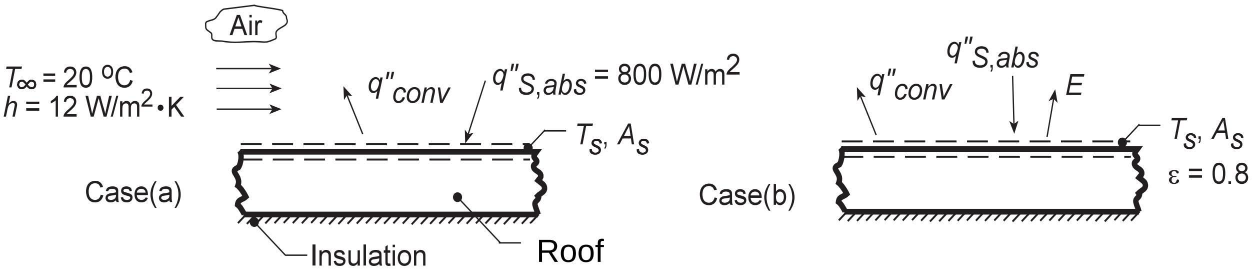
PROBLEM 1.72

KNOWN: Top surface of car roof absorbs solar flux, $q''_{S,abs}$, and experiences for case (a): convection with air at T_∞ and for case (b): the same convection process and radiation emission from the roof.

FIND: Temperature of the roof, T_s, for the two cases. Effect of airflow on roof temperature.

SCHEMATIC:



ASSUMPTIONS: (1) Steady-state conditions, (2) Negligible heat transfer to auto interior, (3) Negligible radiation from atmosphere.

ANALYSIS: (a) Apply an energy balance to the control surfaces shown on the schematic. For an instant of time, $\dot{E}_{in} - \dot{E}_{out} = 0$. Neglecting radiation emission, the relevant processes are convection between the plate and the air, q''_{conv}, and the absorbed solar flux, $q''_{S,abs}$. Considering the roof to have an area A_S,

$$q''_{S,abs} \cdot A_S - hA_S\left(T_S - T_\infty\right) = 0$$

$$T_S = T_\infty + q''_{S,abs}/h$$

$$T_S = 20^\circ C + \frac{800 W/m^2}{12 W/m^2 \cdot K} = 20^\circ C + 66.7^\circ C = 86.7^\circ C \qquad <$$

(b) With radiation emission from the surface, the energy balance has the form

$$q''_{S,abs} \cdot A_S - q_{conv} - E \cdot A_S = 0$$

$$q''_{S,abs} A_S - hA_S\left(T_S - T_\infty\right) - \varepsilon A_S \sigma T_S^4 = 0 .$$

Substituting numerical values, with temperature in absolute units (K),

$$800 \frac{W}{m^2} - 12 \frac{W}{m^2 \cdot K}\left(T_S - 293 K\right) - 0.8 \times 5.67 \times 10^{-8} \frac{W}{m^2 \cdot K^4} T_S^4 = 0$$

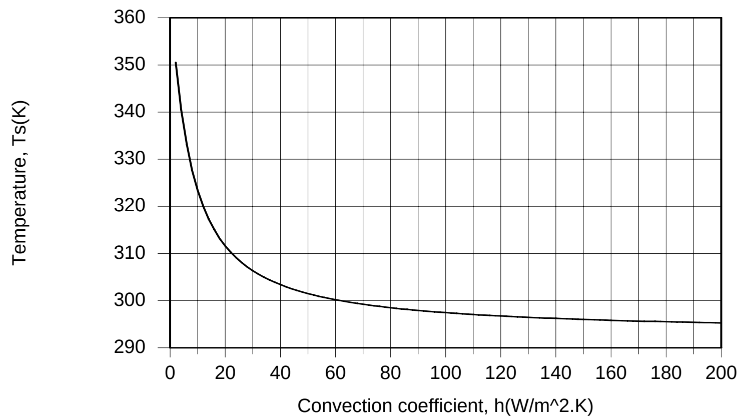
$$12 T_S + 4.536 \times 10^{-8} T_S^4 = 4316$$

It follows that T_s = 320 K = 47°C. <

Continued...

PROBLEM 1.72 (Cont.)

(c) Parametric calculations were performed using the IHT *First Law Model* for an *Isothermal Plane Wall*. As shown below, the roof temperature depends strongly on the velocity of the auto relative to the ambient air. For a convection coefficient of h = 40 W/m^2·K, which would be typical for a velocity of 55 mph, the roof temperature would exceed the ambient temperature by less than 10°C.



COMMENTS: By considering radiation emission, T_s decreases, as expected. Note the manner in which q''_{conv} is formulated using Newton's law of cooling; since q''_{conv} is shown leaving the control surface, the rate equation must be $h\left(T_S - T_\infty\right)$ and not $h\left(T_\infty - T_S\right)$.