Heat Transfer Assignments

Problem 6.4: Infiltration Calculation for a Swinging Door

Problem Statement

Assuming a crack method, compute the infiltration for a swinging door that is used occasionally, assuming it is:

1. tight-fitting,
2. average-fitting, and
3. loose-fitting.

The door has dimensions of $0.9\,\mathrm{m} \times 2.0\,\mathrm{m}$ and is on the windward side of a house exposed to a $13\,\mathrm{m/s}$ wind. Neglect internal pressurization and stack effect. If the door is on a bank in Rapid City, SD, what is the resulting heating load due to the door for each fitting classification?

Diagram of the Problem

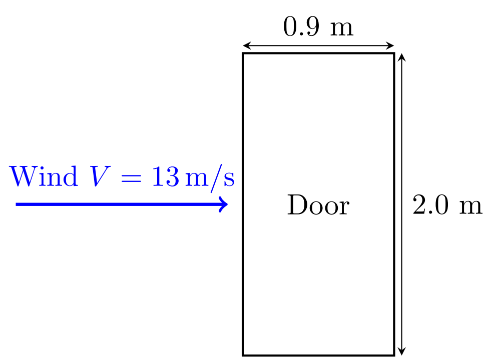

Figure 1: Swinging door on the windward side of the house

Solution

Given Data

- Door dimensions: $W = 0.9\,\mathrm{m}, H = 2.0\,\mathrm{m}$
- Wind speed: $V = 13\,\mathrm{m/s}$
- Air density: $\rho = 1.2\,\mathrm{kg/m^3}$
- Specific heat of air: $c_p = 1005\,\mathrm{J/(kg \cdot K)}$

- Indoor temperature: $T_i = 21\,^\circ\mathrm{C}$
- Outdoor temperature: $T_o = -18\,^\circ\mathrm{C}$
- Temperature difference: $\Delta T = T_i - T_o = 39\,^\circ\mathrm{C}$
- Pressure coefficient for windward side: $C_p = 0.7$
- Flow exponent: $n = 0.65$
- Standard air leakage rates at $\Delta P = 10\,\mathrm{Pa}$:
  - Tight-fitting door: $q_{10} = 0.15\,\mathrm{L/(s \cdot m)}$
  - Average-fitting door: $q_{10} = 0.3\,\mathrm{L/(s \cdot m)}$
  - Loose-fitting door: $q_{10} = 0.6\,\mathrm{L/(s \cdot m)}$

Pressure Difference Due to Wind

The pressure difference across the door due to wind is calculated as follows:

$$
\begin{aligned}
\Delta P &= \frac{1}{2}\rho V^2 C_p \\
&= \frac{1}{2} \times 1.2\,\mathrm{kg/m^3} \times (13\,\mathrm{m/s})^2 \times 0.7 \\
&= 70.98\,\mathrm{Pa}
\end{aligned}
$$

Air Leakage Rate per Unit Length

Using the equation to adjust for different pressure differences:

$$
q = q_{10}\left(\frac{\Delta P}{10}\right)^n
$$

To keep this section clear, let's summarize the results for different door fitting types:

$$
\begin{aligned}
q_{\text{tight}} &= 0.5358\,\mathrm{L/(s \cdot m)} \\
q_{\text{average}} &= 1.0716\,\mathrm{L/(s \cdot m)} \\
q_{\text{loose}} &= 2.1432\,\mathrm{L/(s \cdot m)}
\end{aligned}
$$

Total Infiltration Rate

The total infiltration rate can be calculated by multiplying the leakage rate by the perimeter of the door ($L = 2(W + H) = 5.8\,\mathrm{m}$):

$$
\begin{aligned}
Q_{\text{tight}} &= 3.11\,\mathrm{L/s} = 0.003\,11\,\mathrm{m^3/s} \\
Q_{\text{average}} &= 6.22\,\mathrm{L/s} = 0.006\,22\,\mathrm{m^3/s} \\
Q_{\text{loose}} &= 12.43\,\mathrm{L/s} = 0.012\,43\,\mathrm{m^3/s}
\end{aligned}
$$

Heating Load Due to Infiltration

The heating load $\dot{Q}$ is calculated as follows:

$$\begin{aligned}
\dot{Q}_{\text{tight}} &= \rho Q_{\text{tight}} c_p \Delta T = 146.2\,\text{W} \\
\dot{Q}_{\text{average}} &= 292.4\,\text{W} \\
\dot{Q}_{\text{loose}} &= 584.8\,\text{W}
\end{aligned}$$

Conclusion

The resulting heating load due to infiltration through the door is:

- Tight-fitting door: $\dot{Q}_{\text{tight}} = 146.2\,\text{W}$
- Average-fitting door: $\dot{Q}_{\text{average}} = 292.4\,\text{W}$
- Loose-fitting door: $\dot{Q}_{\text{loose}} = 584.8\,\text{W}$

Improving the door's fitting can significantly reduce the heating load.

Problem 6.10: Transmission Heat Loss Calculation

House Diagram

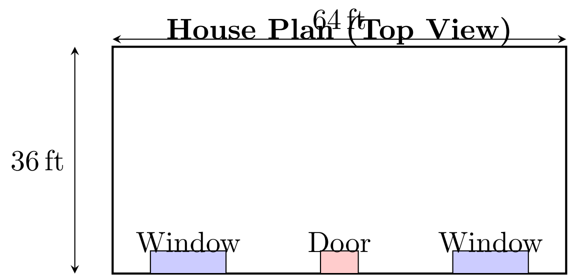

Figure 2: Diagram illustrating the house dimensions, windows, and doors

Solution

Design Temperature Difference

Assuming:

- Indoor design temperature: $T_{\text{in}} = 70\,^{\circ}\text{F}$
- Outdoor design temperature: $T_{\text{out}} = -5\,^{\circ}\text{F}$ (99% winter design temperature for Des Moines, IA)

Temperature difference:

$$\Delta T = T_{\text{in}} - T_{\text{out}} = 70\,^{\circ}\text{F} - (-5\,^{\circ}\text{F}) = 75\,^{\circ}\text{F}$$

House Dimensions

- Length (L): 64 ft
- Width (W): 36 ft
- Ceiling height (H): 8 ft

Calculations

1. Perimeter

$$P = 2(L + W) = 2\,(64\,\text{ft} + 36\,\text{ft}) = 200\,\text{ft}$$

2. Gross Wall Area

$$A_{\text{wall, gross}} = P \times H = 200\,\text{ft} \times 8\,\text{ft} = 1600\,\text{ft}^2$$

3. Window Area Total windows: 3 windows × 4 sides = 12 windows
Area per window:

$$A_{\text{window}} = 3\,\text{ft} \times 4\,\text{ft} = 12\,\text{ft}^2$$

Total window area:

$$A_{\text{windows, total}} = 12 \times 12\,\text{ft}^2 = 144\,\text{ft}^2$$

4. Door Area Total doors: 3
Area per door:

$$A_{\text{door}} = 3\,\text{ft} \times 6.75\,\text{ft} = 20.25\,\text{ft}^2$$

Total door area:

$$A_{\text{doors, total}} = 3 \times 20.25\,\text{ft}^2 = 60.75\,\text{ft}^2$$

5. Net Wall Area

$$A_{\text{wall, net}} = A_{\text{wall, gross}} - A_{\text{windows, total}} - A_{\text{doors, total}} = 1600\,\text{ft}^2 - 144\,\text{ft}^2 - 60.75\,\text{ft}^2 = 1395.25\,\text{ft}^2$$

6. Ceiling and Floor Area

$$A_{\text{ceiling}} = A_{\text{floor}} = L \times W = 64\,\text{ft} \times 36\,\text{ft} = 2304\,\text{ft}^2$$

U-values and R-values

Walls Given $R_{\text{wall}} = 0.44\,\text{h}/(\text{ft}^2 \cdot {}^\circ\text{F} \cdot \text{Btu})$
Calculate U_{wall}:

$$U_{\text{wall}} = \frac{1}{R_{\text{wall}}} = \frac{1}{0.44} = 2.273\,\text{Btu}/(\text{h} \cdot \text{ft}^2 \cdot {}^\circ\text{F})$$

Windows Assuming $U_{\text{window}} = 0.35\,\text{Btu}/(\text{h} \cdot \text{ft}^2 \cdot {}^\circ\text{F})$

Doors Assuming $U_{\text{door}} = 0.5\,\text{Btu}/(\text{h} \cdot \text{ft}^2 \cdot {}^\circ\text{F})$

Roof-Ceiling Given $U_{\text{ceiling}} = 0.083\,\text{Btu}/(\text{h} \cdot \text{ft}^2 \cdot {}^\circ\text{F})$

Floor Perimeter heat loss factor F_p for slab with 2 ft edge insulation:

$$F_p = 0.4\,\text{Btu}/(\text{h} \cdot \text{ft} \cdot {}^\circ\text{F})$$

Heat Loss Calculations

1. Walls

$$Q_{\text{walls}} = U_{\text{wall}} \times A_{\text{wall, net}} \times \Delta T = 2.273\,\text{Btu}/(\text{h} \cdot \text{ft}^2 \cdot {}^\circ\text{F}) \times 1395.25\,\text{ft}^2 \times 75\,{}^\circ\text{F} = 237\,399\,\text{Btu/h}$$

2. Windows

$$Q_{\text{windows}} = U_{\text{window}} \times A_{\text{windows, total}} \times \Delta T = 0.35\,\text{Btu/(h} \cdot \text{ft}^2 \cdot {}^\circ\text{F)} \times 144\,\text{ft}^2 \times 75\,{}^\circ\text{F} = 3780\,\text{Btu/h}$$

3. Doors

$$Q_{\text{doors}} = U_{\text{door}} \times A_{\text{doors, total}} \times \Delta T = 0.5\,\text{Btu/(h} \cdot \text{ft}^2 \cdot {}^\circ\text{F)} \times 60.75\,\text{ft}^2 \times 75\,{}^\circ\text{F} = 2278\,\text{Btu/h}$$

4. Roof-Ceiling

$$Q_{\text{ceiling}} = U_{\text{ceiling}} \times A_{\text{ceiling}} \times \Delta T = 0.083\,\text{Btu/(h} \cdot \text{ft}^2 \cdot {}^\circ\text{F)} \times 2304\,\text{ft}^2 \times 75\,{}^\circ\text{F} = 14\,361\,\text{Btu/h}$$

5. Floor

$$Q_{\text{floor}} = F_p \times P \times \Delta T = 0.4\,\text{Btu/(h} \cdot \text{ft} \cdot {}^\circ\text{F)} \times 200\,\text{ft} \times 75\,{}^\circ\text{F} = 6000\,\text{Btu/h}$$

Total Heat Loss

$$\begin{aligned} Q_{\text{walls, revised}} &= U_{\text{wall, revised}} \times A_{\text{wall, net}} \times \Delta T \\ &= 0.069\,\text{Btu/(h} \cdot \text{ft}^2 \cdot {}^\circ\text{F)} \times 1395.25\,\text{ft}^2 \times 75\,{}^\circ\text{F} \\ &= 7228\,\text{Btu/h} \end{aligned}$$

Revised Wall Calculation

Assuming walls have insulation $R_{\text{insulation}} = 13$ and total $R_{\text{wall, total}} = 14.5$:

$$U_{\text{wall, revised}} = \frac{1}{R_{\text{wall, total}}} = \frac{1}{14.5} = 0.069\,\text{Btu/(h} \cdot \text{ft}^2 \cdot {}^\circ\text{F)}$$

Recalculate wall heat loss:

$$Q_{\text{walls, revised}} = U_{\text{wall, revised}} \times A_{\text{wall, net}} \times \Delta T = 0.069\,\text{Btu/(h} \cdot \text{ft}^2 \cdot {}^\circ\text{F)} \times 1395.25\,\text{ft}^2 \times 75\,{}^\circ\text{F} = 7228\,\text{Btu/h}$$

Revised total heat loss:

$$\begin{aligned} Q_{\text{total, revised}} &= Q_{\text{walls, revised}} + Q_{\text{windows}} + Q_{\text{doors}} + Q_{\text{ceiling}} + Q_{\text{floor}} \\ &= 7228\,\text{Btu/h} + 3780\,\text{Btu/h} + 2278\,\text{Btu/h} + 14\,361\,\text{Btu/h} + 6000\,\text{Btu/h} \\ &= 33\,647\,\text{Btu/h} \end{aligned}$$

Conclusion

The revised total transmission heat loss for the structure, with additional insulation, is approximately 33 647 Btu/h. The inclusion of insulation significantly lowers the heat transfer through the building, highlighting the importance of well-insulated building components.

Teaching Points

- Use diagrams to visually understand the problem setup and dimensions.
- Proper insulation drastically reduces heating or cooling loads.
- Always cross-check the units and calculations to avoid overflow errors.