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THE CALCULATION OF AIR INFILTRATION RATES CAUSED BY WIND AND STACK ACTION FOR TALL BUILDINGS

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THE CALCULATION OF AIR INFILTRATION RATES CAUSED BY WIND AND STACK ACTION FOR TALL BUILDINGS

ANALYZED

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The air that leaks through cracks and openings in a building envelope contributes to the heating and cooling loads of a building. Because its contribution to the total loads can be quite large, accurate estimates of infiltration rates are required for proper sizing of HVAC systems and analyzing the performance of various energy conservation measures. At present, methods for calculating infiltration rates are either over simplified with possible attendant large errors or very complicated involving the use of a computer model building.

A method for calculating the air infiltration rate caused by stack action was given in a previous ASHRAE paper[1] by the authors. For this paper, it was necessary to develop methods for calculating infiltration rates caused by wind action alone and in combination with stack action. A literature search for suitable wind pressures measurements for air infiltration calculations revealed that investigations of wind pressures on tall buildings have been directed almost exclusively to improving structural load calculations with measurements concentrated on those areas of the wall surfaces likely to be exposed to the greatest wind pressures. As air can leak through any part of exterior walls, detailed information on the distribution of wind pressures is required for infiltration calculation.

Recently, the National Aeronautical Establishment of the National Research Council of Canada (NRCC) conducted extensive pressure measurements on a tall building model in a boundary layer wind tunnel. Wind pressure data from this investigation were made available to the authors and, with the aid of a computer model building, procedures for calculating air infiltration rates were developed.

WIND TUNNEL PRESSURE MEASUREMENTS

Wind pressures on the surfaces of a plexiglass model representing a building 100 ft (31 m) by 150 ft (46 m) and 600 ft (183 m) high at a 1:400 scale, were measured in the 6 ft (1.83 m) by 9 ft (2.74 m) NRCC wind tunnel. The pressure taps on the model were distributed horizontally at the one-third and two-third heights for the four walls and vertically along the centerline of two adjacent walls (Fig. 1).

The wind velocity profile for a suburban boundary layer was simulated according to the following equation:[2]

$$V_Z = KZ^{1/3} \tag{1}$$

where V_Z is the velocity at height Z above ground and K is constant. The velocity profile was developed in the tunnel using an upstream array of spires. No blocks were used to simulate ground roughness.

The model was placed on the turntable of the working section and was rotated 180 deg with a set of pressure readings taken at each 15-deg increment. They were converted to pressure

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coefficients related to the wind velocity at the roof level using the following equation

$$C_{pz} = \frac{P_z}{P_{vt}} \qquad (2)$$

where

C_{pz} = pressure coefficient at height Z
P_z = pressure at height Z referenced to that of the free air stream
P_{vt} = velocity pressure at roof level

The distribution of wind pressure coefficients for the two horizontal levels for wind angles of 0 and 45 deg with respect to the normal on the long side surface are given in Fig. 2. It shows that they are less than unity and that they vary on the windward wall and are almost constant on the side and leeward walls.

Factors relating the mean and the centerline pressure coefficients were calculated for the two levels and applied to the centerline pressure coefficients for other levels to obtain the vertical distribution of mean pressure coefficients for various wind angles shown in Fig. 3. These values were applied to the computer model building to develop procedures for air infiltration calculations. It was assumed that the pressure coefficients can be applied to buildings with width to length ratio of 1:1 to 1:2 (wind tunnel model was 1:1.5) and to buildings of any height.

COMPUTER MODEL BUILDING

Pressures imposed by wind and temperature difference forces are distributed inside a building in such a way that for steady state, air inflow and outflow for individual compartments are always equal. Hence, for a given outside condition, the patterns of pressure difference and air leakage depend on the flow resistances of all the separations. Modeling a building requires assigning values of flow resistances to the separations.

An open floor office building 100 ft (31 m) by 150 ft (46 m) and a floor height of 10 ft (3 m) was used as a basic model as shown in Fig. 4. The major separations of the model are the exterior walls, walls of vertical shafts and floors. The leakage areas in the major separations for each story were lumped and represented by flow coefficients (see Fig. 4) which were based on the average values obtained from tests conducted on several tall buildings by the authors.[1,3]

The flow of air through a leakage opening can be represented by

$$Q = C\ (\Delta P)^n \qquad (3)$$

where

Q = air leakage rate, cfm (m^3/s)
C = flow coefficient, cfm/in. of water^n ($m^3/s\ Pa^n$)
ΔP = pressure difference, in. of water (Pa)

A flow balance equation can be set up for each compartment in the model using Eq. 3. Given the values of outside pressures, all inside pressures can be solved by iterative calculations; hence, pressure difference and air leakage rate for all separations can be calculated. The mathematical model and the computer program used for this paper are given in Ref 4.

RESULTS AND DISCUSSIONS

Computer calculations were conducted for building heights of 10, 20, 30 and 40 stories and width to length ratios of 1:1, 1:1.5 and 1:2 for wind acting directly on the long wall. The effect of changing the wind angles were investigated on the 20-storey model.

Air Infiltration Caused by Wind

Pressure differences across the exterior walls obtained from the computer results were nondimensionalized by dividing them by the wind velocity pressure at the roof level. For the purpose of this paper, they are referred to as pressure difference coefficient (C_p'). The vertical distribution of pressure difference coefficients for the four walls for wind angles of 0 and 45 deg are shown in Fig. 5. For comparison, the wind pressure coefficients (C_p) from

Fig. 3 are also shown as dashed lines in Fig. 5. For wind angle of 0 deg (normal to the long wall) the C_p' curves are shifted to the right with values of C_p' greater than C_p for the windward wall and less for the leeward and side walls. For wind angle of 45 deg the values of C_p' and C_p are almost identical. The values of C_p' relative to those of C_p vary with wind direction as the former are referenced to the inside pressures which adjust to maintain a balance of air inflow and outflow.

At any level, the sum of the absolute values of C_p' of the windward and leeward or windward and side walls were about equal to those of C_p. Also, air flow inside the model building was mainly from the windward to the leeward and side walls with less than 5% of the total infiltration rate in the vertical direction from the central portion of the building to the upper and lower floors. It would appear that each floor behaved independently and can be treated separately when considering infiltration caused by wind action alone.

Fig. 6 shows the pressure differences across the four walls with changes in wind direction for the model building with width to length ratio of 1:1.5. They are expressed as the ratio of the pressure difference across the exterior wall over that of the long wall with wind acting normal to that wall (Side 1). The ratios can be estimated from the following equations obtained by curve fitting.

$$\text{Side 1} \qquad \frac{\Delta P_{\Theta,1}}{\Delta P_{o,1}} = -0.013\Theta + 1.0 \tag{4}$$

$$\text{Side 2} \qquad \frac{\Delta P_{\Theta,2}}{\Delta P_{o,1}} = 0.0165\Theta - 0.4 \tag{5}$$

$$\text{Side 3} \qquad \frac{\Delta P_{\Theta,3}}{\Delta P_{o,1}} = \begin{cases} -0.005\Theta - 0.14 & \text{for } 0 \leq \Theta \leq 45 \\ 0.003\Theta - 0.5 & \text{for } 45 \leq \Theta \leq 90 \end{cases} \tag{6}$$

$$\text{Side 4} \qquad \frac{\Delta P_{\Theta,4}}{\Delta P_{o,1}} = e^{(0.068\Theta - 6.914)} - 0.388 \tag{7}$$

where

Θ = wind angle measured counter clockwise from normal of Side 1, deg

$\Delta P_{o,1}$ = pressure difference across wall of Side 1 with Θ = 0 deg

$\Delta P_{\Theta,1}$, $\Delta P_{\Theta,2}$, $\Delta P_{\Theta,3}$, $\Delta P_{\Theta,4}$ = pressure differences across walls of Sides 1, 2, 3, and 4 for wind angle = Θ

The pressure difference across the long wall (Side 1) is maximum when Θ = 0 deg and decreases linearly with wind direction to zero at Θ = 75 deg. The pressure difference across the short wall (Side 2) is zero at Θ = 25 deg and increases linearly to a maximum value at Θ = 90 deg. Thus, as the wind angle changes from 0 to 90 deg, air infiltrates through the long wall from 0 to 25 deg, both the long and short walls from 25 to 75 deg and the short wall from 75 to 90 deg.

Fig. 7 shows the variation in infiltration rate with changes in wind angle and expressed as a ratio Q_Θ/Q_o where Q_Θ is the infiltration rate for a given wind angle Θ and Q_o is the long side infiltration rate with Θ = 0 deg. They are given for width to length ratios of 1:1, 1:1.5 and 1:2. Infiltration rates for any wind angle can be estimated from this figure knowing the infiltration rate of the long wall with Θ = 0 deg. It is seen that the maximum infiltration rate occurs when the wind direction is normal to the long wall.

Fig. 5 shows that the pressure difference coefficient, C_p', varies with height above ground. To simplify calculation of infiltration and exfiltration rates with wind acting normal to the long wall, mean pressure difference coefficients, C_{pm}', were calculated by solving for pressure difference, ΔP, in Eq 3 using the total infiltration rates obtained from the computer model results. The values are 0.96, - 0.13 and - 0.38 for the windward, leeward and side walls respectively.

The values of C_p and C_p' discussed so far are related to the wind speed at the roof level. They can be expressed in terms of the meteorological wind speed by using the following equation:

$$\frac{V_t}{V_s} = \left(\frac{G_s}{Z_s}\right)^{1/7} \left(\frac{H}{G}\right)^{1/3} \qquad (8)$$

where

V_t = mean wind speed at top of building, mph (m/s)

Z_s = anemometer height at the meteorological station, ft (m)

V_s = mean wind speed at height Z_s at the meteorological station, mph (m/s)

G_s = gradient height at the meteorological station, ft (m)

H = height of building, ft (m)

G = gradient height at building site, ft (m)

Letting Z_s, G_s and G be 32 ft (10 m), 900 ft (274 m) and 1500 ft (457 m) respectively,[2] the ratio of V_t/V_s is given by the following equation:

$$\frac{V_t}{V_s} = 0.142\ H^{1/3} \qquad (9)$$

Note: When SI units are used, constant 0.142 in Eq 9 is replaced by 0.211.

With $C'_{pm} = \frac{\Delta P_m}{\frac{1}{2}\rho V_t^2}$ and using Eq 9, the mean pressure difference equation with wind acting normal to the wall was developed:

$$\Delta P_m = B\ H^{2/3}\ V_s^2 \qquad (10)$$

where

ΔP_m = mean pressure difference, in of water (Pa)

B = $1.30 \times 10^{-4}\ \rho\ C'_{pm}$ (The values of C'_{pm} are given above; ρ = air density, lb/ft^3.)

The values of B assuming ρ = 0.075 lb/ft^3 are as follows:

	B	(SI Unit)
windward wall	9.33×10^{-6}	(0.0256)
leeward wall	-1.27×10^{-6}	(-0.0035)
side walls	-3.64×10^{-6}	(-0.0100)

The infiltration rate for a given wall can be calculated by

$$Q = C_w\ A\ (\Delta P)^{0.65} \qquad (11)$$

where

Q = infiltration rate, cfm (m^3/s)

A = wall area, sq ft (m^2)

C_w = flow coefficient, cfm/sq ft/(in. of water)$^{0.65}$ (m^3/s/m^2 Pa$^{0.65}$)

By substituting ΔP_m of Eq 10 for ΔP in Eq 11 and applying a factor α for wind direction, the infiltration equation is as follows:

$$Q_w = 5.375 \times 10^{-4}\ \alpha C_w\ LH^{1.435}\ V_s^{1.30} \qquad (12)$$

where

Q_w = infiltration rate caused by wind, cfm (m^3/s)

α = Q_Θ/Q_o (values from Fig. 7 for various wind angles)

C_w = flow coefficient, cfm/sq ft/(in. of water)$^{0.65}$ ($m^3/s/m^2\ Pa^{0.65}$)

L = length of wall, ft (m)

H = building height, ft (m)

V_s = wind speed at weather station, mph (m/s)

Note: When SI units are used, replace constant 5.375×10^{-4} in Eq 12 by 0.0925.

Maximum infiltration rate occurs when wind is acting directly on the long wall with $\alpha = 1.0$.

Suggested values of C_w for curtain wall construction with sealed windows are as follows:[1]

	C_w	(SI Unit)
Tight wall	0.22	0.31×10^{-4}
Average wall	0.66	0.93×10^{-4}
Loose wall	1.30	1.83×10^{-4}
Masonry wall*	4.00	5.63×10^{-4}

* Measurement on one masonry wall building.[6]

The selection of the air tightness value for a curtain wall depends mainly on the joint design and workmanship during building construction. Air leakage tests on several buildings indicated that the exterior walls constructed with close supervision of workmanship can be expected to have low leakage rates.[1]

Example 1

Calculate total infiltration rate caused by 20 mph (8.94 m/s) wind measured at a weather station with wind acting directly on the long wall of a building 100 ft (31 m) by 150 ft (46 m) and 200 ft (61 m) high. The air leakage value of the exterior wall is $C_w = 0.66$ (0.93×10^{-4}). The building is located in a suburban terrain.

From Eq 12

$$Q_w = 5.375 \times 10^{-4} \times 1.0 \times 0.66 \times 150 \times (200)^{1.435} \times (20)^{1.30}$$
$$= 5240 \text{ cfm } (2.47\ m^3/s)$$

The corresponding leakage rate obtained from the full computer model was 5356 cfm.

The infiltration rate for other than wind acting normal to the long wall can be calculated using values of α in Fig. 7. For example, with wind angle of $\Theta = 45$ deg the value of α for width to length ratio of 1:1.5 is 0.88.

Therefore

$$Q_w = 0.88 \times 5240 = 4611 \text{ cfm } (2.18\ m^3/s)$$

4690 cfm (computer result)

Nearby structures can affect wind pressures around a building. To investigate this effect on infiltration rate, wind pressure coefficients given by Bailey and Vincent[5] were applied to the computer model building. Results indicated that with the height of the shielding building of one-third, two-thirds and equal to the height of the shielded building and the distance between the buildings within 3 times the building width, the infiltration rate of the fully exposed building was reduced by 0, 20 and 60% respectively.

Air Infiltration Caused by Stack Action

The general equation for calculating infiltration rate caused by stack action was given in a previous ASHRAE paper by the authors.[1]

$$Q_s = C_w S \left[0.52\ \gamma\ p \left(\frac{\Delta T}{T_i T_o}\right)\right]^{n_w} \frac{(\beta H)^{n_w+1}}{n_w+1} \qquad (13)$$

where

Q_s = total infiltration rate caused by stack action, cfm (m^3/s)

C_w = exterior wall flow coefficient, cfm/ft^2 of wall area (in. of water)^n ($m^3/s/m^2Pa^n$)

S = perimeter of the building, ft (m)

γ = ratio of actual to theoretical pressure difference (thermal draft coefficient)

p = atmospheric pressure, lb/in.^{2} (Pa)

T_o = absolute temperature outside, R(K)

T_i = absolute temperature inside, R(K)

ΔT = inside-outside temperature difference, $T_i - T_o$, R (K)

n_w = flow exponent

β = ratio of height of neutral pressure level above ground to building height

Note - When SI units are used, constant 0.52 in Eq 12 is replaced by 0.0342.

The thermal draft coefficient, γ, depends on the air tightness of the exterior walls relative to that of the interior construction. With the interior completely open, the value of γ is one, whereas with each story completely sealed from others, it is zero. Measured values of γ on a few buildings[7] indicate that 0.80 may be used for office buildings. Measured values of γ for apartment buildings are not available. They will probably be lower than those of office buildings because of looser exterior wall construction and tighter interior construction with compartmentation of floor spaces and fewer elevator and service shafts. Assuming a value of γ for office buildings would give a conservative estimate of infiltration rates for apartment buildings.

Eq 13 can be simplified for practical purposes by assuming the following: p = 14.7 psia (101.3 KPa) T_i = 530 R (294 K), n_w = 0.65 and β = 0.50 (neutral pressure level at mid-height). Substituting these values in Eq 13 gives

$$Q_s = 0.0123\ C_w\ S\ \left(\gamma\frac{\Delta T}{T_o}\right)^{0.65} H^{1.65} \qquad (14)$$

Note - When SI units are used, constant 0.0123 in Eq 13 is replaced by 0.96.

Example 2

Calculate infiltration rate caused by stack action for the same building as in Example 1 with outside temperature of 0 F (-18 C), inside temperature of 75 F (24 C), no wind and γ = 1 (about the same as for the computer model).

From Eq 14,

$$Q_s = 0.0123 \times 0.66 \times 500\ \left(1 \times \frac{75}{460}\right)^{0.65} (200)^{1.65} = 7818 \text{ cfm } (3.69\,m^3/s)$$

7670 cfm (computer result)

Infiltration rates caused by wind action alone (wind normal to the long wall) and stack action alone for various wind speeds, inside-outside temperature differences and building heights are given in Fig. 8. They are expressed in cfm/sq ft of long wall area. The graph is based on C_w = 0.66 (9.3×10^{-4}) and γ = 1. For other values of C_w, the infiltration rates for wind and stack actions in Fig. 8 should be adjusted in direct proportion. For other values of γ, the infiltration rate for stack action should be adjusted by multiplying it by $\gamma^{0.65}$. For wind angle other than normal to the long wall, the infiltration rate for wind action should be multiplied by a factor given in Fig. 7.

The graph was constructed to permit direct comparison of infiltration rates caused by wind and stack action. They are both expressed in cfm/sq ft of long wall area (Side 1 in Fig. 8). To account for the variation in width to length ratio when considering stack action, the infiltration rates are plotted against an adjusted inside-outside temperature difference using the following equation which was deduced from Eq 13.

$$\Delta T_a = \left(\frac{1 + w/\ell}{1.67} \right)^{1.54} \Delta T \tag{15}$$

where

ΔT_a = adjusted inside-outside temperature difference

ΔT = inside-outside temperature difference

w = width

ℓ = length

From Eq 15, ΔT_a equals ΔT for width to length ratio of 1:1.5.

In Fig. 8, any point on a constant building height line will give the wind velocity and ΔT_a required to produce equal infiltration rates. For example, for a building height of 200 ft (61 m), the infiltration rate caused by ΔT_a of 45 F (25 C) is equal to that caused by wind of 20 mph (8.94 m/s) as given by Point 1 of Fig. 8.

Air Infiltration Caused by the Combined Action of Wind and Stack Action

The computer results indicated that the air infiltration rates caused by stack action alone, Q_s, and wind action alone, Q_w, cannot be added to obtain the infiltration rate caused by the combination of both actions, Q_{ws}.

An equation was developed to calculate Q_{ws},

$$\frac{Q_{ws}}{Q_{lrg}} = 1 + 0.24 \left(\frac{Q_{sml}}{Q_{lrg}} \right)^{3.3} \tag{16}$$

where

Q_{ws} = infiltration rate caused by combined wind and stack action

Q_{lrg} = larger value of Q_w and Q_s

Q_{sml} = smaller value of Q_w and Q_s

The two ratios in Eq 16 are plotted on Fig. 9. It shows that Q_{ws} is about equal to the infiltration rate caused by the larger of the two motive forces. When Q_w equals Q_s, Q_{sw} is 24% greater than either Q_w or Q_s.

Example 3

Calculate infiltration rate caused by both wind and stack action for the same building as in Examples 1 and 2 for wind speed of 20 mph (8.94 m/s), outside temperature of 0 F (-18 C) and inside temperature of 75 F (24 C).

From the results of Examples 1 and 2,

$$Q_w = 5240 \text{ cfm } (2.45 \text{ m}^3/\text{s})$$

$$Q_s = 7180 \text{ cfm } (3.39 \text{ m}^3/\text{s})$$

Since Q_s is larger than Q_w, from Eq 16,

$$\frac{Q_{sml}}{Q_{lrg}} = \frac{5240}{7180} = 0.730$$

$$\frac{Q_{ws}}{Q_{lrg}} = 1 + 0.24\ (0.730)^{3.3} = 1.085$$
(also from Fig. 9)

$$Q_{ws} = 7180 \times 1.085$$
$$= 7790 \text{ cfm } (3.67\ m^3/s)$$
8253 cfm (computer result)

The calculation of infiltration rates on a floor-by-floor or zone-by-zone basis would require a different approach than the one for overall infiltration rate. The computer results indicated that the pressure difference across the exterior wall at any level can be approximated by the algebraic sum of the pressure differences caused by wind and stack action.

$$\Delta P_{ws} = \Delta P_w + \Delta P_s \tag{17}$$

where

ΔP_{ws} = pressure difference caused by wind and stack action

ΔP_w = pressure difference caused by wind action

ΔP_s = pressure difference caused by stack action

Although the pressure difference caused by the building air handling system was not included in this study, it likely can be added to the right hand side of Eq 17.

The pressure difference caused by stack action at any level is given by

$$\Delta P_s = 0.52\ \gamma\ p\ h \left(\frac{\Delta T}{T_i T_o} \right) \tag{18}$$

where

h = distance from neutral pressure level, ft (m)

Note - When SI units are used constant 0.52 in Eq 18 is replaced by 0.0342.

Replacing h by (β-N) H in Eq 18,

where

N = ratio of height of level above ground to building height

$$\Delta P_s = 0.52\ \gamma\ p\ (\beta - N)\ H \left(\frac{\Delta T}{T_i T_o} \right) \tag{19}$$

Assuming p = 14.7 psia (101.3 KPa),

β = 0.5 (neutral pressure level at mid-height)

and T_i = 530 R (294 K),

Eq 19 becomes

$$\Delta P_s = 0.0143\ \gamma\ (0.5 - N)\ H \left(\frac{\Delta T}{T_o} \right) \tag{20}$$

Note - When SI units are used constant 0.0143 in Eq 20 is replaced by 11.68.

For wind acting normal to the long wall, equations for pressure difference caused by wind were developed from pressure difference coefficient, C_p', given in Fig. 5. They are as follows:

Windward Wall

from N = 0 to 0.7

$$\Delta P_w = (0.72 \text{ to } 0.48\ N)\ H^{2/3}\ V_s^2 \times 10^{-5} \tag{21}$$

Note - When SI units are used replace constant 10^{-5} by 0.0275

from N - 0.7 to 1.0

$$\Delta P_w = 1.05\ H^{2/3}\ V_s^2 \times 10^{-5} \tag{22}$$

Note - When SI units are used replace constant 1.05×10^{-5} by 0.0289

Leeward Wall

$$\Delta P_w = -1.27\ H^{2/3}\ V_s^2 \times 10^{-6} \tag{23}$$

Note - When SI units are used replace constant 1.27×10^{-6} by 0.0035.

Side Wall

$$\Delta P_w = -3.64\ H^{2/3}\ V_s^2 \times 10^{-6} \tag{24}$$

Note - When SI units are used replace constant 3.64×10^{-6} by 0.010

For wind angles other than normal to the long wall apply factors from Eq 4, 5, 6 and 7 or Fig. 6 to pressure differences obtained from Eq 21.

Example 4

Calculate infiltration rates on the 5th floor of a 20-story building 100 ft (31 m) by 150 ft (46 m) and floor height of 10 ft (3.05 m) caused by a 20 mph (8.94 m/s) wind acting directly on the long wall and outside temperature of 0 F (-18 C) and inside temperature of 75 F (24 C). $\Upsilon = 1$; $C_w = 0.66\ (0.93 \times 10^{-4})$.

$$\Delta P_s = 0.0143 \times 1\ (0.5 - \frac{5}{20})\ \ 200\ (\frac{75}{460}) \tag{20}$$

= 0.116 in. of water (29.0 Pa)

0.123 in. of water (computer result)

Windward Wall

$$\Delta P_w = (0.72 + 0.48 \times \frac{5}{20})\ \ 200^{2/3}\ 20^2 \times 10^{-5} \tag{21}$$

= 0.115 in. of water (28.6 Pa)

0.116 in. of water (computer result)

$$\Delta P_{ws} = 0.115 + 0.116 \tag{17}$$

= 0.231 in. of water (57.5 Pa)

0.223 in. of water (computer result)

$$Q_{ws} = 0.66 \times 10 \times 150\ (0.231)^{0.65} \tag{11}$$

= 382 cfm (0.18 m^3/s)

378 cfm (computer result)

Leeward Wall

$$\Delta P_w = -1.27 \times 200^{2/3}\ 20^2 \times 10^{-6} \tag{23}$$

= -0.017 in. of water (4.32 Pa)

-0.015 in. of water (computer result)

$$\Delta P_{ws} = -0.017 + 0.116 \tag{17}$$

= 0.099 in. of water (24.6 Pa)

0.093 in. of water (computer result)

$$Q_{ws} = 0.66 \times 10 \times 150\ (0.099)^{0.65} \quad (11)$$
$$= 220 \text{ cfm } (0.17\ m^3/s)$$
214 cfm (computer result)

Side Walls

$$\Delta P_w = -3.64 \times 200^{2/3}\ 20^2 \times 10^{-6} \quad (24)$$
$$= -0.50 \text{ in. of water } (12.4 \text{ Pa})$$
-0.049 in. of water (computer result)

$$\Delta P_{ws} = -0.050 + 0.116 \quad (17)$$
$$= 0.066 \text{ in. of water } (16.4 \text{ Pa})$$
0.059 in. of water (computer result)

$$Q_{ws} = 0.66 \times 10 \times 100\ (0.066)^{0.65} \quad (11)$$
$$= 113 \text{ cfm } (0.10\ m^3/s)$$
106 cfm (computer result)

The total infiltration for the 5th floor is 382 + 214 + 2 x 106 = 808 cfm (0.38 m^3/s). Computer result is 804 cfm.

SUMMARY

By applying the pressure data obtained from a wind tunnel model study to a computer model building, a simple procedure for calculating exterior wall pressure differences and air infiltration rates for various wind velocities and direction was developed. The wind tunnel pressure data were assumed to apply to buildings of any height and width to length ratio of 1:1 to 1:2. Although they were obtained for a building in a suburban terrain, these data would apply to most buildings except those in a large city center. A limited study on the effect of nearby buildings indicated that infiltration rates can be reduced by as much as 60% of those for a fully exposed building.

Procedures for calculating infiltration rates caused by the combined action of wind and temperature difference forces were developed for the total building or for individual floors or zones. This study has indicated that the overall infiltration rate is governed by the larger of the two motive forces and that the exterior wall pressure differences at any level caused by wind and stack action are additive.

Procedures for infiltration calculations which are illustrated by examples can be used for proper sizing of HVAC systems and for energy load analysis on an hour by hour basis. The results obtained by using the procedures given in this paper can be expected to be in good agreement with those obtained from the use of a computer model building.

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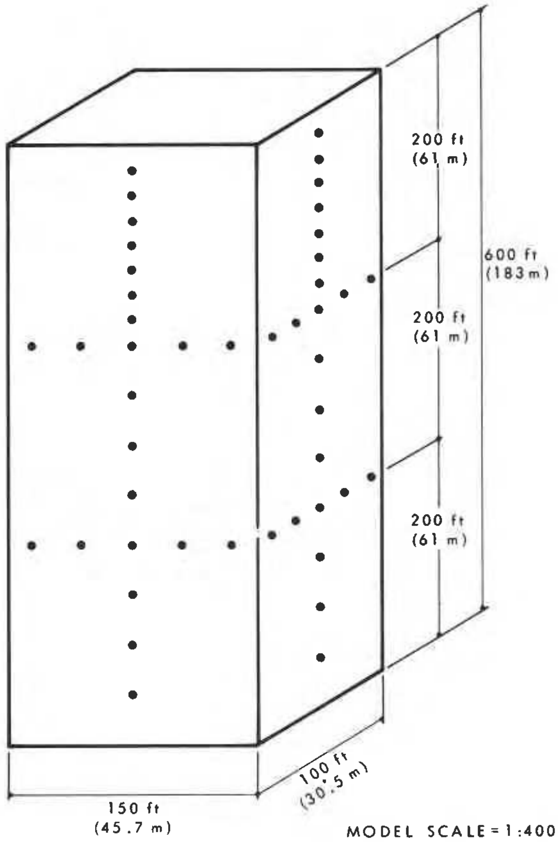

Fig. 1 Location of pressure taps on wind tunnel model

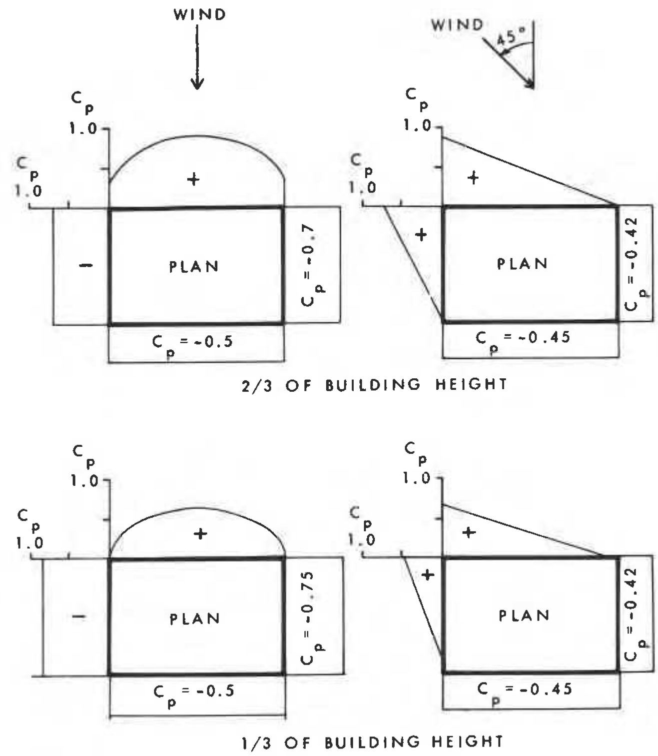

Fig. 2 Horizontal distribution of wind pressure coefficients, C_p

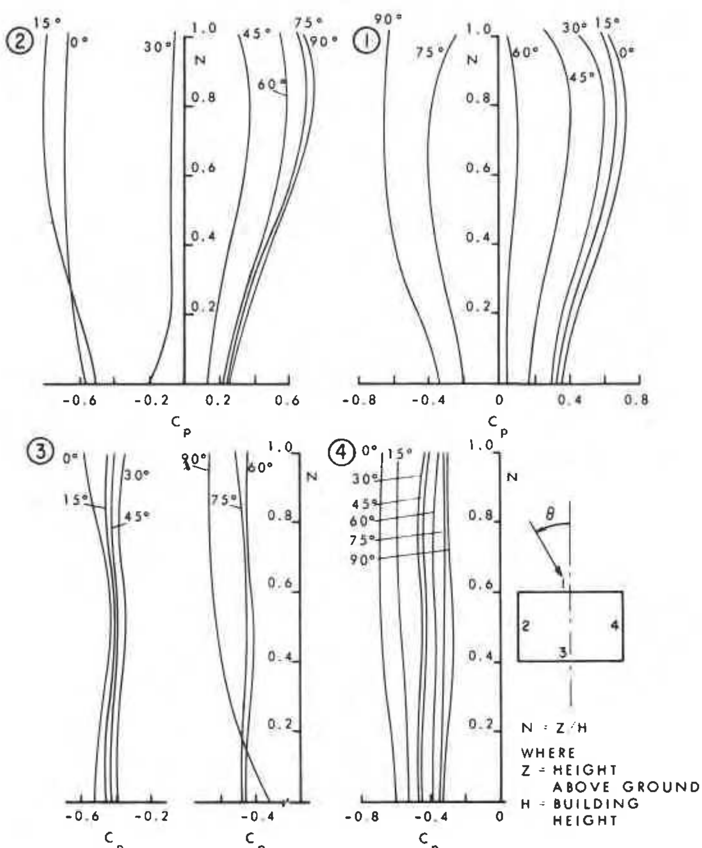

Fig. 3 Vertical distributions of mean wind pressure coefficient, C_p

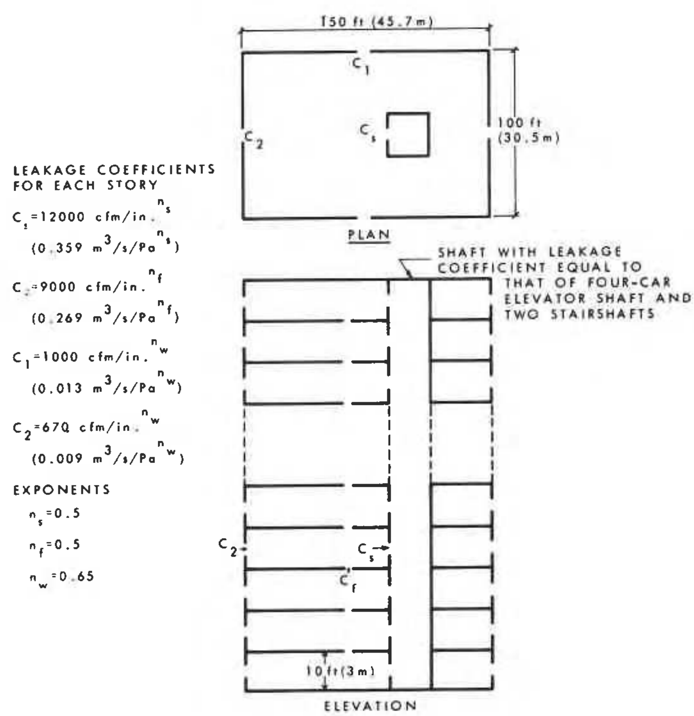

Fig. 4 Computer building model

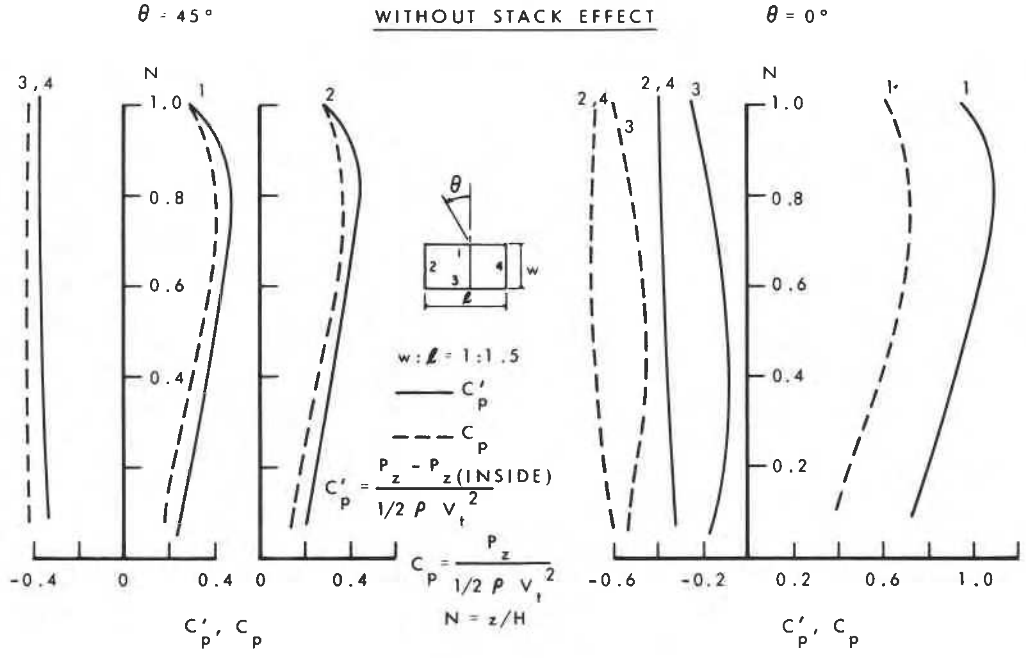

Fig. 5 Pressure difference coefficient, C_p', and wind pressure coefficient, C_p' vs height

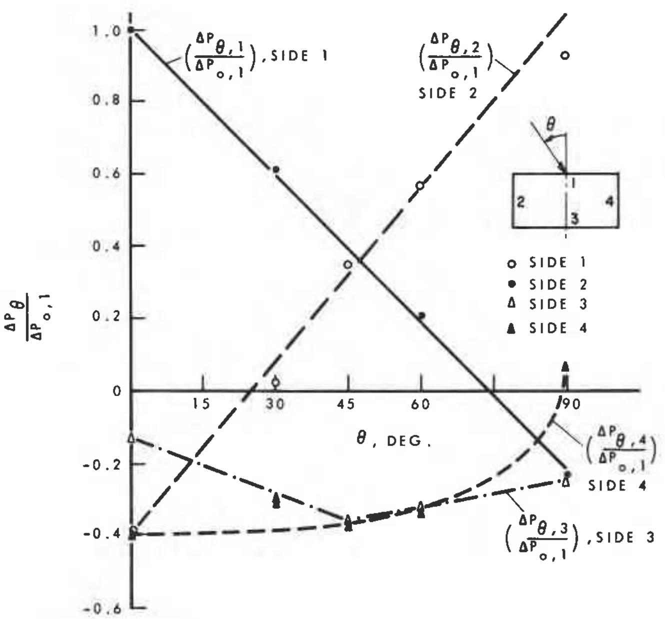

Fig. 6 Effect of wind direction on the mean pressure differences across exterior walls

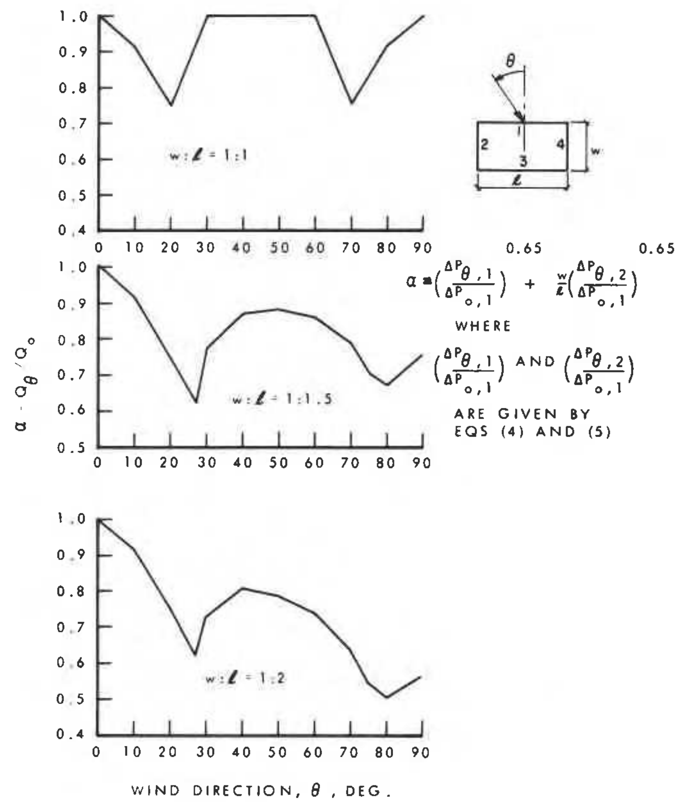

Fig. 7 Correction factor of air infiltration rate due to wind approaching at various directions

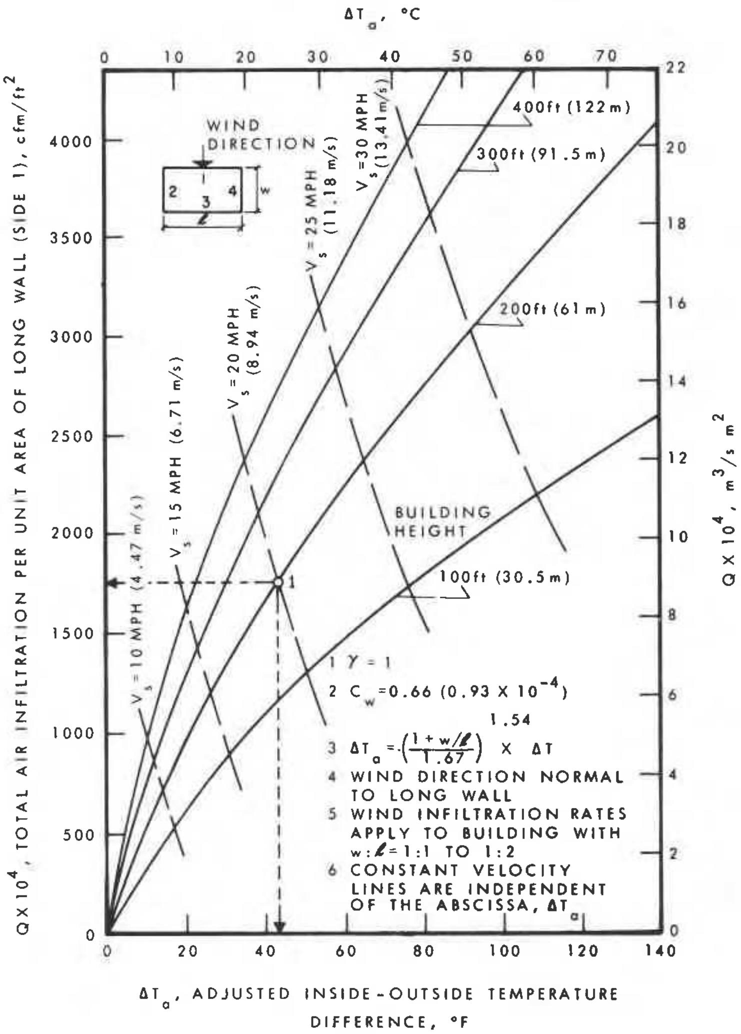

Fig. 8 Air infiltration rates caused either by wind or stack action

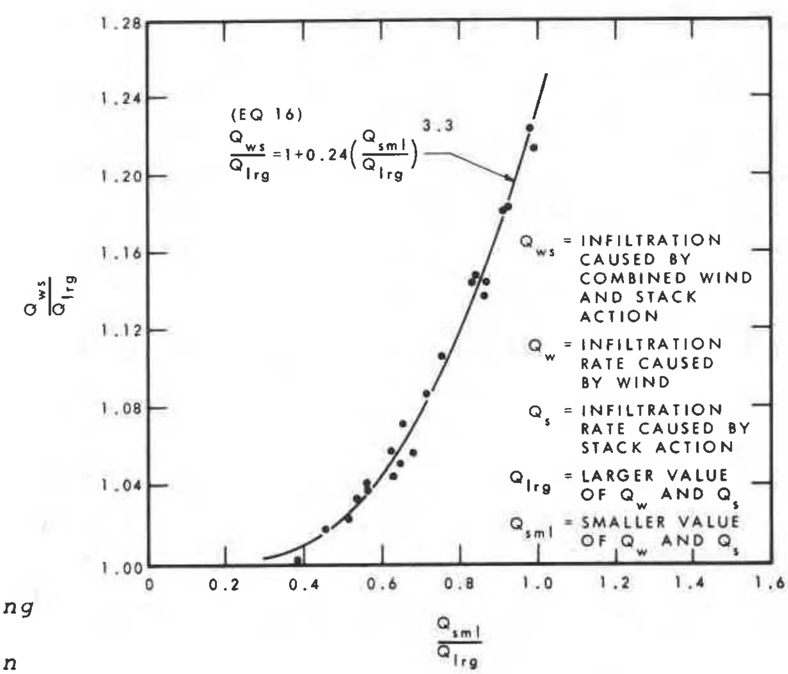

Fig. 9 Factors for determining infiltration rates caused by combined wind and stack action

SOMMAIRE

L'application à un modèle mathématique des données sur la pression obtenues au cours de l'étude d'une maquette aérodynamique a permis de mettre au point une méthode très simple pour calculer les différences de pression exercées sur les murs extérieurs et les différents taux d'infiltration de l'air, compte tenu de la direction et de la vitesse du vent. La présente étude a indiqué que le taux maximal d'infiltration est fonction de la plus grande des deux forces motrices et que les différences de pression exercées sur les murs extérieurs à n'importe quel niveau et due aux effets du vent et aux effets de tirage sont cumulatives.