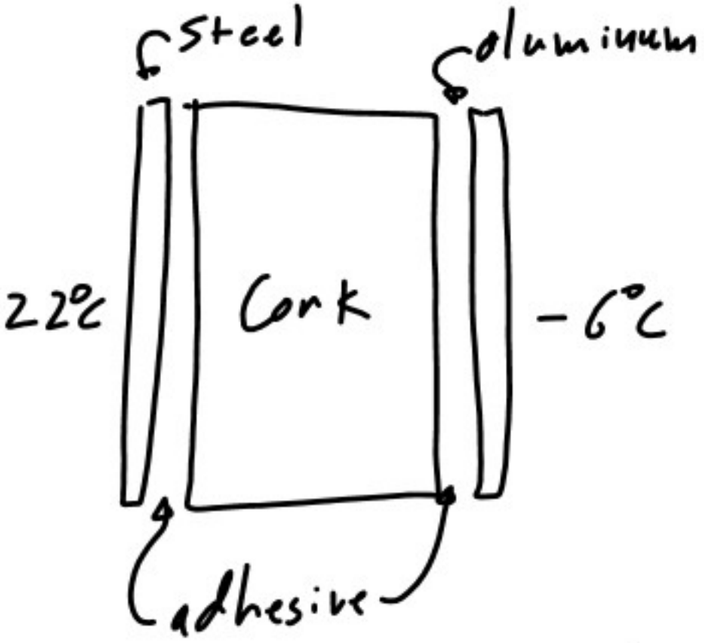
3.24 A commercial grade cubical freezer, 3 m on a side, has a composite wall consisting of an exterior sheet of 6.35-mm-thick plain carbon steel, an intermediate layer of 100-mm-thick cork insulation, and an inner sheet of 6.35-mm-thick aluminum alloy (2024). Adhesive interfaces between the insulation and the metallic strips are each characterized by a thermal contact resistance of $R''_{t,c} = 2.5 \times 10^{-4}\ \mathrm{m^2 \cdot K/W}$. What is the steady-state cooling load that must be maintained by the refrigerator under conditions for which the outer and inner surface temperatures are 22°C and –6°C, respectively?



$$R_{tot} = \frac{L_s}{k_s} + 2R''_{tc} + \frac{L_c}{k_c} + \frac{L_a}{k_a}$$

$L_s = L_a = 6.35\ mm$

$L_c = 100\ mm$

$k_a = 177 \frac{W}{m\,K}$

$k_c = 0.039 \frac{W}{m\,K}$

$k_s = 60.5 \frac{W}{m\,K}$

$$R''_{tot} = \frac{L_s}{k_s} + 2R''_{tc} + \frac{L_c}{k_c} + \frac{L_a}{k_a}$$

$$= \frac{0.00635\,m}{60.5 \frac{W}{m\,K}} + 2 \cdot 2.5 \times 10^{-4} \frac{m^2 K}{W} + \frac{0.1\,m}{0.039 \frac{W}{m\,K}} + \frac{0.00635\,m}{177 \frac{W}{m\,K}}$$

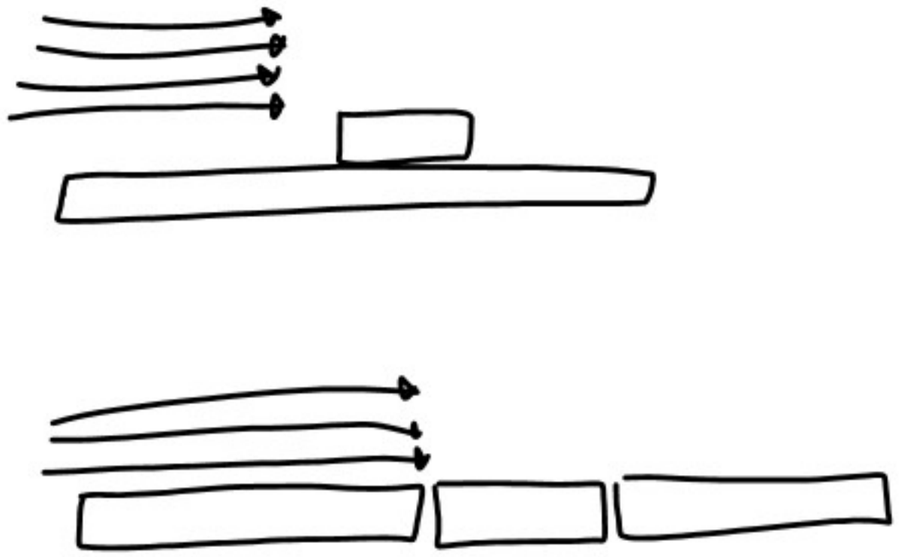
$$= 2.56 \frac{m^2 K}{W}$$

$$q'' = \frac{T_{so} - T_{si}}{R''_{tot}} = \frac{22°C - (-6°C)}{2.56 \frac{m^2 K}{W}} = 10.9 \frac{W}{m^2}$$

$A_s = 3\,m \cdot 3\,m \cdot 6 = 54\,m^2$

$q = A_s q'' = 54\,m^2\, 10.9 \frac{W}{m^2} \approx \boxed{590\,W}$

7.33 A square (10 mm × 10 mm) silicon chip is insulated on one side and cooled on the opposite side by atmospheric air in parallel flow at $u_\infty = 20$ m/s and $T_\infty = 24°C$. When in use, electrical power dissipation within the chip maintains a uniform heat flux at the cooled surface. If the chip temperature may not exceed 80°C at any point on its surface, what is the maximum allowable power? What is the maximum allowable power if the chip is flush mounted in a substrate that provides for an unheated starting length of 20 mm?



$q = A_s q''$ $\quad A_s = (10\ mm)^2 = (0.01\ m)^2 = 1 \times 10^{-4}\ m^2$

$T_f = \frac{24 + 30}{2} = 52°C \approx 325\ K$

$q'' = \bar{h}(T_s - T_\infty) = \bar{h}(30°C - 24°C) = \bar{h}\ 6\ K$

$q = \bar{h}\ 1 \times 10^{-4}\ m^2\ 6\ K = \bar{h}\ 6 \times 10^{-4}\ m^2 K$