a}$: radiative heat transfer coefficient between glazing and ambient air



(a) Heat transfer network (b) Resistance network

- Calculations of all the components of U_t is complicated.

Energy Loss of a Flat Plate Collector

- A relatively simple alternative formula can be used:

$$U_t = \frac{1}{\dfrac{N_g}{\dfrac{C}{T_p}\left[\dfrac{T_p - T_a}{N_g + f}\right]^{0.33} + \dfrac{1}{h_w}}} + \frac{\sigma(T_p^2 + T_a^2)(T_p + T_a)}{\dfrac{1}{\varepsilon_p + 0.05N_g(1 - \varepsilon_p)} + \dfrac{2N_g + f - 1}{\varepsilon_g} - N_g}$$

$$f = (1 - 0.04h_w + 0.0005h_w^2)(1 + 0.091N_g)$$

$$C = 365.9\,(1 - 0.00883\,\alpha + 0.0001298\,\alpha^2)$$

$$h_w = \frac{8.6V^{0.6}}{L^{0.4}}$$

Energy Loss of a Flat Plate Collector

N_g = number of glass covers

T_p = absorber plate temperature

T_a = ambient temperature

σ = Stefan-Boltzmann constant

ε_p = emittance of absorber plate

ε_g = emittance of glazing

α = Tilt angle

V = Wind velocity

L = Collector length

Energy Loss of a Flat Plate Collector

- U_b can be found from:

$$U_b = \frac{1}{\dfrac{t_b}{k_b} + \dfrac{1}{h_{c,b-a}}}$$

Where,

t_b = thickness of back insulation (m).

k_b = conductivity of back insulation (W/m-K).

$h_{c,\,b-a}$ = convection heat loss coefficient from back to ambient (W/m^2-K).

Energy Loss of a Flat Plate Collector

- U_e can be found from:

$$U_e = \frac{1}{\dfrac{t_e}{k_e} + \dfrac{1}{h_{c,e-a}}}$$

Where,

t_e = thickness of edge insulation (m).
k_e = conductivity of edge insulation (W/m-K).
$h_{c,\, e-a}$ = convection heat loss coefficient from edge to ambient (W/m^2-K).

Energy Gain of a Flat Plate Collector

- The useful energy gain of a flat plate collector is given by:

  $Q_u = S \times A_c - Q_{loss}$

- Expanding all terms,

$$Q_u = A_c[G_t(\tau\alpha) - U_L(T_p - T_a)]$$

- The useful energy gained by the collector is transferred completely to the working fluid. Therefore,

$$Q_u = A_c[G_t(\tau\alpha) - U_L(T_p - T_a)] = \dot{m}c_p[T_o - T_i]$$

Where,

- ***T_i*** **: fluid inlet temperature**
- ***T_o*** **: fluid outlet temperature**

Heat Removal Factor

$$Q_u = A_c[G_t(\tau\alpha) - U_L(T_p - T_a)] = \dot{m}c_p[T_o - T_i]$$

- Calculating T_p accurately is difficult.
- It is more convenient to express Q_u in terms of the fluid temperatures.
- A useful definition is the heat removal factor (F_R):

$$F_R = \frac{\text{Actual output}}{\text{Output for plate temperature} = \text{Fluid inlet temperature}}$$

Heat Removal Factor

- By using the heat removal factor (F_R), the useful energy gain equation becomes:

$$Q_u = A_c F_R [G_t(\tau\alpha) - U_L(T_i - T_a)]$$

- F_R depends on many factors, and it can be found analytically.
- F_R can also be found experimentally.

Collector Efficiency

- Collector efficiency (η) is defined as the:
- η = useful energy gain / irradiation incident on the collector

$$\eta = \frac{Q_u}{G_t A_c}$$

- This equation can be expressed in terms of F_R:

$$\eta = F_R\left[(\tau\alpha) - \frac{U_L(T_i - T_a)}{G_t}\right]$$

Collector Efficiency

- The efficiency equation can be rearranged as follows:

$$\eta = F_R(\tau\alpha) - F_R U_L \frac{T_i - T_a}{G_t}$$

- If changes in F_R and U_L are small, the equation above represents a straight line, where:
  - **$(T_i - T_a) / G_t$ is the independent variable**
  - **η is the dependent variable**
  - **$F_R(\tau\alpha)$ is the intercept**
  - **$(-F_R U_L)$ is the slope**

Collector Efficiency

$$\eta = F_R(\tau\alpha) - F_R U_L \frac{T_i - T_a}{G_t}$$