6-3 TRANSMISSION HEAT LOSSES

The heat transferred through walls, ceilings, roof, window glass, floors, and doors is all sensible heat transfer, referred to as *transmission heat loss* and computed from

$$\dot{q} = U A(t_i - t_o) \tag{6-1}$$

The overall heat-transfer coefficient is determined as discussed in Chapter 5, where the area A is the net area for the given component for which U was calculated. A separate calculation is made for each different surface in each room of the structure. To ensure a thorough job in estimating the heat losses manually, a worksheet should be used. A worksheet provides a convenient and orderly way of recording all the coefficients and areas. Summations are conveniently made by room and for the complete structure. Likewise, this can be done with a spreadsheet, or with a computer program. Many such programs are available, such as the one named HvacLoadExplorer given on the website noted in the preface and described in Chapter 8. Section 6-10 discusses the use of the program for heating load calculations.

6-4 INFILTRATION

Most structures have some air leakage or infiltration. This results in a heat loss, because the cold dry outdoor air must be heated to the inside design temperature and moisture must be added to increase the humidity to the design value. The sensible heat required (to increase the temperature) is given by

$$\dot{q}_s = \dot{m}_o c_p (t_i - t_o) \tag{6-2a}$$

where:

$\dot{m}_o$ = mass flow rate of the infiltrating air, lbm/hr or kg/s
c_p = specfic heat of the air, Btu/(lbm-F) or J/(kg-C)

Infiltration is usually estimated on the basis of volume flow rate at outdoor conditions. Equation 6-2a then becomes

$$\dot{q}_s = \frac{\dot{Q} c_p (t_i - t_o)}{v_o} \tag{6-2b}$$

where:

$\dot{Q}$ = volume flow rate, ft^3/hr or m^3/s
v_o = specfic volume, ft^3/lbm or m^3/kg

The latent heat required to humidify the air is given by

$$\dot{q}_l = \dot{m}_o (W_i - W_o) i_{fg} \tag{6-3a}$$

where:

$W_i - W_o$ = difference in design humidity ratio, lbmv/lbma or kgv/kga
i_{fg} = latent heat of vaporization at indoor conditions, Btu/lbmv or J/kgv

In terms of volume flow rate of air, Eq. 6-3a becomes

$$\dot{q}_l = \frac{\dot{Q}}{v_o} (W_i - W_o) i_{fg} \tag{6-3b}$$

Experimental data are required to use Eq. 6-5 directly; however, the relation is useful in understanding the problem. For example, Fig. 6-1 shows the leakage rate for some windows and doors as a function of the pressure difference and the type of crack. The curves clearly exhibit the behavior of Eq. 6-5.

The pressure difference of Eq. 6-5 results from three different effects:

$$\Delta P = \Delta P_w + \Delta P_s + \Delta P_p \tag{6-6}$$

where:

ΔP_w = pressure difference due to the wind
ΔP_s = pressure difference due to the stack effect
ΔP_p = difference due to building pressurization

Each of the pressure differences is taken as positive when it causes flow of air to the inside of the building.

The pressure difference due to the wind results from an increase or decrease in air velocity and is calculated by

$$\Delta P_w = \frac{\rho}{2g_c}(\bar{V}_w^2 - \bar{V}_f^2) \tag{6-7a}$$

where ΔP_w has the unit of lbf/ft^2 when consistent English units are used or Pa for SI units. The velocity $\bar{V}_f$ is the velocity of the wind at the building boundary. Note that ΔP_w is positive when $\bar{V}_w > \bar{V}_f$, which gives an increase in pressure. The velocity $\bar{V}_f$ is not known or easily predictable; therefore, it is assumed equal to zero in this application and a pressure coefficient, defined by

$$C_p = \Delta P_w / \Delta P_{wt} \tag{6-8}$$

Pressure coeff

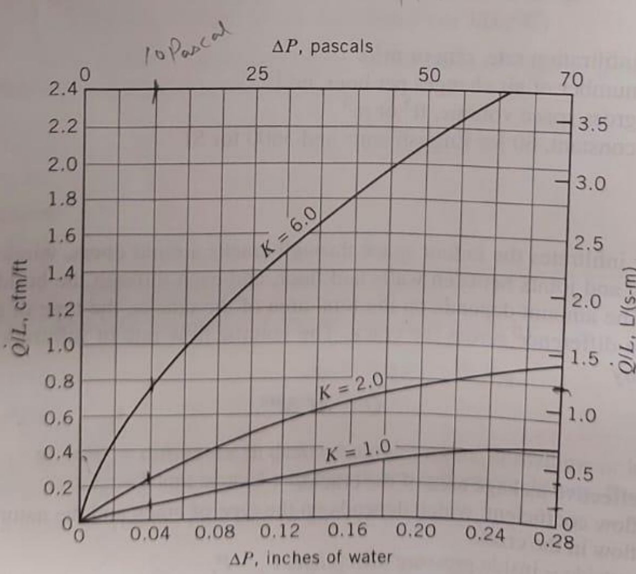

Figure 6-1 Window and door infiltration characteristics. (Reprinted by permission, from *ASHRAE Cooling and Heating Load Calculation Manual*, 2nd ed., 1992.)

is used to allow for the fact that $\bar{V}_f$ is not zero. The pressure difference ΔP_{wt} is the computed pressure difference when $\bar{V}_f$ is zero. The pressure coefficient may be positive or negative. Finally, Eq. 6-7a may be written

$$\frac{\Delta P_w}{C_p} = \frac{\rho}{2g_c}\bar{V}_w^2 \qquad (6\text{-}7b)$$

Wind Pressure diff

The pressure coefficient depends on the shape and orientation of the building with respect to the wind. To satisfy conditions of flow continuity, the air velocity must increase as air flows around or over a building; therefore, the pressure coefficient will change from a positive to a negative value in going from the windward to the leeward side. The pressure coefficients will also depend on whether the wind approaches normal to the side of the building or at an angle. Figure 6-2 gives average wall pressure coefficients for low-rise buildings. Buildings are classified as *low-rise* or *high-rise*, where high-rise is defined as having height greater than three times the crosswind width ($H > 3W$). The average roof pressure coefficient for a low-rise building with the roof inclined less than 20 degrees is approximately 0.5. Figures 6-3 and 6-4 give average pressure coefficients for high-rise buildings. There is an increase in pressure coefficient with height; however, the variation is well within the approximations of the data in general.

The stack effect occurs when the air density differs between the inside and outside of a building. On winter days, the lower outdoor temperature causes a higher pressure at ground level on the outside and consequent infiltration. Buoyancy of the warm inside air leads to upward flow, a higher inside pressure at the top of the building, and exfiltration of air. In the summer, the process reverses with infiltration in the upper portion of the building and exfiltration in the lower part.

Considering only the stack effect, there is a level in the building where no pressure difference exists. This is defined as the *neutral pressure level*. Theoretically, the neutral pressure level will be at the midheight of the building if the cracks and other

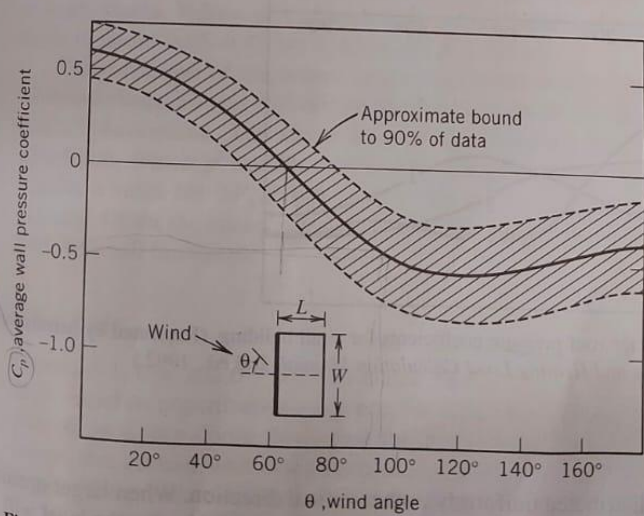

Figure 6-2 Variation of wall averaged pressure coefficients for a low-rise building. (Reprinted by permission from *ASHRAE Cooling and Heating Load Calculation Manual*, 2nd ed., 1992.)

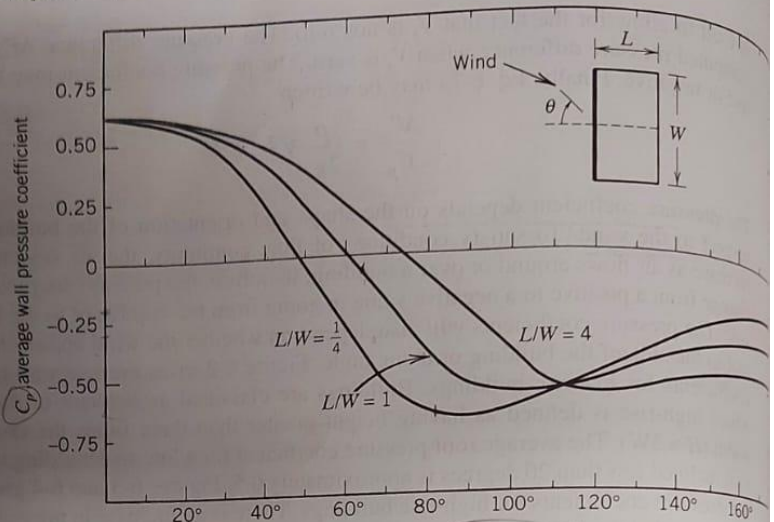

Figure 6-3 Wall averaged pressure coefficients for a tall building. (Reprinted by permission from *ASHRAE Cooling and Heating Load Calculation Manual*, 2nd ed., 1992.)

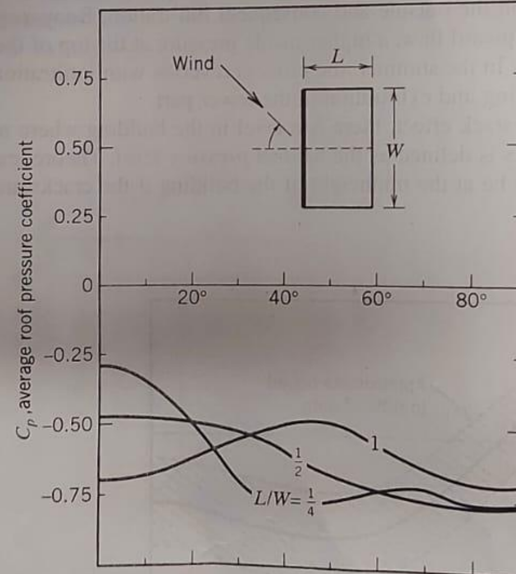

Figure 6-4 Average roof pressure coefficients for a tall building. (Reprinted by permission from *ASHRAE Cooling and Heating Load Calculation Manual*, 2nd ed., 1992.)

openings are distributed uniformly in the vertical direction. When larger openings dominate in the lower portion of the building, the neutral pressure level will be lowered. Similarly, the neutral pressure level will be raised by larger openings in the upper portion of the building. Normally the larger openings will occur in the lower p the building because of doors. The theoretical pressure difference with no internal separations is given by

$$\Delta P_{st} = \frac{P_o h}{R_a} \frac{g}{g_c} \left(\frac{1}{T_o} - \frac{1}{T_i} \right) \tag{6-9}$$

where:

P_o = outside pressure, psia or Pa
h = vertical distance, up or down, from neutral pressure level, ft or m
T_o = outside temperature, R or K
T_i = inside temperature, R or K
R_a = gas constant for air, (ft-lbf)/(lbm-R) or J/(kg-K)

The floors in a conventional building offer resistance to vertical air flow. Furthermore, this resistance varies depending on how stairwells and elevator shafts are sealed. When the resistance can be assumed equal for each floor, a single correction, called the *draft coefficient*, can be used to relate the actual pressure difference ΔP_s to the theoretical value ΔP_{st}:

$$C_d = \frac{\Delta P_s}{\Delta P_{st}} \tag{6-10}$$

The flow of air from floor to floor causes a decrease in pressure at each floor; therefore, ΔP_s is less than ΔP_{st}, and C_d is less than one. Using the draft coefficient, Eq. 6-9 becomes

$$\Delta P_s = \frac{C_d P_o h g}{R_a g_c} \left(\frac{1}{T_o} - \frac{1}{T_i} \right) \tag{6-11}$$

Figure 6-5 is a plot of Eq. 6-11 for an inside temperature of 75 F or 24 C, sea-level outside pressure, and winter temperatures; however, Fig. 6-5 can be used for summer stack effect with little loss in accuracy.

The draft coefficient depends on the tightness of the doors in the stairwells and elevator shafts. Values of C_d range from 1.0 for buildings with no doors in the stairwells to about 0.65–0.85 for modern office buildings.

Pressurization of the indoor space is accomplished by introducing more makeup air than exhaust air and depends on the design of the air distribution system rather than natural phenomena. The space may be depressurized by improper or maladjusted equipment, which is usually undesirable. For purposes of design, the designer must assume a value for ΔP_p, taking care to use a value that can actually be achieved in practice. Often the space is pressurized in an attempt to offset infiltration, especially with very tall buildings.

Calculation Aids

Figures 6-1, 6-6, and 6-7 and associated Tables 6-1, 6-2, and 6-3 give the infiltration rates, based on experimental evidence, for windows and doors, curtain walls, and commercial swinging doors. Note that the general procedure is the same in all cases, except that curtain wall infiltration is given per unit of wall area rather than crack length. The pressure differences are estimated by the methods discussed earlier, and the values for the coefficient K are given in Tables 6-1, 6-2, and 6-3. The use of storm sashes and storm doors is common. The addition of a storm sash with crack length and a K-value equal to the prime window reduces infiltration by about 35 percent.

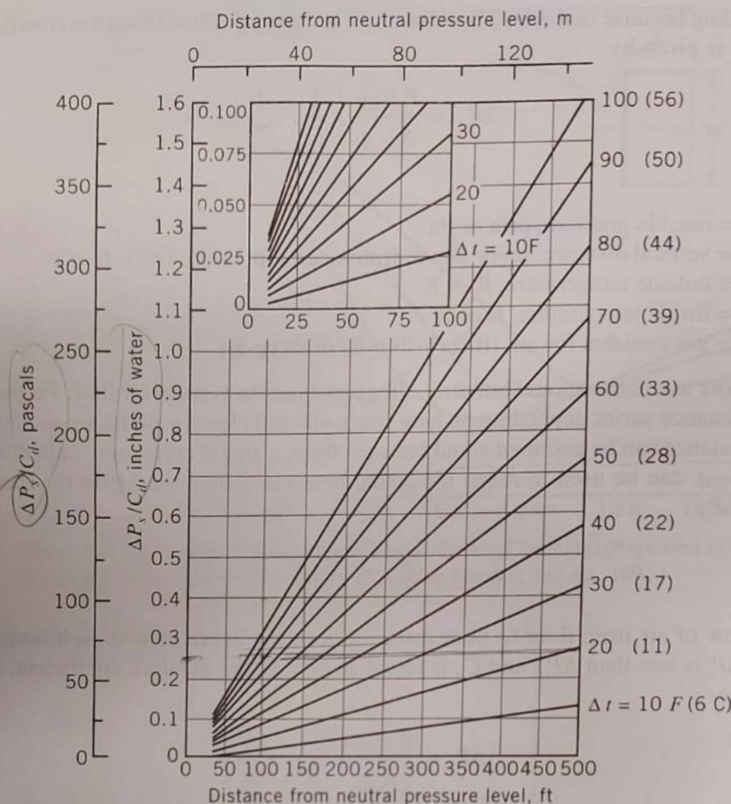

Figure 6-5 Pressure difference due to stack effect. (Reprinted by permission from *ASHRAE Cooling and Heating Load Calculation Manual*, 2nd ed., 1992.)

Commercial buildings often have a rather large number of people going and coming, which can increase infiltration significantly. Figures 6-8 and 6-9 have been developed to estimate this kind of infiltration for swinging doors. The infiltration rate per door is given in Fig. 6-8 as a function of the pressure difference and a traffic coefficient that depends on the traffic rate and the door arrangement. Figure 6-9 gives the traffic coefficients as a function of the traffic rate and two door types. Single-bank doors open directly into the space; however, there may be two or more doors at one location. Vestibule-type doors are best characterized as two doors in series so as to form an air lock between them. These doors often appear as two pairs of doors in series, which amounts to two vestibule-type doors.

The stack effect is small in low-rise buildings, and wall infiltration is usually very low; therefore, only wind effects and crackage need be considered. In high-rise buildings the stack effect may be dominant, with a relatively large amount of leakage through the walls and around fixed window panels. All pressure effects as well as window, door, and wall leakage should be considered for high-rise buildings.

Theoretically, it is possible to predict which sides of a building will experience infiltration and which will experience exfiltration by use of the pressure coefficient

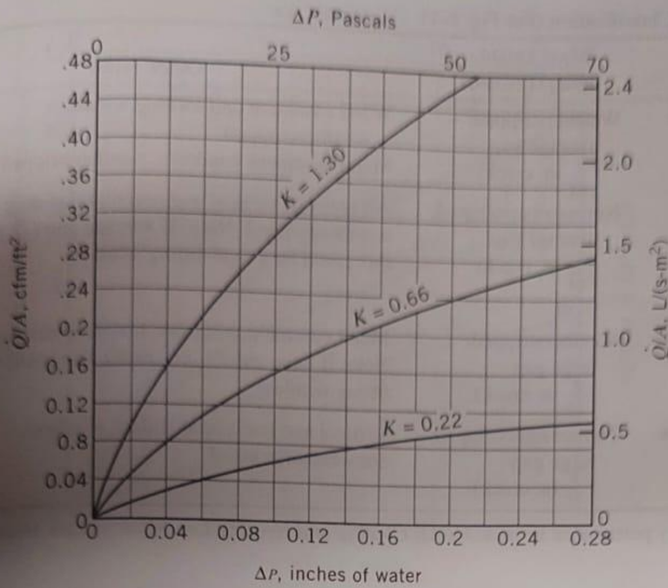

Figure 6-6 Curtain wall infiltration for one room or one floor. (Reprinted by permission from *ASHRAE Cooling and Heating Load Calculation Manual*, 2nd ed., 1992.)

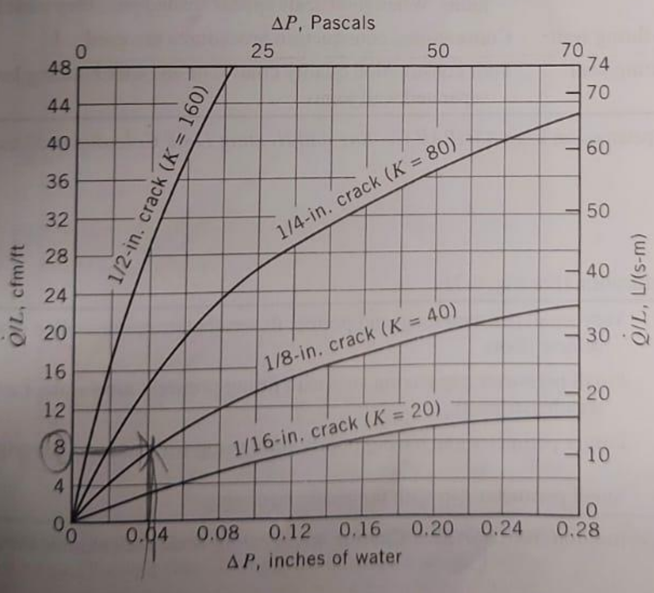

Figure 6-7 Infiltration through cracks around a closed swinging door. (Reprinted by permission from *ASHRAE Cooling and Heating Load Calculation Manual*, 2nd ed., 1992.)

Table 6-1 Window Classification (For Fig. 6-1)

	Wood Double-hung (Locked)	Other Types
Tight-fitting window $K = 1.0$	Weatherstripped, average gap ($\frac{1}{64}$ in. crack)	Wood casement and awning windows, weatherstripped Metal casement windows; weatherstripped
Average-fitting window $K = 2.0$	Nonweatherstripped, average gap ($\frac{1}{64}$ in. crack) or	All types of vertical and horizontal sliding windows, weatherstripped. Note: If average gap ($\frac{1}{64}$ in. crack) this could be a tight-fitting window.
	Weatherstripped, large gap ($\frac{3}{32}$ in. crack)	Metal casement windows, nonweatherstripped. Note: If large gap ($\frac{3}{32}$ in. crack), this could be a loose-fitting window.
Loose-fitting window $K = 6.0$	Nonweatherstripped, large gap ($\frac{3}{32}$ in. crack)	Vertical and horizontal sliding windows, nonweatherstripped

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Table 6-2 Curtain Wall Classification (For Fig. 6-6)

Leakage Coefficient	Description	Curtain Wall Construction
$K = 0.22$	Tight-fitting wall	Constructed under close supervision of workmanship on wall joints. When joint seals appear inadequate, they must be redone
$K = 0.66$	Average-fitting wall	Conventional construction procedures are used
$K = 1.30$	Loose-fitting wall	Poor construction quality control or an older building having separated wall joints

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Table 6-3 Door Classification (For Fig. 6-7)

Tight-fitting door $K = 1.0$	Very small perimeter gap and perfect fit weatherstripping—often characteristic of new doors
Average-fitting door $K = 2.0$	Small perimeter gap having stop trim fitting properly around door and weatherstripped
Loose-fitting door $K = 6.0$	Larger perimeter gap having poorly fitting stop trim and weatherstripped or Small perimeter gap with no weatherstripping

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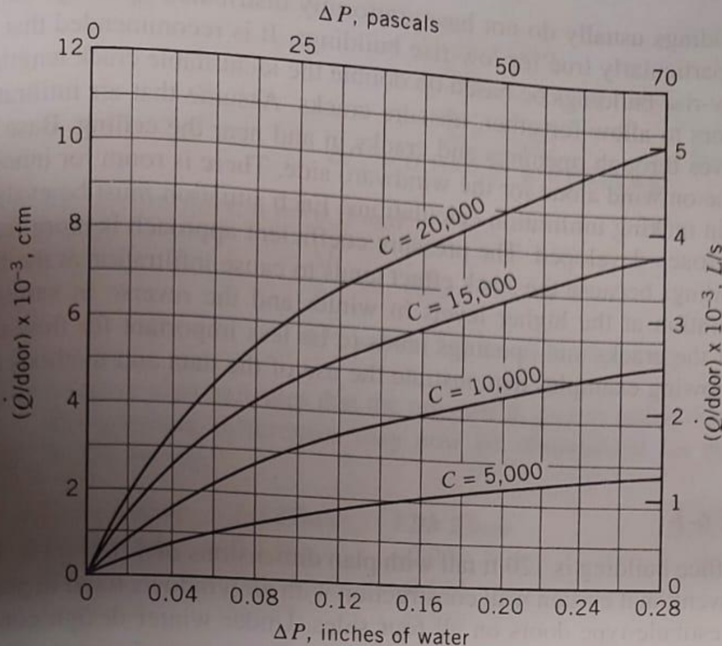

Figure 6-8 Swinging-door infiltration characteristics with traffic. (Reprinted by permission from *ASHRAE Cooling and Heating Load Calculation Manual*, 2nd ed., 1992.)

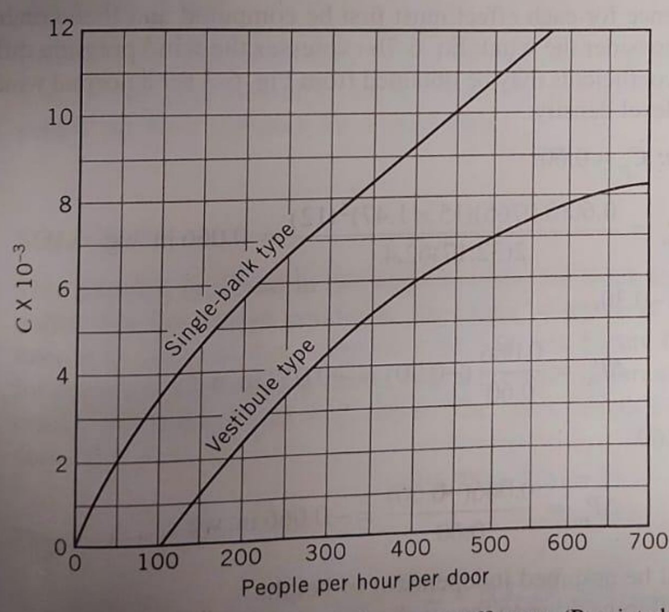

Figure 6-9 Flow coefficient dependence on traffic rate. (Reprinted by permission from *ASHRAE Cooling and Heating Load Calculation Manual*, 2nd ed., 1992.)

However, buildings usually do not have uniformly distributed openings on all sides. This will be particularly true for low-rise buildings. It is recommended that the infiltration for low-rise buildings be based on double the identifiable crack length for windows and doors to allow for other, obscure cracks. Assume that air infiltrates on all sides and leaves through openings and cracks in and near the ceiling. Base the pressure difference on wind alone for the windward side. There is room for innovation by the designer in making infiltration calculations. Each situation must be evaluated and a rational approach developed. The pressure coefficient approach is more feasible for high-rise buildings because the stack effect tends to cause infiltration at the lower levels and exfiltration at the higher levels in winter and the reverse in summer. Nonuniformity of the cracks and openings tends to be less important for flow continuity here. The following examples demonstrate the use of the data and methods described previously.

EXAMPLE 6-1

A 12-story office building is 120 ft tall with plan dimensions of 120×80 ft. The structure is of conventional curtain wall construction with all windows fixed in place. There are double vestibule-type doors on all four sides. Under winter design conditions, a wind of 15 mph blows normal to one of the long dimensions. Estimate the pressure differences for all walls for the first and twelfth floors. Consider only wind and stack effects. The indoor–outdoor temperature difference is 60 F.

SOLUTION

The pressure difference for each effect must first be computed and then combined to find the total. First consider the wind: Eq. 6-7b expresses the wind pressure difference where the pressure coefficients may be obtained from Fig. 6-3 for a normal wind. Then using standard sea-level density:

Windward Side: $C_p = 0.60$,

$$\Delta P_w = \frac{0.60(0.0765)(15 \times 1.47)^2(12)}{2(32.17)62.4} = 0.066 \text{ in. wg}$$

Leeward: $C_p = -0.30$,

$$\Delta P_w = \frac{0.066}{0.60}(-0.30) = -0.033 \text{ in. wg}$$

Sides: $C_p = -0.60$

$$\Delta P_w = \frac{0.066(-0.60)}{0.60} = -0.066 \text{ in. wg}$$

The wind effect will be assumed independent of height.

The pressure difference due to the stack effect can be computed from Eq. 6-11 or more easily determined from Fig. 6-5. Because there are more openings in the lower part of the building, assume that the neutral pressure level is at the fifth floor instead of at the sixth. Also assume that the draft coefficient is 0.8. Then for the first floor, $h = 40$ ft, and from Fig. 6-5

how?

and

$$\frac{\Delta P_s}{C_d} = 0.10$$

is it because in fig 6-5 distance from neutral pressure level to h = 40 ft?

$$\Delta P_s = 0.10(0.8) = 0.08 \text{ in.wg}$$

For the twelfth floor, $h = 70$ ft and

$$\frac{\Delta P_s}{C_d} = -0.12$$

$$\Delta P_s = -0.12(0.8) = -0.096 \text{ in.wg}$$

The negative sign indicates that the pressure is greater inside the building than outside.

The pressure differences may now be summarized for each side where $\Delta P = \Delta P_w + \Delta P_s$ in. wg:

Orientation	*1st Floor*	*12th Floor*
Windward	0.146	−0.030
Sides	0.014	−0.162
Leeward	0.047	−0.129

These results show that air will tend to infiltrate on most floors on the windward wall. Infiltration will occur on about the lower four floors on the leeward wall. All other surfaces will have exfiltration.

EXAMPLE 6-2

Estimate the infiltration rate for the leeward doors of Example 6-1. The doors have $\frac{1}{8}$ in. cracks, and the traffic rate is low except at 5:00 P.M., when the traffic rate is 350 people per hour per door for a short time.

SOLUTION

This problem is solved in two steps to allow for crack leakage and infiltration due to traffic. For the design condition, the effect of traffic is negligible; however, it is of interest to compute this component for 5:00 P.M. Figure 6-7 pertains to crack leakage for commercial swinging doors. For a pressure difference of 0.047 in.wg and $\frac{1}{8}$ in. cracks, the leakage rate is 8 cfm/ft. The crack length for standard double swinging doors is

$$L = 3(6.75) + 2(6) = 32 \text{ ft}$$

from where?

Then

$$\dot{Q} = \frac{\dot{Q}}{L} L = 8(32) = 256 \text{ cfm}$$

?

Vestibule-type doors will tend to decrease the infiltration rate somewhat like a storm sash or a storm door. Assume a 30 percent reduction; then

$$\dot{Q} = (1 - 0.3)256 = 179 \text{ cfm}$$