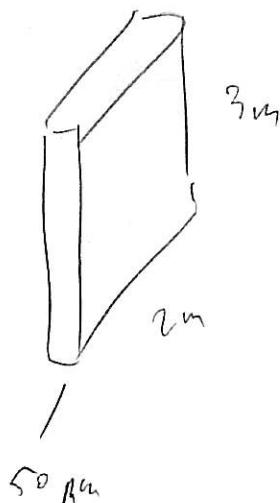


Ex 2.1:

$$\Delta T = 20^\circ C$$

$$q = u \Delta T = \frac{k}{C} A \Delta T$$

$$Q = u A \Delta T = \frac{k}{C} A \Delta T$$

$$q = \left( \frac{0.029 \frac{W}{mK}}{0.05 \text{ m}} \right) (20 \text{ K})$$

$$= \left( 0.58 \frac{W}{m^2 K} \right) (20 \text{ K}) = \underline{\underline{11.6 \frac{W}{m^2}}}$$

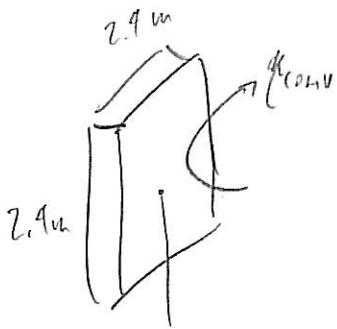
$$Q = q A = \left( 11.6 \frac{W}{m^2} \right) (3 \text{ m})(2 \text{ m}) = \underline{\underline{69.6 W}}$$

$$u = \underline{\underline{0.58 \frac{W}{m^4 K}}} \rightarrow R = \frac{1}{u} = \frac{1}{0.58} = 1.72 \frac{m^4 K}{W} (\text{SI})$$

$$R = \underline{\underline{1.72}} \times \underline{\underline{5.678}} = \underline{\underline{R \cdot 9.8}} \frac{h \cdot f^2 \cdot ^\circ F}{B_m}$$

Ex. 2.2

$$\Delta T = 3 \text{ K}$$



$$T_{air} = 21^\circ\text{C}$$

$$T_{surf} = 18^\circ\text{C}$$

Heat loss to/from vertical surface

$$h_{conv} = 1.92 \left( \frac{\Delta T}{L} \right)^{1/4}$$

$$= 1.92 \left( \frac{3 \text{ K}}{2.4 \text{ m}} \right)^{1/4} = 1.50 \frac{\text{W}}{\text{m}^2 \text{K}}$$

$$q = h_{conv} \Delta T = 1.5 \frac{\text{W}}{\text{m}^2 \text{K}} (3 \text{ K}) = 4.5 \frac{\text{W}}{\text{m}^2 \text{K}}$$

$$Q = q A = \left( 4.5 \frac{\text{W}}{\text{m}^2 \text{K}} \right) (2.4 \text{ m})(2.4 \text{ m}) \approx \underline{\underline{26 \text{ W}}}$$

From air to wall.

PK 2.3

~~Q = AER m<sup>3</sup>/hr~~

$$\left. \begin{array}{l} T_{out} = 35^\circ C \\ T_{in} = 20^\circ C \end{array} \right\} \Delta T = 15 K$$

$$AER = 0.5 \text{ /hr}$$

$$V = 800 \text{ m}^3 \longrightarrow AER = \frac{V}{F}$$

$$Q = m c_p \Delta T$$

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

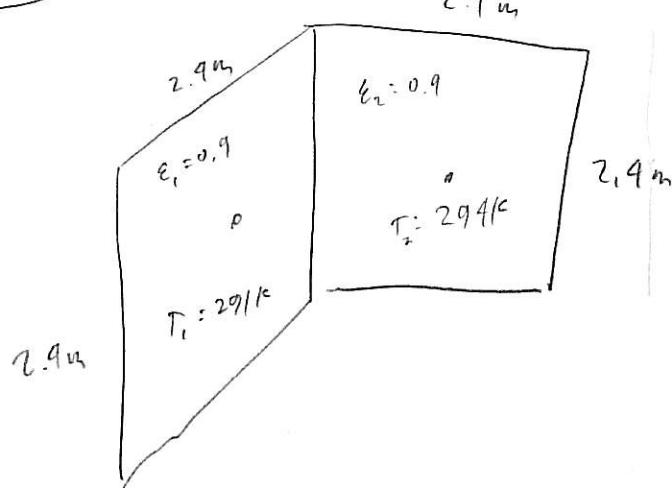
$$\therefore \bar{V} = (AER) \cdot (V) = 0.5 \cdot (800 \text{ m}^3) = 400 \text{ m}^3/\text{hr}$$

$$Q = \rho \bar{V} c_p \Delta T$$

$$Q = \left( 1.2 \frac{\text{kg}}{\text{m}^3} \right) \left( 400 \frac{\text{m}^3}{\text{hr}} \right) \left( 1000 \frac{\text{J}}{\text{kg}} \right) \left( 15 \text{ K} \right) \left( \frac{1 \text{ hr}}{3600 \text{ s}} \right)$$

$$Q = \underline{2000} \quad \underline{\omega} = \underline{2} \text{ kW}$$

Ex. 2.4



$$A_1 = A_2$$

$$q_{1 \rightarrow 2} = \frac{A_1 \sigma (T_1^4 - T_2^4)}{\frac{1 - \epsilon_1}{\epsilon_1} + \frac{A_1}{A_2} \cdot \frac{1 - \epsilon_2}{\epsilon_2} + \frac{1}{F_{12}}} = ?$$

L

$$F_{12} = 1 + \left( \frac{w_1}{w_2} \right) - \frac{\left[ 1 + \left( \frac{w_1}{w_2} \right)^2 \right]^{1/2}}{2} = 0.29 \quad \text{or} \quad F_{12} = 1 - \sin \left( \frac{90^\circ}{2} \right) = 0.29$$

$$q_{1 \rightarrow 2} = 4.64 \frac{W}{m^2}$$

$$Q_{1 \rightarrow 2} = q A = 4.64 \frac{W}{m^2} \times (2.9m) \times (2.9m)$$

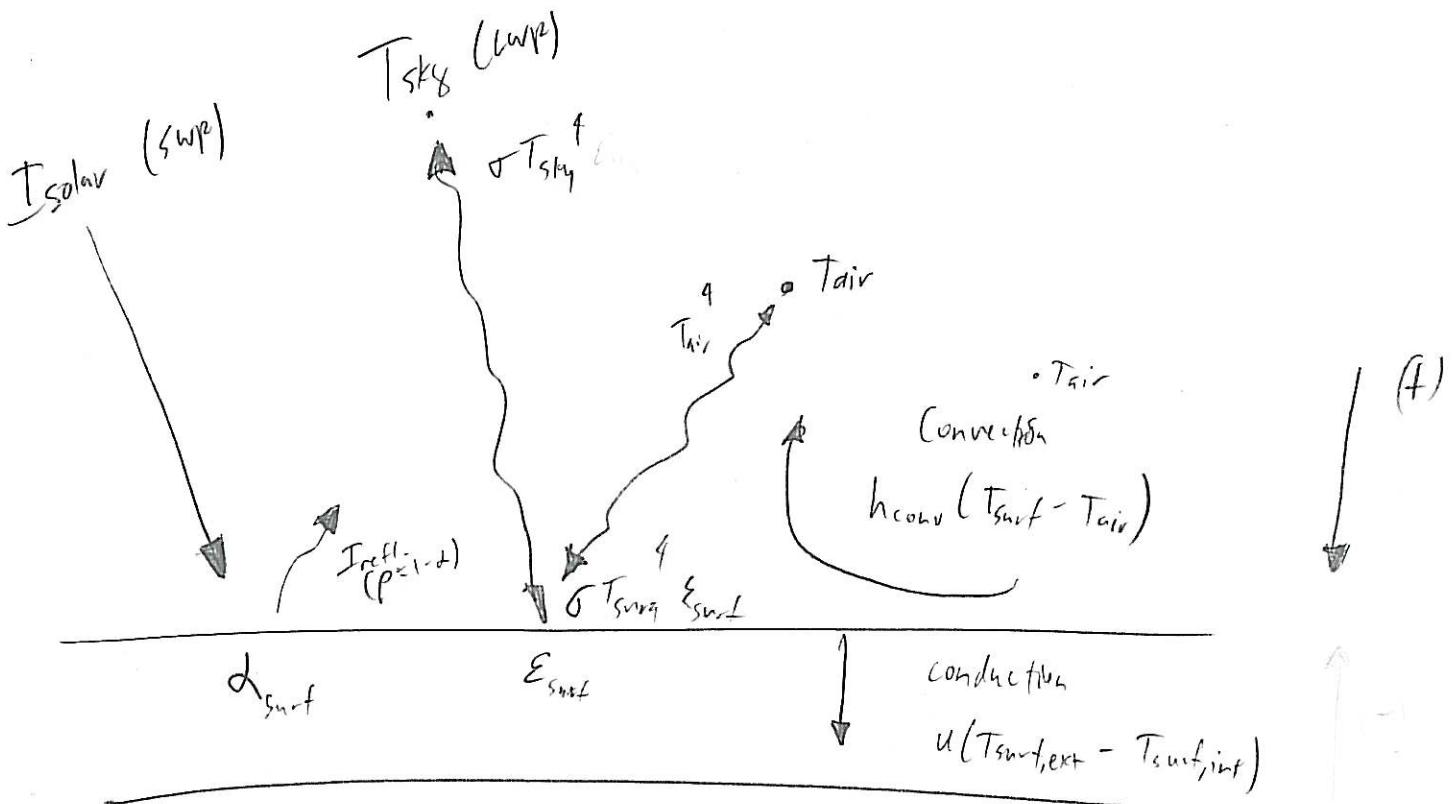
$$\underline{Q = 26.7 W}$$

$$\text{If } \epsilon_1 = 0.1 \rightarrow q = \frac{17.03}{12.56} = 1.36 \frac{W}{m^2}$$

$$\underline{Q = 7.8 W} \quad (\rightarrow \text{lower !})$$

17.03

$$\frac{(5.67 \times 10^{-8} \frac{W}{m^2 K^4})(294^4 - 291^4)}{\underbrace{\frac{1 - 0.1}{0.1} + \frac{1 - 0.9}{0.9} + \frac{1}{0.29}}_{3.67}}$$



sky, air, ground



$$q_{\text{solar}} + q_{\text{wr}} + q_{\text{conv}} - q_{\text{cond}} = 0$$

$$\begin{aligned}
 & \alpha I_{\text{solar}} + \epsilon_{\text{surf}} \sigma F_{\text{sky}} \left( T_{\text{sky}}^4 - T_{\text{surf}}^4 \right) \\
 & + \epsilon_{\text{surf}} \sigma F_{\text{air}} \left( T_{\text{air}}^4 - T_{\text{surf}}^4 \right) \\
 & + h_{\text{conv}} (T_{\text{air}} - T_{\text{surf}}) \quad \text{see discussion re: this parameter}
 \end{aligned}$$

$$- u (T_{\text{surf},\text{ext}} - T_{\text{surf},\text{int}}) = 0 \quad \text{see Spreadsheet}$$

Ex. 2.5

$$\begin{array}{c}
 \text{Top Left: } T_{\text{sol,irr}} \\
 \text{Top Right: } \epsilon_{\text{sky}}^{\text{surf}} F_{\text{sky}}^4 + \epsilon_{\text{air}}^{\text{surf}} F_{\text{air}}^4 + h_{\text{conv}}(T_{\text{surf}} - T_{\text{air}}) \\
 \text{Bottom Left: } \alpha \\
 \text{Bottom Middle: } \epsilon \\
 \text{Bottom Right: } u(SI)
 \end{array}$$

$$\begin{aligned}
 \alpha I_{\text{sol,irr}} + \epsilon_{\text{surf}} \sigma F_{\text{sky}} (T_{\text{sky}}^4 - T_{\text{surf}}^4) + \epsilon_{\text{surf}} \sigma F_{\text{air}} (T_{\text{air}}^4 - T_{\text{surf}}^4) + h_{\text{conv}} (T_{\text{air}} - T_{\text{surf}}) \\
 - u (T_{\text{surf}} - T_{\text{in}}) = 0
 \end{aligned}$$

$$\checkmark \quad \alpha I_{\text{sol,irr}} = (0.9)(1000 \frac{W}{m^2}) = 900 \frac{W}{m^2}$$

Assume  $\epsilon_{\text{surf}} = 0.9$ ,  $F_{\text{sky}} = 1.0$ ,  $F_{\text{air}} = 1.0$ ,  $h_{\text{conv}} =$  w/outh: should be 0

$$\text{Estimate } h_{\text{conv}} = 1.52 (T_{\text{surf}} - T_{\text{air}})^{1/3}$$

$$\begin{aligned}
 \text{Estimate } T_{\text{sky}} &= \left[ \epsilon_{\text{sky}} \left( T_{\text{air}}^4 \right)^{1/4} \left( 1 + 0.0015 \ln \left( \frac{T_{\text{sky}}^4 - T_{\text{air}}^4}{T_{\text{air}}^4} \right) \right) T_{\text{air}}^4 \right]^{1/3} \\
 &\rightarrow \epsilon_{\text{sky}} = \left[ 0.787 + 0.714 \ln \left( \frac{T_{\text{surf}}^4}{273^4} \right) \right] \underbrace{\left( 1 + 0.0024 N \dots \right)}_{=1} \\
 &\quad \epsilon_{\text{sky}} = 0.79
 \end{aligned}$$

$$T_{\text{sky}} \left( (0.79)(20 + 273.15) \right)^{1/4} = 276.6 \text{ K}$$

$$q_{\text{conv}} = h_{\text{conv}} (T_{\text{air}} - T_{\text{surf}}) = \left[ 1.52 (T_{\text{surf}} - T_{\text{air}})^{1/3} \right] (T_{\text{air}} - T_{\text{surf}}), \quad \underline{\epsilon_{\text{all}} = 0}$$

$$q_{\text{conv}} = \epsilon \sigma F_{\text{sky}} (T_{\text{sky}}^4 - T_{\text{surf}}^4) + \epsilon \sigma F_{\text{air}} (T_{\text{air}}^4 - T_{\text{surf}}^4) \dots$$

$$q_{\text{conv}} = - u (T_{\text{surf}} - T_{\text{in}}) \dots$$

Chicago's latitude =  $41.9^{\circ}N$

$$LST = CT + \frac{1}{15}(L_{std} - L_{loc}) + E - DT$$

Ex. 2-G  $CT = 14 + \frac{25}{60} = 14.42 \text{ hr}$

$$\underline{L_{std} = 90^{\circ}W} \quad \underline{L_{loc} = 93^{\circ}W}$$

$$\underline{DT = 1}$$

From Table,  $E = \underline{-0.10 \text{ hr}}$

$$\underline{\underline{LST = 14.42 + \frac{1}{15}(90 - 93) - 0.10 - 1 = 13.12 \text{ hr}}}$$

$$h = 15(LST - 12) = 15(13.12 - 12) = \underline{\underline{16.8 \text{ degrees}}}$$

( $16.8^{\circ}$  away from solar noon)

Ex 2-J

$$\ell = 40^{\circ}$$

$$\text{Altitude angle} = \beta$$

$$LST = 7.5$$

$$\text{Azimuth} = \phi$$

From table on B(7  $\rightarrow d = 16.3^{\circ}$ )

$$h = 15(LST - 12) = 15(7.5 - 12) = -67.5^{\circ}$$

$$\sin \beta = \cos \ell \cos h \cos d + \sin \ell \sin d = \cos(40^{\circ}) \cos(-67.5^{\circ}) \cos(16.3^{\circ}) + \sin(40^{\circ}) \sin(16.3^{\circ})$$

$$\sin \beta = 0.462 \rightarrow \sin^{-1}(0.462) = 27.5^{\circ} = \underline{\underline{\beta}}$$

$$\cos \phi = \frac{1}{\cos \beta} \left( \cos d \sin \ell \cos h - \sin d \cos \ell \right) = \frac{1}{\cos(27.5^{\circ})} \left( \cos(16.3^{\circ}) \sin(40^{\circ}) \cos(-67.5^{\circ}) - \sin(16.3^{\circ}) \cos(40^{\circ}) \right)$$

$$\cos \phi = 0.035 \rightarrow \cos^{-1}(0.035) = \underline{\underline{88.0^{\circ}}} = \underline{\underline{\phi}}$$

\* prior to solar noon,  $\phi$  is negative

$$\phi = \underline{\underline{-88.0^{\circ}}}$$

Ex. 2.8

$$\lambda = 36^\circ$$

$$LST = 15 \text{ hours}$$

$$\Psi = \text{surface azimuth} = -25^\circ$$

$$\Sigma = 60^\circ$$

$$\text{Table for June 7} \rightarrow d = 22.7^\circ$$

$$h = 15(15-12) = 45^\circ$$

$$\sin \beta = \cos(36^\circ) \cos(45^\circ) \cos(22.7^\circ) + \sin(36^\circ) \sin(22.7^\circ) = 0.7545$$

$$\beta = 49.0^\circ$$

$$\cos \phi = \frac{1}{\cos \beta} [\cos d \sin l \cos h - \sin d \cos l] = 0.109$$

$$\phi = 83.8^\circ$$

$$\gamma' = |\phi - \psi|$$

| surface azimuth  
 | solar azimuth

$$\psi = -25^\circ$$

$$\phi = 83.8^\circ$$

$$\gamma' = \left| 83.8^\circ - (-25^\circ) \right| = 108.8^\circ$$

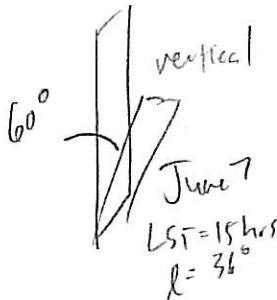
$$\cos \theta = \cos \beta \cos \gamma' \sin \Sigma + \sin \beta \cos \Sigma$$

$$= \cos(49) \cos(108.8) \sin(60) + \sin(49) \cos(60) = 0.194$$

$$\theta = \cos^{-1}(0.194) = 78.8^\circ$$

why done care?

Ex. 2.9



$$I_{\text{solar}} = I_0 + I_d + I_R$$

$$D = 78.8^\circ \quad \beta = 49.0^\circ \quad d = 22.7^\circ \quad \Sigma = 60^\circ \quad h = 45^\circ$$

$$\boxed{I_D = I_{DN} \cos \theta}$$

$$\hookrightarrow I_{DN} = A e^{-\frac{\beta}{\sin \beta}} = \left(1090 \frac{W}{m^2}\right) e^{-\frac{0.205}{\sin(49^\circ)}} \approx 831 \frac{W}{m^2}$$

0.762

$$\boxed{I_0 = \left(831 \frac{W}{m^2}\right) \cos(78.8^\circ) = 161 \frac{W}{m^2}}$$

$$\boxed{I_d = I_{dH} \frac{1 + \cos \varepsilon}{2}}$$

$$\hookrightarrow I_{dH} = C I_{DN} = (0.134)(831) = 111 \frac{W}{m^2}$$

$$\boxed{I_d = \left(111 \frac{W}{m^2}\right) \left(\frac{1 + \cos(60^\circ)}{2}\right) = 83 \frac{W}{m^2}}$$

$$\boxed{I_p = \frac{\rho_g I_H (1 - \cos \varepsilon)}{2}}$$

"sun's zenith angle"

$$\hookrightarrow I_H = I_{DN} \cos \theta_H + I_{dH}$$

$$\cos \theta_H = \cos l \cos h \cos d + \sin l \sin d$$

$$= \cos(36) \cos(45) \cos(22.7) + \sin(36) \sin(22.7) = 0.7545$$

$$\theta_H = \cos^{-1}(0.7545) = 41.0^\circ$$

$$I_H = (831) \cos(41) + 111 = 738 \frac{W}{m^2}$$

$$\boxed{I_R = \frac{(0.15)(738)(1 - \cos(60))}{2} = 28 \frac{W}{m^2}}$$

$$\boxed{\begin{aligned} I_{\text{total}} &= \\ &= 272 \frac{W}{m^2} \end{aligned}}$$