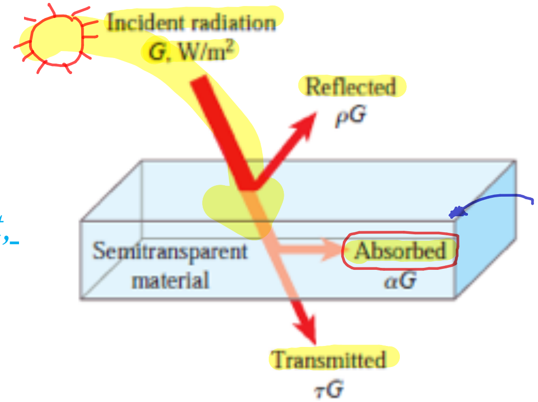
TOPIC 4(A)- Calculations

Solar collector calculations

(thermodynamics book, chapter 18 “RENEWABLE ENERGY”)

1. Solar Radiation

When solar radiation strikes a surface, *part of it is absorbed, part of it is reflected, and the remaining part, any, is transmitted*.



That is, $\alpha + \tau + \rho = 1$

where τ is the transmissivity, ρ is the reflectivity, and α is the absorptivity of the surface for solar energy.

$G \; (W/m^2)$

$A \; (m^2)$

$\dot{Q}_{incident} = GA$

(W)

TABLE 18–2

Comparison of the solar absorptivity α_s of some surfaces with their emissivity ε at room temperature

Surface	α_s	ε
Aluminum		
Polished	0.09	0.03
Anodized	0.14	0.84
Foil	0.15	0.05
Copper		
Polished	0.18	0.03
Tarnished	0.65	0.75
Stainless steel		
Polished	0.37	0.60
Dull	0.50	0.21
Plated metals		
Black nickel oxide	0.92	0.08
Black chrome	0.87	0.09
Concrete	0.60	0.88
White marble	0.46	0.95
Red brick	0.63	0.93
Asphalt	0.90	0.90
Black paint	0.97	0.97
White paint	0.14	0.93
Snow	0.28	0.97
Human skin (Caucasian)	0.62	0.97

Here, we also define **emissivity ε of a surface as a measure of how closely a real surface approximates a blackbody**, for which ε = 1. Therefore, the emissivity of a surface varies between zero and one, 0 < ε < 1.

$\boxed{\dot{Q}_{incident} = GA}$

absorbed

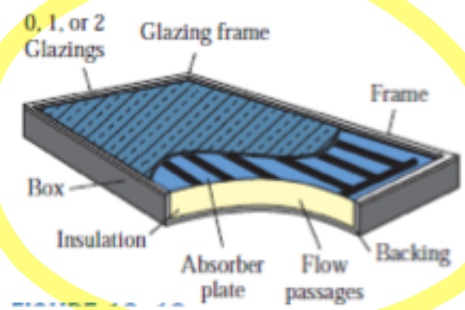
$\dot{Q}_{abs} = \tau\alpha AG$

$\dot{Q}_{incident} = GA \quad (Watt)$

2. Flat-Plate Solar Collector

The rate of solar heat absorbed by the absorber plate is:

$$\dot{Q}_{abs} = \tau \alpha A G$$



where τ is the transmissivity of the glazing, α is the absorptivity of the absorber plate, A is the area of the collector surface, in m^2, and G is the solar *insolation* or *irradiation* (solar radiation incident per unit surface area), in $\boxed{W/m^2}$. Heat is lost from the collector by convection to the surrounding air and by radiation to the surrounding surfaces and sky, and it can be expressed as

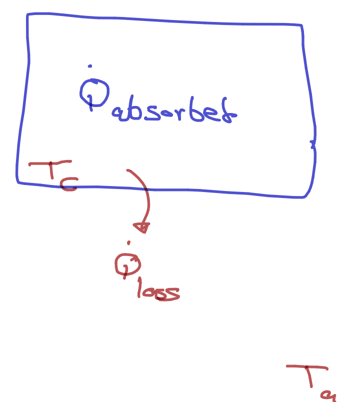
$$\dot{Q}_{loss} = UA(T_c - T_a)$$

where U is the overall heat transfer coefficient, in $W/m^2 \cdot °C$, that accounts for combined effects of convection and radiation, T_c is the average collector temperature, and T_a is the ambient air temperature, both in °C. The useful heat transferred to the water is the difference between the heat absorbed and the heat lost:

$$\dot{Q}_{useful} = \dot{Q}_{abs} - \dot{Q}_{loss}$$

$$= \tau \alpha A G - UA(T_c - T_a)$$

$$= A(\tau \alpha G - U(T_c - T_a))$$



If the mass flow rate of water flowing through the collector $\dot{m}$ is known, the useful heat can also be determined from:

4-28

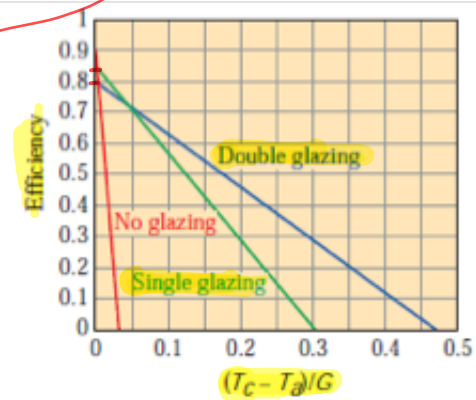
$$\dot{Q}_{useful} = \dot{m}\, C_p \,(T_{w,out} - T_{w,in})$$

where c_p is the specific heat of water, in J/kg·°C, $T_{w,in}$ and $T_{w,out}$ are the inlet and outlet temperatures of water, respectively. For the same useful heat, a higher mass flow rate would yield a lower temperature rise for water in the collector.

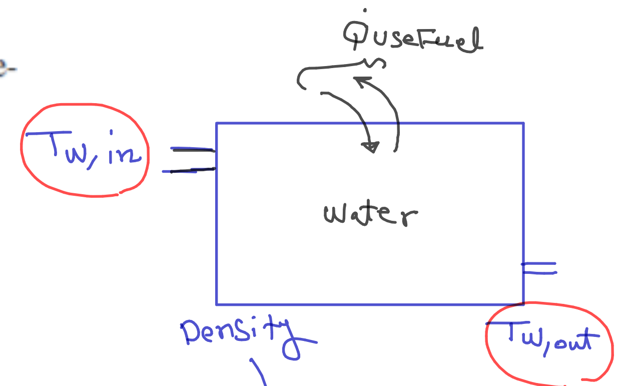
The efficiency of a solar collector may be defined as the ratio of the useful heat delivered to water to the radiation incident on the collector:

$$\eta_c = \frac{\dot{Q}_{useful}}{\dot{Q}_{incident}} = \frac{\tau\alpha\, A G - U A\,(T_c - T_a)}{A G}$$

$$\eta_c = \frac{\text{out Put}}{\text{inPut}}$$



$$\boxed{\eta_c = \tau\alpha - U\,\frac{(T_c - T_a)}{G}}$$



$$\dot{m} = \rho\, \dot{V}$$

Mass Flow rate (kg/s)

Density kg/m³

volume Flow rate m³/s

$$\dot{Q}_{useful} = \dot{m}\, C_p \,(T_{w,out} - T_{w,in})$$

TABLE 18–5

Typical flat-plate solar collector properties (Source: Mitchell, 1983)

	$\tau\alpha$	U, W/m²·°C	U, Btu/h·ft²·°F
No glazing	0.90	28	5
Single glazing	0.85	2.8	0.5
Double glazing	0.80	1.7	0.3

Equation 18–6 gives the collector efficiency as a function of average temperature of the collector. However, this temperature is usually not available. Instead, water temperature at the collector inlet is available. The collector efficiency may be defined as a function of the water inlet temperature as

$$\eta_c = F_R\,\tau\alpha - F_R\,U\,\frac{T_{w,in} - T_a}{G}$$

where F_R is the **collector heat removal factor**.

This relation is known as **Hottel-Whillier-Bliss equation**.

The solar collector is normally fixed in position. As the angle of solar incident radiation changes throughout the day, the product $\tau\alpha$ also changes. This change can be accounted for by including an *incident angle modifier* $K_{\tau\alpha}$ in Eq. 18–7 as

$$\eta_c = K_{\tau\alpha}\,F_R\,\tau\alpha - F_R\,U\,\frac{T_{w,in} - T_a}{G}$$

EXAMPLE 18–1 **Efficiency of a Flat-Plate Solar Collector**

The specifications of two flat-plate collectors are as follows:

Single glazing: $\tau = 0.96$, $\alpha = 0.96$, $U = 9\ \text{W/m}^2\cdot°\text{C}$

Double glazing: $\tau = 0.93$, $\alpha = 0.93$, $U = 6.5\ \text{W/m}^2\cdot°\text{C}$

F_R

The heat removal factor for both collectors is 0.95, the solar insolation is 550 W/m², and the ambient air temperature is 23°C. For each collector, determine (*a*) the collector efficiency if the water enters the collector at 45°C, (*b*) the temperature of water at which the collector efficiency is zero, and (*c*) the maximum collector efficiency. Take the incident angle modifier to be 1. (*d*) Also, plot the collector efficiency as a function of $(T_c - T_a)/G$ for each collector.

G T_a $T_{w,in}$ $K_{\tau\alpha}$

a)

$$\boxed{\eta_c = K_{\tau\alpha} F_R \tau\alpha - F_R U \frac{T_{w,in} - T_a}{G}}$$

Single :-

$$\eta_c = 1 * 0.95 * 0.96 * 0.96 - 0.95 * 9 * \frac{45 - 23}{550}$$

$$= 0.534$$

Double :-

$$\eta_c = 1 * 0.95 * 0.93 * 0.93 - 0.95 * 6.5 * \frac{45 - 23}{550}$$

$$= 0.575$$

b) $\eta_c = 0$

$$K_{\tau\alpha} F_R \tau\alpha - F_R U \frac{T_{w,in} - T_a}{G} = 0$$

$$\Longrightarrow K_{\tau\alpha} F_R \tau\alpha = F_R U \frac{T_{w,in} - T_a}{G}$$

Single :-

$$1 * 0.95 * 0.96 * 0.96 = 0.95 * 9 * \frac{T_{w,in} - 23}{550}$$

$$T_{w,in} = 79.3°C$$

Double :-

$$1 * 0.95 * 0.93 * 0.93 = 0.95 * 6.5 * \frac{T_{w,in} - 23}{550}$$

$$T_{w,in} = 96.2°C$$

c) η_c is MAXIMUM @ $T_{w,in} = T_a$

$$T_{w,in} - T_a = 0$$

$$\eta_{c,Max} = K_{\tau\alpha} F_R \tau\alpha$$

Single $\eta_{c,Max} = 1 * 0.95 * 0.96 * 0.96 = 0.876$

Double $\eta_{c,Max} = 1 * 0.95 * 0.93 * 0.93 = 0.822$

18–29 Solar radiation is incident on a flat-plate collector at a rate of 930 W/m^2 (G). The glazing has a transmissivty of 0.82 (τ) and the absorptivity of absorber plate is 0.94 (α). Determine the maximum efficiency of this collector.

$$\eta_c = \tau\alpha - U\cancel{\frac{T_c - T_a}{G}}^{\,0}$$

η_c is Max @ $T_c = T_a$

$$T_c - T_a = 0$$

$$\eta_{c,Max} = \tau\alpha$$

$$= 0.82 * 0.94 = 0.771$$

$$= 77.1\ \%$$

H.W

18–30 Solar radiation is incident on a flat-plate collector at a rate of 750 W/m². The glazing has a transmissivity of 0.86 and the absorptivity of absorber plate is 0.95. The heat loss coefficient of the collector is 3 W/m²·°C. The collector is at an average temperature of 45°C and the ambient air temperature is 23°C. Determine the efficiency of this collector.

$$\eta_c = \tau\alpha - U \frac{T_c - T_a}{G}$$

$$= 0.86 * 0.95 - (3) \frac{45 - 23}{750}$$

$$= 0.729 = 72.9\ \%$$

H.W

18–35 A solar power plant utilizes parabolic trough collectors with a total collector area of 2500 m². The solar irradiation is 700 W/m². If the efficiency of this solar plant is 8 percent, what is the power generated? *Answer:* 140 kW

$$\eta_{th,\,Solar} = \frac{\dot{W}_{out}}{\dot{Q}_{incident}} = \frac{\dot{W}_{out}}{A_c\, G}$$

$$\dot{W}_{out} = \eta_{th}\, A_c\, G$$

$$= 0.08 * 2500 * 700$$

$$= 140{,}000\ W$$

$$= 140\ kW$$

18–32 Solar radiation is incident on a flat-plate collector at a rate of 880 W/m². The product of the transmissivty of glazing and the absorptivity of absorber plate is 0.82. The collector has a surface area of 33 m². This collector supplies hot water to a facility at a rate of 6.3 L/min. Cold water enters the collector at 18°C. If the efficiency of this collector is 70 percent, determine the temperature of hot water provided by the collector. *Answer:* 64.3°C

$$\dot{m} = \rho \dot{V}$$

$$= 1 \ \text{kg/L} * 6.3 \ \text{L}/60 \ \text{sec}$$

$$= 0.105 \ \text{kg/s}$$

$$\dot{Q}_{incident} = A G = 33 * 880$$

$$= 29040 \ \text{W}$$

$$\eta_c = \frac{\dot{Q}_{useful}}{\dot{Q}_{incident}} \quad \Big\} \quad \dot{Q}_{useful} = 0.7 * 29040$$

$$\dot{Q}_{useful} = 20328 \ \text{W}$$

$$\dot{Q}_{useful} = \dot{m} \, c_p \, (T_{w,out} - T_{w,in})$$

$$20328 = 0.105 * 4.28 \, (T_{w,out} - 18)$$

$$T_{w,out} = 64.3^\circ \text{C}$$

$$\dot{m} = \rho \dot{V}$$

$$\dot{Q}_{useful} = \dot{m} \, c_p \, (T_{w,out} - T_{w,in})$$

?? ?? ??

$$\eta = \frac{\dot{Q}_{useful} \ ???}{\dot{Q}_{incident}}$$

$$A G$$

$$\rho = 1000 \ \text{kg/m}^3$$

$$= 1 \ \text{kg/L}$$

18–48 A typical winter day in Reno, Nevada (39° N latitude), is cold but sunny, and thus the solar heat gain through the windows can be more than the heat loss through them during daytime. Consider a house with double-door-type windows that are double paned with 3-mm-thick glasses and 6.4 mm of air space and have aluminum frames and spacers. The overall heat transfer coefficient for this window is 4.55 W/m²·°C. The house is maintained at 22°C at all times. Determine if the house is losing more or less heat than it is gaining from the sun through an east window on a typical day in January for a 24-h period if the average outdoor temperature is 10°C. *Answer:* less

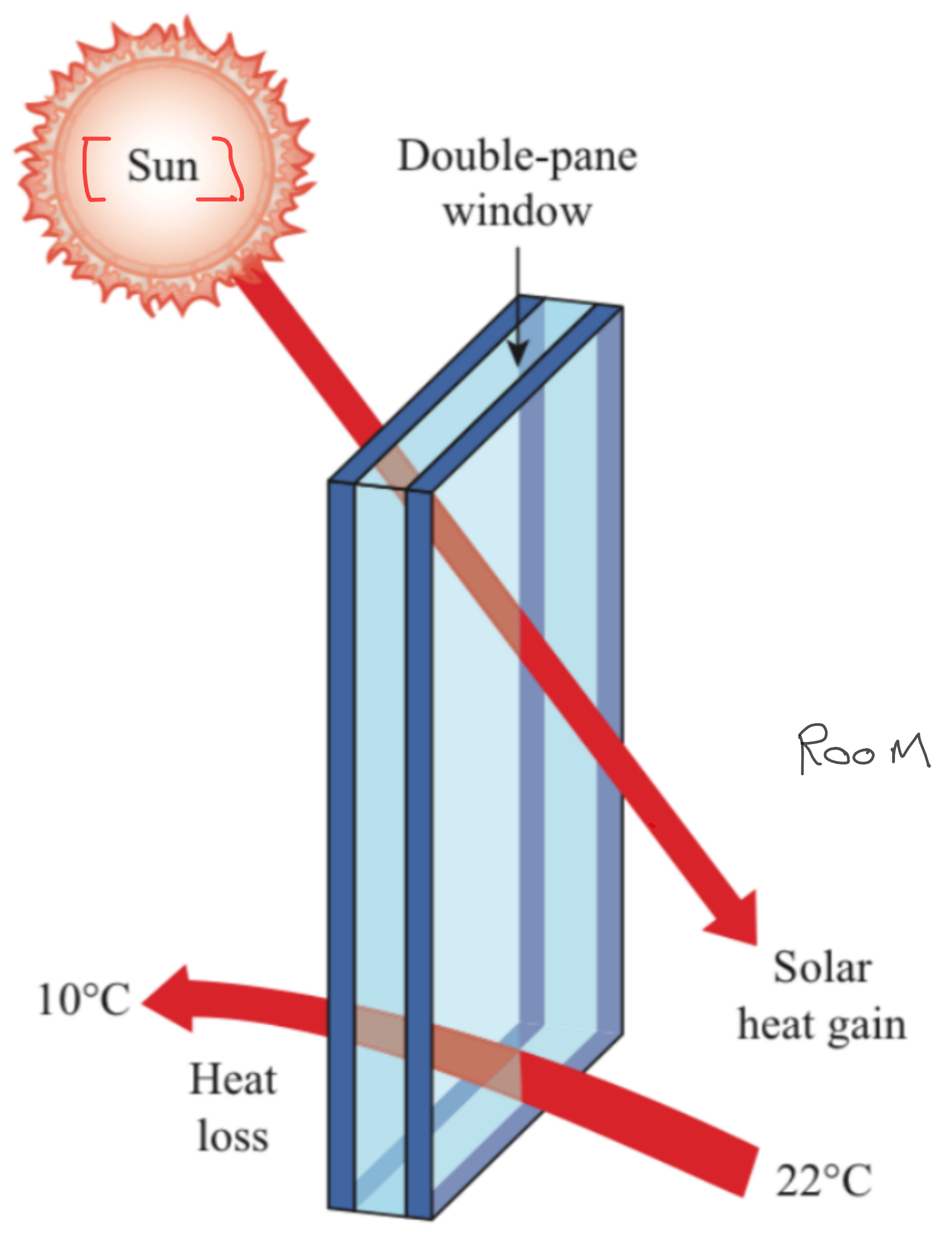


FIGURE P18–48

$SC = \boxed{0.88}$ } Table $\boxed{18-5}$

$SHGC = 0.87\ SC$

$\Downarrow$

$\dot{Q}_{solar,gain} = SHGC\ A_{glazing} \times q_{solar,daily\ total}$

$U = 4.55\ W/m^2 \cdot C$

$q = 1863\ Wh/m^2$ } Table 18-3

$\dot{M} = M/\Delta t$ $\dot{E} = E/\Delta t$ $\dot{Q} = Q/\Delta t \Rightarrow Q_{loss} = \dot{Q}_{loss}\,\Delta t$

18–48 A typical winter day in Reno, Nevada (39° N latitude), is cold but sunny, and thus the solar heat gain through the windows can be more than the heat loss through them during daytime. Consider a house with double-door-type windows that are double paned with 3-mm-thick glasses and 6.4 mm of air space and have aluminum frames and spacers. The overall heat transfer coefficient for this window is 4.55 W/m²·°C. The house is maintained at 22°C at all times. Determine if the house is losing more or less heat than it is gaining from the sun through an east window on a typical day in January for a 24-h period if the average outdoor temperature is 10°C. *Answer:* less

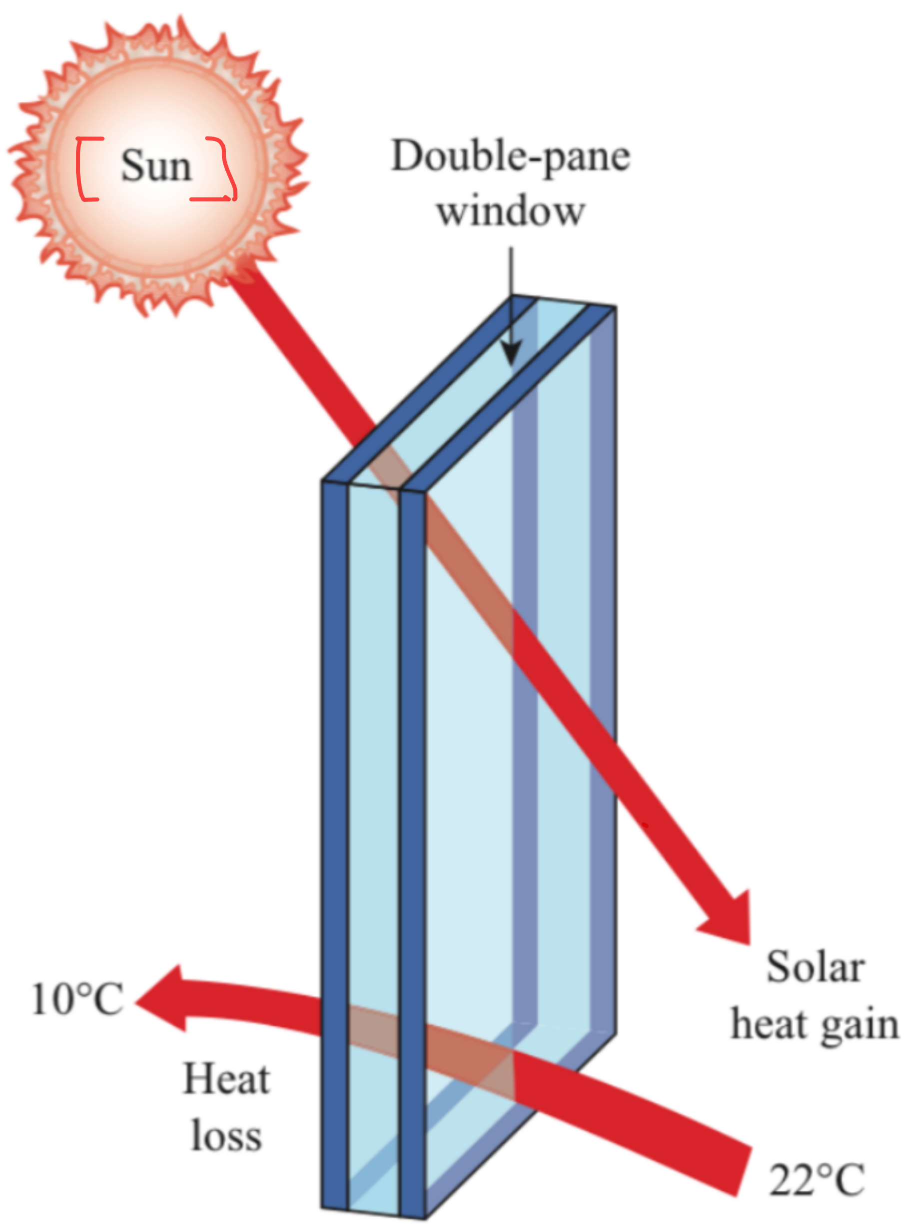


FIGURE P18–48

$SHGC = 0.87 * 0.88$

$= 0.7656$

$Q_{Solar,\,gain} = SHGS * A_{glazing} * q_{Solar\ daily\ total}$

$= 0.7656 * 1 * 1863$

$= 1426\ Wh = 1.426\ kWh$

$Q_{loss,\,window} = \dot{Q}_{loss} * \Delta t$

$= U_{Window} A_{Wind} (T_i - T_{o,av}) * 24\ hr$

$= 4.55 * 1 * (22 - 10) * 24\ hr$

$= 1310\ Wh = 1.31\ kWh$

$Q_{loss,\,window} < Q_{Solar,\,gain}$

through East windows in January

$\dot{M} = M/\Delta t$ $\dot{E} = E/\Delta t$ $\dot{Q} = Q/\Delta t \Rightarrow Q_{loss} = \dot{Q}_{loss}\,\Delta t$

18–48 A typical winter day in Reno, Nevada (39° N latitude), is cold but sunny, and thus the solar heat gain through the windows can be more than the heat loss through them during daytime. Consider a house with double-door-type windows that are double paned with 3-mm-thick glasses and 6.4 mm of air space and have aluminum frames and spacers. The overall heat transfer coefficient for this window is 4.55 W/m²·°C. The house is maintained at 22°C at all times. Determine if the house is losing more or less heat than it is gaining from the sun through an east window on a typical day in January for a 24-h period if the average outdoor temperature is 10°C. *Answer:* less

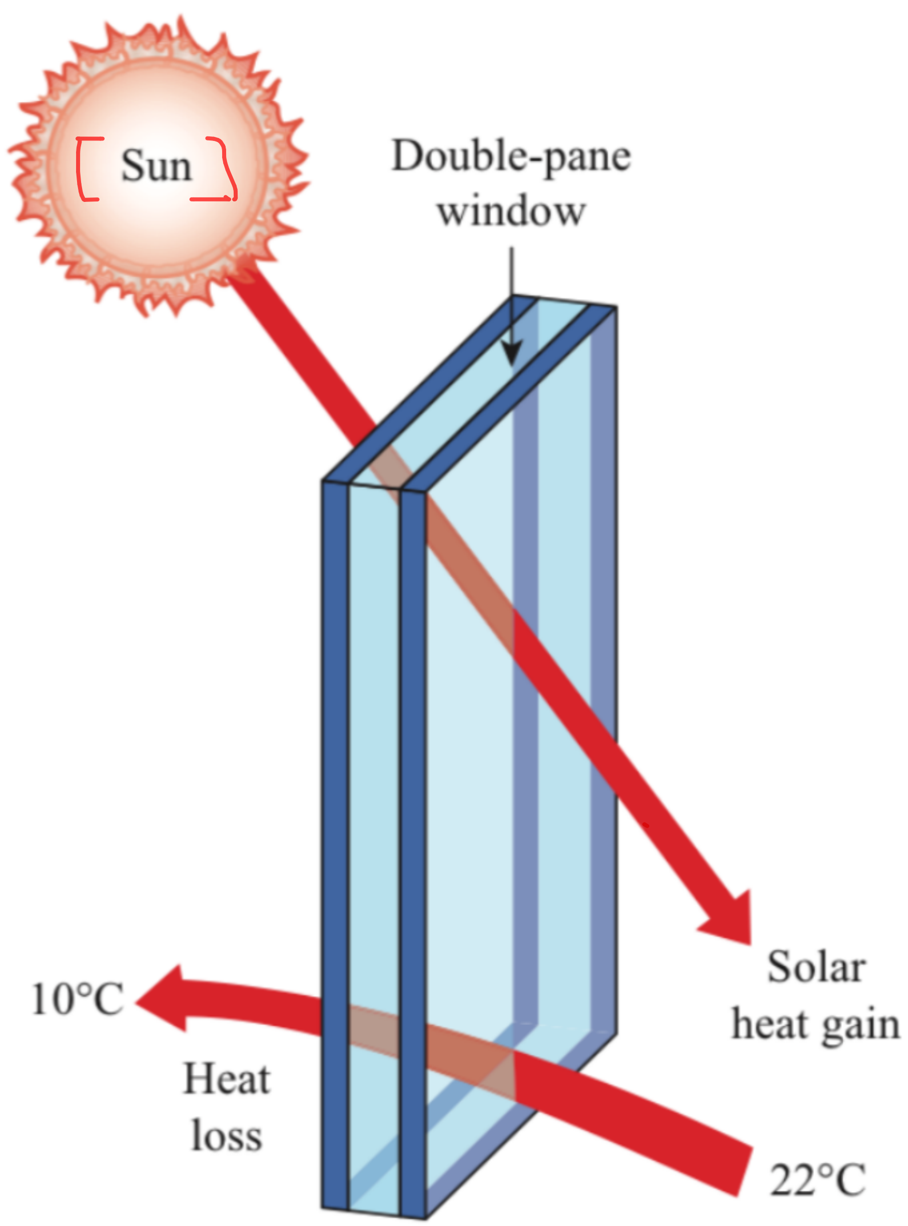


FIGURE P18–48

$SHGC = 0.87 * 0.88$

$= 0.7656$

$Q_{solar,gain} = SHGS * A_{glazing} * q_{solar\ daily\ total}$

$= 0.7656 * 1 * 1863$

$= 1426\ Wh = 1.426\ kWh$

$Q_{loss,window} = \dot{Q}_{loss} * \Delta t$

$= U_{window} A_{wind} (T_i - T_{o,av}) * 24\,hr$

$= 4.55 * 1 * (22-10) * 24\,hr$

$= 1310\ Wh = 1.31\ kWh$

$Q_{loss,window} < Q_{solar,gain}$

through East windows in January

3. Concentrating Solar Collector

The most common type of concentrating solar collector is **parabolic trough collector**

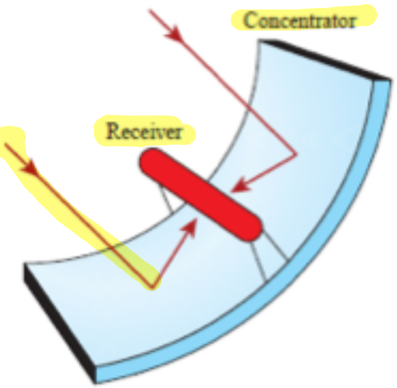
In a concentrating collector, solar radiation is incident on the collector surface, called aperture area A_a, and this radiation reflected or redirected into a smaller receiver area A_r. The concentration factor CR is then defined as

$$CR = \frac{A_a}{A_r} > 1$$

The value of CR is greater than one. The greater the value of CR, the greater the hot fluid temperature. The effectiveness of the aperture-to-receiver process is functions of orientation of surfaces and their radiative properties such as absorptivity and reflectivity. This effectiveness is expressed by an optical efficiency term η_{ar}. Then, the net rate of solar radiation supplied to the receiver is

$$\dot{Q}_r = \eta_{ar} A_a G$$

where G is the solar irradiation, in W/m2



(a)


(b)

The **rate of heat loss from the collector** is expressed as

$$\dot{Q}_{\text{loss}} = UA_r(T_c - T_a)$$

The **useful heat transferred** to the fluid is:

$$\dot{Q}_{\text{useful}} = \dot{Q}_r - \dot{Q}_{\text{loss}} = \eta_{ar}A_aG - UA_r(T_c - T_a)$$

The efficiency of this solar collector is *defined as the ratio of the useful heat delivered to the fluid to the radiation incident on the collector*:

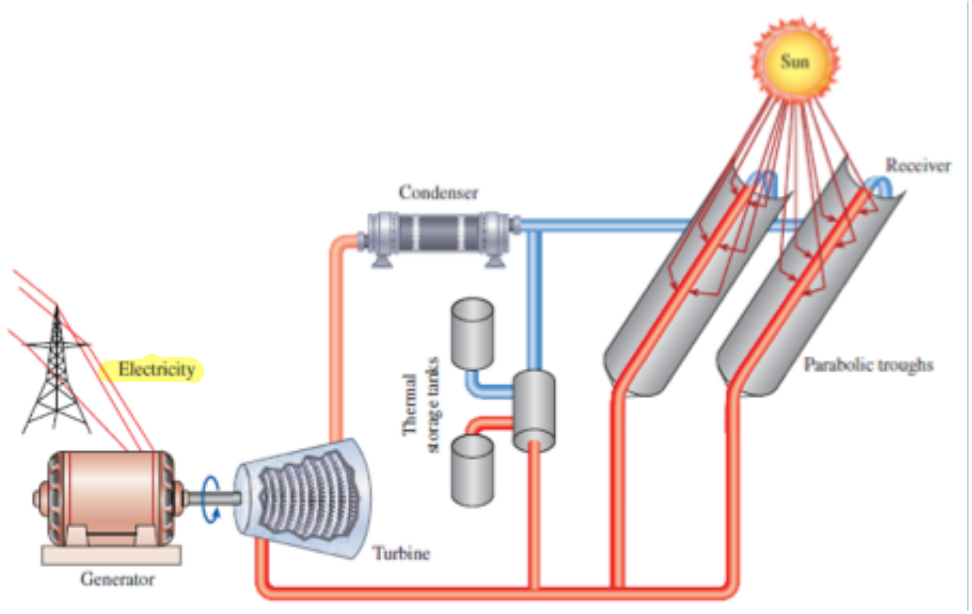
$$\eta_c = \frac{\dot{Q}_{\text{useful}}}{\dot{Q}_{\text{incident}}} = \frac{\eta_{ar}A_aG - UA_r(T_c - T_a)}{A_aG}$$

$$= \eta_{ar} - \frac{UA_r(T_c - T_a)}{A_aG} = \eta_{ar} - \frac{U(T_c - T_a)}{\text{CR} \times G}$$

Therefore, *the collector efficiency is maximized for maximum values of the optical efficiency of the aperture-to-receiver process ηar and the concentration factor CR*.

The efficiency of concentrating collectors is greater than that of flat-plate collector

- Linear Concentrating Solar Power Collector



The efficiency of <u>*a solar system used to produce electricity*</u> may be defined as the power produced divided by the total solar irradiation. That is,

$$\eta_{\text{th,solar}} = \frac{\dot{W}_{\text{out}}}{\dot{Q}_{\text{incident}}} = \frac{\dot{W}_{\text{out}}}{A_c G}$$

where *Ac* is the collector surface area receiving solar irradiation and *G* is the solar irradiation.

$SHGC = 0.87\ SC$

$\Downarrow$

$\phi_{Solar,gain} = SHGC\ A_{glazing} \times q_{Solar\ daily\ total}$

18–47 Consider a building in New York (40° N latitude) that has 76 m² of window area on its south wall. The windows are double-pane heat-absorbing type, and are equipped with light-colored venetian blinds with a shading coefficient of SC = 0.30. Determine the total solar heat gain of the building through the south windows at solar noon in April. What would your answer be if there were no blinds at the windows?

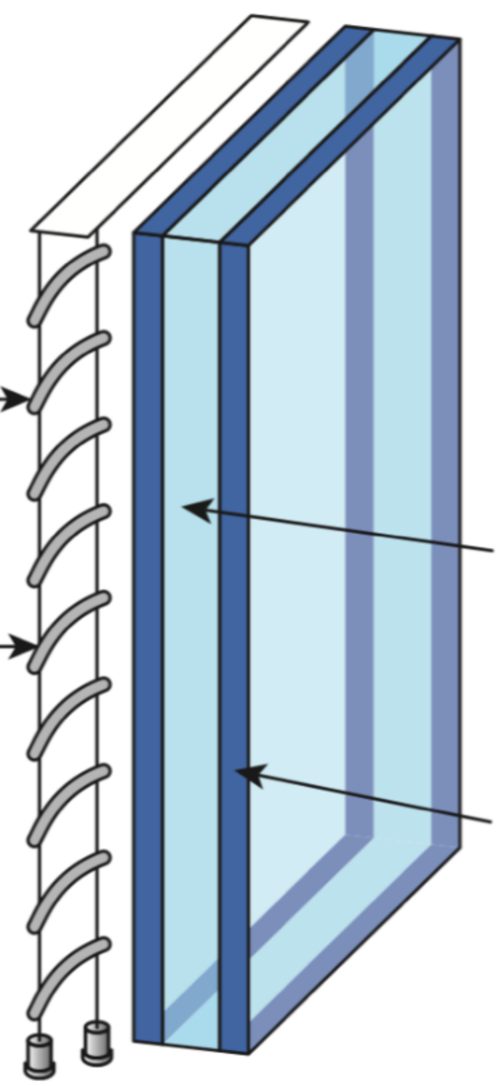


FIGURE P18–47

Without blinds SC = 0.58 } Table 18-6

With blinds SC = 0.3 } given

$\dot{q} = 559\ W/m^2$] Table 18-3

Without the blinds :-

$SHGC = 0.87\ SC$

$= 0.87 * 0.58 = 0.5046$

$\dot{Q}_{solar,gain} = SHGC\ A_{glazing}\ \dot{q}_{solar,incident}$

$= 0.5046 * 76 * 559$

$= 21440\ W$

With the blinds :-

$SHGC = 0.87 * 0.3 = 0.261$

$\dot{Q}_{solar,gain} = SHGC * A_{glazing} * \dot{q}_{solar,incident}$

$= 0.261 * 76 * 559$

$= 11090\ W$

18–45 A house located in Boulder, Colorado (40° N latitude), has ordinary double-pane windows with 6-mm-thick glasses and the total window areas are 8, 6, 6, and 4 m^2 on the south, west, east, and north walls, respectively. Determine the total solar heat gain of the house at 9:00, 12:00, and 15:00 solar time in July. Also, determine the total amount of solar heat gain per day for an average day in January.

Month	Time	Solar radiation incident on the surface, W/m^2			
		North	East	South	West
July	9:00	117	701	190	114
July	12:00	138	149	395	149
July	15:00	117	114	190	701
January	Daily total	446	1863	5897	1863

Analysis The solar heat gain coefficient (SHGC) of the windows is determined from Eq.12-57 to be

$$SHGC = 0.87 \times SC = 0.87 \times 0.82 = 0.7134$$

The rate of solar heat gain is determined from

$$\dot{Q}_{\text{solar gain}} = SHGC \times A_{\text{glazing}} \times \dot{q}_{\text{solar, incident}}$$
$$= 0.7134 \times A_{\text{glazing}} \times \dot{q}_{\text{solar, incident}}$$

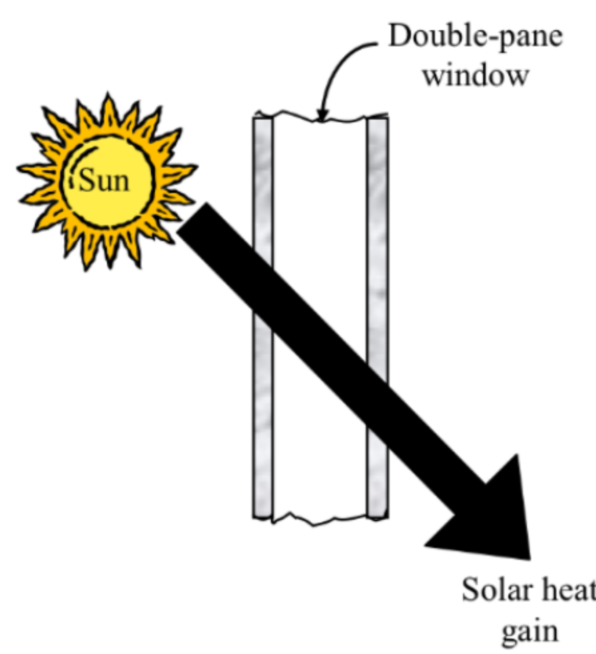
Then the rates of heat gain at the 4 walls at 3 different times in July become

North wall:

$$\dot{Q}_{\text{solar gain},9:00} = 0.7134 \times (4\ m^2) \times (117\ W/m^2) = \mathbf{334\ W}$$
$$\dot{Q}_{\text{solar gain},1200} = 0.7134 \times (4\ m^2) \times (138\ W/m^2) = \mathbf{394\ W}$$
$$\dot{Q}_{\text{solar gain},15:00} = 0.7134 \times (4\ m^2) \times (117\ W/m^2) = \mathbf{334\ W}$$

East wall:

$$\dot{Q}_{\text{solar gain},9:00} = 0.7134 \times (6\ m^2) \times (701\ W/m^2) = \mathbf{3001\ W}$$
$$\dot{Q}_{\text{solar gain},1200} = 0.7134 \times (6\ m^2) \times (149\ W/m^2) = \mathbf{638\ W}$$
$$\dot{Q}_{\text{solar gain},15:00} = 0.7134 \times (6\ m^2) \times (114\ W/m^2) = \mathbf{488\ W}$$



South wall:

$$\dot{Q}_{\text{solar gain},9:00} = 0.7134 \times (8\ m^2) \times (190\ W/m^2) = \mathbf{1084\ W}$$
$$\dot{Q}_{\text{solar gain},1200} = 0.7134 \times (8\ m^2) \times (395\ W/m^2) = \mathbf{2254\ W}$$
$$\dot{Q}_{\text{solar gain},15:00} = 0.7134 \times (8\ m^2) \times (190\ W/m^2) = \mathbf{1084\ W}$$

West wall:

$$\dot{Q}_{\text{solar gain},9:00} = 0.7134 \times (6\ m^2) \times (114\ W/m^2) = \mathbf{488\ W}$$
$$\dot{Q}_{\text{solar gain},1200} = 0.7134 \times (6\ m^2) \times (149\ W/m^2) = \mathbf{638\ W}$$
$$\dot{Q}_{\text{solar gain},15:00} = 0.7134 \times (6\ m^2) \times (701\ W/m^2) = \mathbf{3001\ W}$$

Similarly, the solar heat gain of the house through all of the windows in January is determined to be

January:

$$\dot{Q}_{\text{solar gain,North}} = 0.7134 \times (4\ m^2) \times (446\ Wh/m^2 \cdot day) = 1273\ Wh/day$$
$$\dot{Q}_{\text{solar gain,East}} = 0.7134 \times (6\ m^2) \times (1863\ Wh/m^2 \cdot day) = 7974\ Wh/day$$
$$\dot{Q}_{\text{solar gain,South}} = 0.7134 \times (8\ m^2) \times (5897\ Wh/m^2 \cdot day) = 33{,}655\ Wh/day$$
$$\dot{Q}_{\text{solar gain,West}} = 0.7134 \times (6\ m^2) \times (1863\ Wh/m^2 \cdot day) = 7974\ Wh/day$$

Therefore, for an average day in January,

$$\dot{Q}_{\text{solar gain per day}} = 1273 + 7974 + 33{,}655 + 7974 = 58{,}876\ Wh/day \cong \mathbf{58.9\ kWh/day}$$

$$\dot{Q}_{\text{Solar,gain}} = \underset{\Downarrow\ 0.87\ SC}{SHGC} \times A_{\text{glazing}} \times \dot{q}_{\text{solar incident}}$$

18–48 A typical winter day in Reno, Nevada (39° N latitude), is cold but sunny, and thus the solar heat gain through the windows can be more than the heat loss through them during daytime. Consider a house with double-door-type windows that are double paned with 3-mm-thick glasses and 6.4 mm of air space and have aluminum frames and spacers. The overall heat transfer coefficient for this window is 4.55 W/m²·°C. The house is maintained at 22°C at all times. Determine if the house is losing more or less heat than it is gaining from the sun through an east window on a typical day in January for a 24-h period if the average outdoor temperature is 10°C. *Answer:* less

18–49 Repeat Prob. 18–48 for a south window.

$$SHGC = 0.87 * 0.88$$
$$= 0.7656$$

$$Q_{Solar,\,gain} = SHGS * A_{glazing} * q_{Solar\ daily\ total}$$
$$= 0.7656 * 1 * 5897\ Wh/m^2$$
$$= 4515\ Wh = 4.515\ kWh$$

$$Q_{loss,\,window} = \dot{Q}_{loss} * \Delta t$$
$$= U_{Window} A_{Wind} (T_i - T_{o,av}) * 24\ hr$$
$$= 4.55 * 1 * (22 - 10) * 24\ hr$$
$$= 1310\ Wh = 1.31\ kWh$$

$$Q_{loss,\,window} < Q_{Solar,\,gain}$$

through South windows in January

1 therm = 29.31 kW hr

18–44 A manufacturing facility located at 32° N latitude has a glazing area of 60 m² facing west that consists of doublepane windows made of clear glass (SHGC = 0.766). To reduce the solar heat gain in summer, a reflective film that will reduce the SHGC to 0.35 is considered. The cooling season consists of June, July, August, and September, and the heating season, October through April. The average daily solar heat fluxes incident on the west side at this latitude are 2.35, 3.03, 3.62, 4.00, 4.20, 4.24, 4.16, 3.93, 3.48, 2.94, 2.33, and 2.07 kWh/day·m² for January through December, respectively. Also, the unit costs of electricity and natural gas are \$0.15/kWh and \$0.90/therm, respectively. If the coefficient of performance of the cooling system is 3.2 and the efficiency of the furnace is 0.90, determine the net annual cost savings due to installing reflective coating on the windows. Also, determine the simple payback period if the installation cost of reflective film is \$15/m². *Answers:* \$39, 23 years

$\dot{Q}_{Solar,\ Summer} = 4.24 * 30 + 4.16 * 31 + 3.93 * 31 + 3.48 * 30$

$= 482 \ kWh/m^2 \cdot year$

$\dot{Q}_{Solar,\ Winter} = 2.94 * 31 + 2.33 * 30 + 2.07 * 31 + 2.35 * 31 + 3.03 * 28 + 3.62 * 31 + 4 * 30 = 615 \ kWh/m^2 \cdot year$

Cooling load decrease (Summer) $= \dot{Q}_{Solar\ Sumer} * A_{glazing} (SHGC_{without\ Film} - SHGC_{with\ Film})$

$= 482 * 60 * (0.766 - 0.35)$

$= 12031 \ kWh/year$

Heating load increase (Winter) $= \dot{Q}_{Solar\ winter} * A_{glazing} (SHGC_{without\ Film} - SHGC_{with\ Film})$

$= 615 * 60 * (0.766 - 0.35)$

$= 15350 \ kWh/year = 523.7 \ therms/year$

Decrease in Cooling Cost $= \text{Cooling load Decrease} * \text{unit Cost of electricity} / Cop$

$= 12031 * 0.15 / 3.2$

$= 564 \ \$/year$

$$\text{increase in heating Cost} = \text{Heating load increase} * \text{Unit Cost Fuel} / \text{efficiency}$$

$$= 523.7 * 0.9 / 0.9$$

$$= 524 \ \$/\text{year}$$

$$\text{Cost Saving} = \text{Decrease in Cooling Cost} - \text{increase in heating Cost}$$

$$= 564 \ \$ - 524 \ \$$$

$$= 40 \ \$/\text{year}$$

$$\text{Implementation Cost} = 15 \ \$/m^2 * 60 \ m^2$$

$$= 900 \ \$$$

$$\text{Simple Payback Period} = \frac{\text{Implementation Cost}}{\text{Cost Saving}}$$

$$= \frac{900 \ \$}{40 \ \$/\text{year}} = 22.5 \ \text{Years}$$