



NRC Publications Archive Archives des publications du CNRC

Pressure differences caused by wind on two tall buildings

Tamura, G. T.; Wilson, A. G.

This publication could be one of several versions: author's original, accepted manuscript or the publisher's version. /
La version de cette publication peut être l'une des suivantes : la version prépublication de l'auteur, la version
acceptée du manuscrit ou la version de l'éditeur.

Publisher's version / Version de l'éditeur:

ASHRAE Transactions, 74, 2, pp. 170-181, 1969-02-01

NRC Publications Record / Notice d'Archives des publications de CNRC:

<https://nrc-publications.canada.ca/eng/view/object/?id=47b087b9-d404-42cc-bde2-f9afa16ce627>

<https://publications-cnrc.canada.ca/fra/voir/objet/?id=47b087b9-d404-42cc-bde2-f9afa16ce627>

Access and use of this website and the material on it are subject to the Terms and Conditions set forth at

<https://nrc-publications.canada.ca/eng/copyright>

READ THESE TERMS AND CONDITIONS CAREFULLY BEFORE USING THIS WEBSITE.

L'accès à ce site Web et l'utilisation de son contenu sont assujettis aux conditions présentées dans le site

<https://publications-cnrc.canada.ca/fra/droits>

LISEZ CES CONDITIONS ATTENTIVEMENT AVANT D'UTILISER CE SITE WEB.

Questions? Contact the NRC Publications Archive team at

PublicationsArchive-ArchivesPublications@nrc-cnrc.gc.ca. If you wish to email the authors directly, please see the first page of the publication for their contact information.

Vous avez des questions? Nous pouvons vous aider. Pour communiquer directement avec un auteur, consultez la première page de la revue dans laquelle son article a été publié afin de trouver ses coordonnées. Si vous n'arrivez pas à les repérer, communiquez avec nous à PublicationsArchive-ArchivesPublications@nrc-cnrc.gc.ca.



National Research
Council Canada

Conseil national de
recherches Canada

Canada

Ser
TH1
N21r2
no. 392
c. 2
BLDG

595
ANALYSED

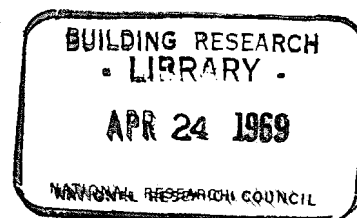
NATIONAL RESEARCH COUNCIL OF CANADA
CONSEIL NATIONAL DE RECHERCHES DU CANADA

PRESSURE DIFFERENCES CAUSED BY WIND ON TWO TALL BUILDINGS

by
G. T. Tamura and A. G. Wilson

Reprinted from
ASHRAE TRANSACTIONS
Vol. 74, Part II, 1968
p. 170-181

Research Paper No. 392
of the
Division of Building Research



OTTAWA
February, 1969

Price 25 cents

10494
NRC 10628

DIFFERENCES DE PRESSION CAUSEES PAR LE VENT
AUX ALENTOURS DE DEUX EDIFICES ELEVES

SOMMAIRE

Les auteurs ont déterminé les différences de pression dues à l'action du vent de part et d'autre des murs d'édifices de 45 et de 34 étages dans le centre d'une grande ville. Ils ont effectué une analyse régressive des enregistrements des pressions pour déterminer les coefficients de pression du vent pour les deux édifices. Les coefficients variaient beaucoup selon les variations de direction le long du gradient vertical de vitesse du vent et l'effet de bouclier des édifices avoisinants. Les vitesses de vent relevées in situ furent comparées avec les vitesses de vent mesurées à la station météorologique. On a remarqué que la relation entre les deux observations variait à cause des traits généraux de la configuration du sol aux deux endroits.



No. 2085

G. T. TAMURA
Member ASHRAE

A. G. WILSON
Member ASHRAE

Pressure Differences Caused by Wind on Two Tall Buildings

Estimating the quantity of air leakage for a building requires a knowledge of the pressure difference pattern over the exterior wall, as well as the air leakage characteristics of the exterior wall components. Wind is one of the major forces causing the pressure differences which result in air leakages. The other forces are chimney action and the imbalance of supply and exhaust air of the mechanical ventilation system.

Information on the pressure patterns resulting from wind, as a function of building configuration, can be found in many references dealing with model studies in wind tunnels¹. Velocity conditions in such studies are usually idealized. In reality, wind conditions are affected by the surrounding terrain and adjacent buildings. Because of the complex nature of the wind, and the difficulties of measuring it under the non-steady conditions that occur in nature, there is little information on pressure patterns for actual buildings.

As part of a study on the pressure differences that occur across building enclosures, pressure measurements were conducted on two tall buildings (44 and 34 stories) located in Montreal. The first

phase of this investigation dealt with the exterior wall pressure differences caused by chimney action and mechanical ventilation system operation. Pressure differences across the exterior wall and interior separations were measured during calm periods at various outside temperatures. The results of these measurements have been reported².

The second phase dealt with the pressure differences across the exterior wall which were caused by wind. For this study, continuous wind and pressure records were obtained and a regression analysis was carried out with the aid of a digital computer to determine wind pressure coefficients for both buildings. The results of the analysis are given in this paper.

DESCRIPTION OF THE TEST BUILDINGS

Buildings A and B, shown in Figs. 1 and 2, are commercial office buildings located in downtown Montreal. A contour map describing the characteristics of the terrain in which Buildings A and B are located is given in Fig. 3.

Building A has 44 stories and is 607 ft above street level to the top of the architectural fence on the roof. Rectangular in shape, it has dimensions of 100 by 140 ft. The 34-story Building B is 436 ft high and has floor dimensions of 117 by 173 ft. A more complete description of the buildings is given in Reference 2.

Fig. 4 shows the location and size of buildings in the immediate vicinity of the two test buildings

G. T. Tamura is a Research Officer, and A. G. Wilson is Head of the Building Service Section, Division of Building Research, National Research Council of Canada, Ottawa. This paper is a contribution of the Division of Building Research of the National Research Council of Canada and is published with the approval of the Director of the Division. This paper was prepared for presentation at the ASHRAE Annual Meeting, Lake Placid, New York, June 24-26, 1968.



Fig. 1 Building A

and gives an indication of the extent to which they are shielded.

For convenience the cardinal directions were arbitrarily chosen at right angles to the building faces. Unless otherwise stated, the cardinal directions are as indicated in Fig. 3.

INSTRUMENTATION

The outside pressure taps were located in the middle of each wall of the two mechanical equipment floors: for Building A at heights of 195 and 545 ft, and for Building B at heights of 135 and 410 ft above street level. The exterior wall pressures were referenced

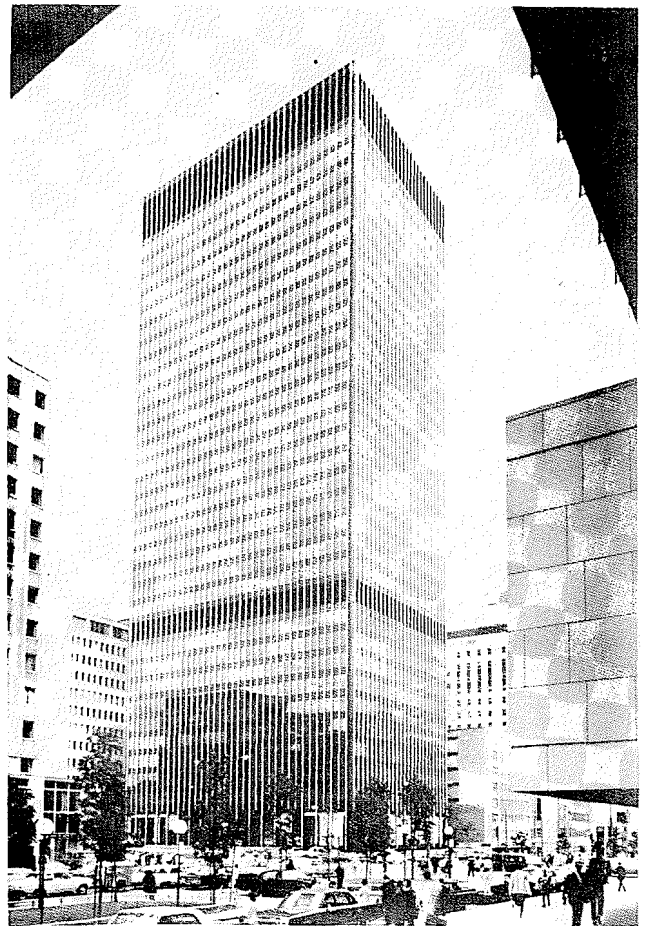


Fig. 2 Building B

to inside pressure taps located two floors away from the corresponding mechanical equipment floor. In addition to the pressure taps at the two upper levels, outside taps were installed on each of the four walls of Building B at the ground floor level.

The outside and inside taps were connected to a strain gauge diaphragm-type pressure transducer (sensitivity 0.002 in. of water) of the pressure recording system located in one of the mechanical equipment floors. The connection between the pressure tap and the pressure transducer was made with $\frac{1}{4}$ -in. plastic tubing which contributed to the lag of the recording system. With 400 ft of $\frac{1}{4}$ -in. plastic tubing (the longest connection used) the time constant of the recording system for a step input was 2.7 sec. The time constant of each pressure tap was different because of the varying lengths of the tube connections.

The outside air temperature was measured with a thermistor located in a sheltered area on the roof of



Fig. 3 Contour map of the terrain surrounding test buildings

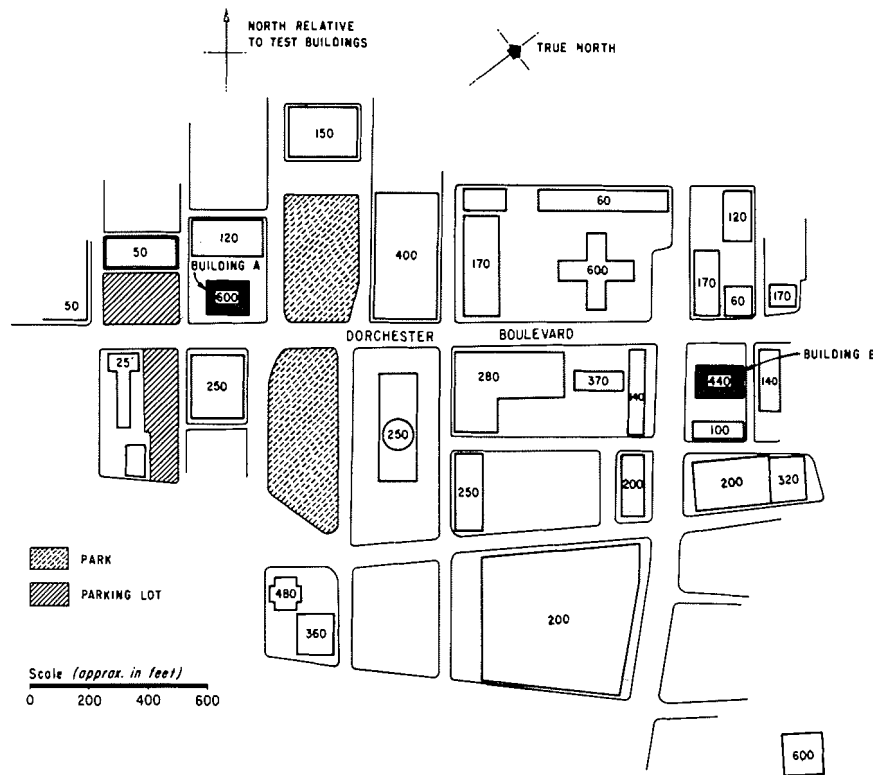


Fig. 4 Plan showing heights of adjacent buildings

the building. The wind speed and direction were measured with a cup-type anemometer that had a mechanism to indicate one of eight wind directions. Each wind direction, therefore, covers a 45-deg segment. The anemometer was located on a radio mast on top of Building A, 200 ft above roof level or approximately 800 ft above street level. The wind information from this anemometer was transmitted by telephone connection and recorded on the pressure recording system of Building B, located 0.3 mile east of Building A.

To compare on-site and meteorological station wind velocities, an additional record of wind information was obtained on an operational recorder. The meteorological station is located 8.3 miles northwest of Building A.

Pressure differences at each pressure tap location, wind speed and direction, and outside air temperature were recorded every 4 mins. on a 16-point millivolt recorder. Wind speed readings, which always followed two pressure readings, were an average speed over a 45-sec interval. The readings were recorded on a strip chart for visual checking. A digital encoder attached to the slider arm shaft of the recording po-

tentiometer was used to record each reading on either magnetic tape or punched paper tape in 3 digit binary numbers. The pressure records were processed and analyzed using an IBM 360 digital computer.

METHOD OF ANALYSIS

The values of the pressure differences across the exterior walls of a building are the net result of the combined action of various forces. It was assumed in this analysis that these pressure differences at any location could be adequately represented by the sum of the pressure differences due to the individual forces at that location.

At any height, the actual pressure difference across an exterior wall caused by chimney effect³ alone, expressed as a function of the inside and outside air temperature, is

$$\Delta p_c = \beta \left(\frac{1}{T} - \frac{1}{t} \right) \quad (1)$$

where

Δp_c = pressure difference across exterior wall caused by chimney action

T = absolute temperature outside
t = absolute temperature inside
β = constant (either positive or negative)

The pressure difference across one face of the exterior wall caused by wind velocity alone can be expressed as a function of the velocity head.

The equation for the velocity head is

$$P_v = \rho \frac{V^2}{2}$$

where

P_v = velocity head
V = wind velocity
ρ = air density.

The actual pressure difference across one face of the exterior wall caused by wind can be expressed as

$$\Delta p_v = \gamma P_v \quad (2)$$

where

Δp_v = pressure difference across an exterior wall caused by wind
γ = wind pressure coefficient
a positive value indicates a higher pressure outside than inside
a negative value indicates a lower pressure outside than inside

The net effect of chimney and wind action and the ventilation system operation on the exterior wall pressure difference is then expressed by the following:

$$\Delta P = \lambda + \beta \left(\frac{1}{T} - \frac{1}{t} \right) + \gamma P_v \quad (3)$$

where

ΔP = the resultant pressure difference across one face of an exterior wall
λ = pressure difference caused by the ventilation system.

If there is little change in the outside temperature during the period under consideration, variations in ΔP are due mainly to the variations in wind speed. The first two terms on the right hand side of Eq 3 are then combined to give the following simple linear relationship:

$$\Delta P = a + \gamma P_v \quad (4)$$

Each section of the record selected for analysis

covered an extended period during which there was a constant outside air temperature (within 10 degs F) and constant wind direction. The mode of operation of the ventilation system also remained constant. The range of wind velocity in each of the selected pressure records was usually not greater than 10 to 15 mph. In order to compute wind pressure coefficients that would be applicable over a wider range, two sections of record with the same wind direction but with different absolute wind speeds were combined for purposes of analysis. The a values were usually not the same, since the outside temperatures for the two sections of records were in most instances different. A dummy variable⁴, Z, was therefore added to Eq 5 to account for the two values of a as follows:

$$\Delta P = a + a_1 Z_1 + \gamma P_v \quad (5)$$

where

$Z_1 = 0$ when the pressure reading is from the first selected record
 $Z_1 = 1$ when the pressure reading is from the second selected record
 a = constant for the first selected record
 $a + a_1$ = constant for the second selected record.

The use of Eq 5 for the determination of the γ values for the four walls at any specific level would also yield 4 values of both a and $a + a_1$ which should be the same for each level. By extending the use of dummy variables, the method of analysis can be further modified so as to yield single values of a and $a + a_1$ for each level for the two sections of record in combination. This technique leads to a better determination of the values of a and $a + a_1$ and should therefore provide better values of wind pressure coefficients, γ .

The equation incorporating the dummy variables is as follows:

$$\Delta P = a + a_1 Z_1 + \gamma_1 P_v + \gamma_2 Z_2 P_v + \gamma_3 Z_3 P_v + \gamma_4 Z_4 P_v \quad (6)$$

where

$Z_i = 0$ if pressure reading is not associated with the i-th wall
 $Z_i = 1$ if pressure reading is associated with the i-th wall

and

$i = 2, 3, 4$

The pressure coefficient for each wall for a given wind direction is then

$$\begin{aligned}\gamma'_1 &= \gamma_1 \\ \gamma'_2 &= \gamma_1 + \gamma_2 \\ \gamma'_3 &= \gamma_1 + \gamma_3 \\ \gamma'_4 &= \gamma_1 + \gamma_4\end{aligned}$$

The wind pressure coefficients were obtained by analyzing each set of selected records to obtain the best fit with Eq 6. In this analysis the values of P_v were based on the velocity head of on-site wind obtained from the anemometer on the radio mast above Building A.

In order to relate the wind pressure coefficients to the wind velocity at the meteorological station, the on-site wind records were correlated with the meteorological wind records. The latter were usually available as hourly average wind speeds. The ratio of on-site hourly average wind velocity and the meteorological wind velocity was determined for each wind direction.

The wind pressure coefficient related to the meteorological wind velocity is then given by

$$\gamma_m = R_v^2 \gamma' \quad (7)$$

where

- R_v = ratio of on-site wind velocity to meteorological wind velocity
- γ_m = pressure coefficient based on meteorological wind velocity
- γ' = pressure coefficient based on on-site wind velocity.

RESULTS AND DISCUSSION

Fig. 5 is an example of the wind and pressure records obtained on-site and their correlation with Eq 6. Results in Fig. 5 are for the west wall of Building A at the 545-ft level with wind from the west direction. These pressures obtained from two selected pressure records with outside air temperatures of 42 F and 10 F are plotted against on-site wind speed. The two curves were determined from the results of the regression analysis.

The pressure differences caused by chimney action and the ventilation system operation (the α values) are the pressure differences corresponding to zero wind velocity. The pressure differences are -0.40 and -0.74 in. of water for outside temperatures

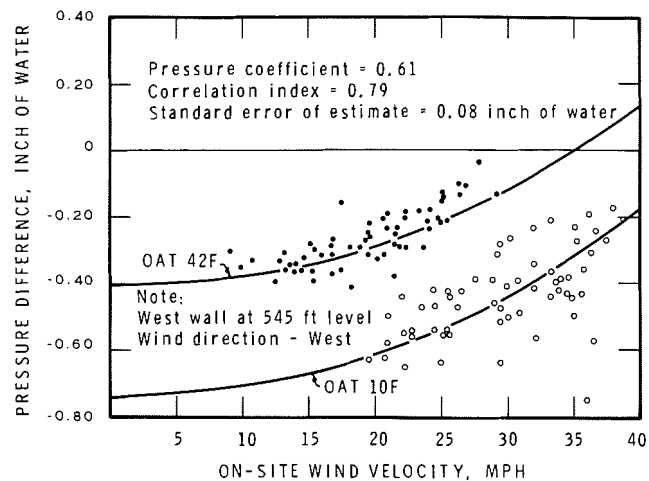


Fig. 5 Pressure differences across windward wall of Building A

of 42 and 10 F respectively. With increase in wind velocity there is a corresponding increase in the pressure differences across the windward wall. For the whole range of on-site wind speeds shown on the graph, however, the pressure differences are negative, with air exfiltration across the windward wall at the 545-ft level, indicating that the pressure difference caused by chimney action constituted a significant portion of the total.

An analysis similar to that represented by Fig. 5 was carried out for each exterior wall pressure tap location and in the process the wind pressure coefficients based on on-site wind were determined. For each wind direction the correlation index and the standard error of estimate, based on on-site wind velocity, were computed for each measuring level.

The correlation index indicates the proportion of the variance in the values of the exterior wall pressure differences explained by the concomitant variation in the wind velocity. A value of unity for the correlation index indicates a perfect correlation, whereas a value of zero would indicate no correlation. The degree of correlation depends on the (1) variation in the wind pattern on a building caused by local obstructions, (2) size of wind gust, (3) variation in wind direction (a given wind direction covers a 45-deg segment), (4) variation in pressure caused by projections on the exterior wall, (5) variation in inside pressure caused by elevators and doors and the operation of the ventilation system, and (6) the accuracy of the wind and pressure measuring equip-

ment. For Building A the correlation index varied from 0.65 to 0.90 at the upper level and 0.33 to 0.87 at the intermediate level; for Building B it varied from 0.43 to 0.82 at the upper level, from 0.11 to 0.61 at the intermediate level and from 0.03 to 0.65 at the ground level. The degree of correlation between concomitant values of on-site wind and wall pressure differences was thus better for higher levels than for lower ones; and was better for Building A than Building B. As would be expected, the better correlations were obtained for pressure tap locations closest to the point of wind velocity measurement and where there was the least shielding.

The standard error of estimate indicates the degree of agreement between the observed pressure differences and those estimated from Eq 6. With reference to Fig. 5, it is a measure of the scatter of the data points around the regression curves. For Building A, values varied from 0.038 to 0.077 in. of water at the upper level, and from 0.013 to 0.079 in. of water at the intermediate level. For Building B, values varied from 0.023 to 0.097 in. of water at the upper level, from 0.017 to 0.064 in. of water at the intermediate level, and from 0.013 to 0.048 in. of water at the lower level.

The method of analysis, utilizing Eq 6, separates the pressure difference due to wind action from that due to chimney action and the ventilation system operation. These pressure difference effects can also be isolated by examining the records obtained during calm periods. This has been done for Building B in Fig. 6, which shows the pressure differences at the 410 and 135-ft levels plotted against outside air temperature. At the 410-ft level the negative pressure difference across the exterior wall increases with decreasing outside air temperature. Because the 135-ft level is close to the neutral zone level of the building the change in the pressure difference with outside air temperature is small.

Fig. 6 also shows the effect of the office-hour and after-hour operation of the ventilation system. After office hours, several ventilation fans were shut down, altering the balance of outside supply and exhaust air. Comparison of the measured wall pressure differences with the line showing pressure differences caused by chimney action alone² in-

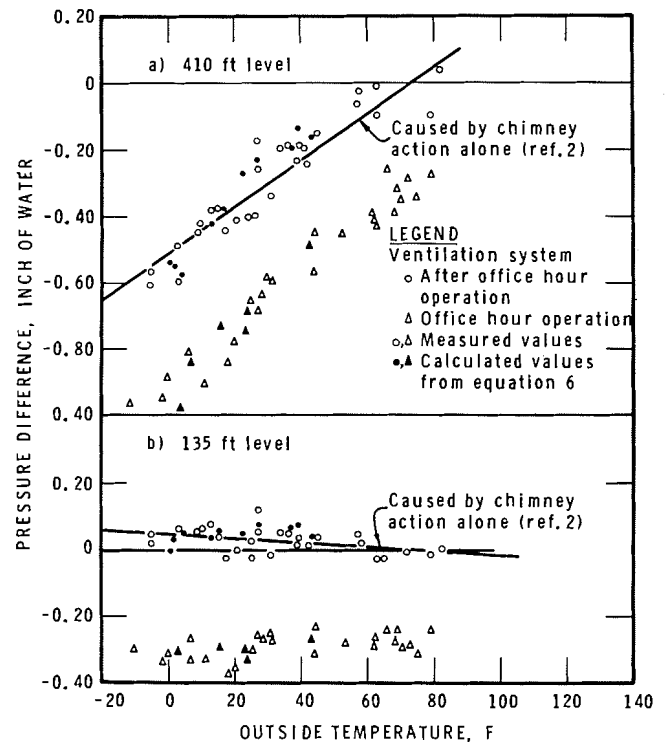


Fig. 6 Exterior wall pressure differences for Building B during calm periods

icates that supply and exhaust air were essentially balanced under the after-hour conditions. When the ventilation system was operating fully there was an imbalance of supply over exhaust, causing a pressurization of approximately 0.2 to 0.3 in. of water at both levels.

The pressure differences due to the combined effects of chimney action and the ventilation system obtained from Eq 6 are also plotted in Fig. 6. The calculated values agree reasonably well with the values measured directly, indicating the validity of Eq 6. It would appear, therefore, that the pressure difference across the exterior wall due to the combined forces can be adequately approximated by summing the pressure differences due to the individual forces.

Wind pressure coefficients computed from Eq 6, referenced to on-site wind measurements, are given in Tables I and II for both buildings. For a given wind direction each pressure coefficient is based on an average of 130 readings for Building A and 180 readings for Building B. The coefficients apply to conditions at the mid-point of the walls where the pressure taps were located.

TABLE I
WIND PRESSURE COEFFICIENTS FOR BUILDING A
BASED ON ON-SITE WIND VELOCITY

WIND DIRECTION	HEIGHT FT	EXTERIOR WALL			
		N	E	S	W
N	545	1.06	-0.46	-0.35	-0.45
	195	0.40	-0.55	-0.52	-0.17
NE	545	0.42	0.39	-0.20	-0.17
	195	0.36	0.13	-0.23	-0.11
E	545	-0.15	0.65	0.10	0.02
	195	0.06	0.23	0.10	0.04
SE	545	-0.30	0.60	0.04	-0.18
	195	-0.08	0.64	0.08	-0.05
S	545	-0.08	0.13	0.79	-0.08
	195	-0.22	0.09	0.08	-0.18
SW	545	-0.32	-0.29	0.24	0.26
	195	-0.44	-0.36	0.10	0.09
W	545	-0.06	-0.21	-0.35	0.61
	195	-0.21	-0.34	-0.49	0.25
NW	545	0.38	-0.29	-0.28	0.16
	195	0.21	-0.30	-0.35	0.16

TABLE II
WIND PRESSURE COEFFICIENTS FOR BUILDING B
BASED ON ON-SITE WIND VELOCITY

WIND DIRECTION	HEIGHT FT	EXTERIOR WALL			
		N	E	S	W
N	410	0.80	-0.35	-0.11	-0.45
	135	0.33	-0.20	-0.08	-0.07
	6	0.09	-0.17	-0.28	-0.12
NE	410	0.44	0.36	-0.08	-0.07
	135	0.42	0.07	-0.10	-0.18
E	410	-0.13	0.41	-0.18	-0.05
	135	0.10	0.05	0.03	-0.01
	6	0.24	0.17	0.08	0.05
SE	410	-0.23	0.03	-0.04	-0.15
	135	-0.03	-0.03	0	-0.04
S	410	-0.11	-0.16	0.32	-0.14
	135	-0.10	-0.18	0.14	0
SW	410	-0.15	-0.19	0.09	0.10
	135	-0.14	-0.19	0.10	0.03
	6	-0.24	0	0.17	-0.01
W	410	-0.08	-0.06	-0.07	0.17
	135	-0.02	-0.07	0	-0.01
	6	0.03	0.03	0.03	0.03
NW	410	0.29	-0.18	-0.11	-0.05
	135	0.21	0.17	-0.07	0
	6	0.05	-0.10	-0.13	-0.05

TABLE III
SUMMATIONS OF PRESSURE COEFFICIENTS FOR
WINDWARD AND LEEWARD WALLS OF BUILDINGS A AND B

BUILDING A			
WIND DIRECTION	545 FT LEVEL	195 FT LEVEL	
North	1.40	0.92	
East	0.63	0.19	
South	0.71	0.30	
West	0.82	0.59	

BUILDING B			
WIND DIRECTION	410 FT LEVEL	135 FT LEVEL	6 FT LEVEL
North	0.92	0.41	0.37
East	0.46	0.06	0.12
South	0.42	0.24	—
West	0.23	0.06	0

In general, the pressure coefficients are positive on windward sides and negative on leeward sides. The values of the coefficients are affected by elevation (generally being higher at upper levels) and vary also with wind direction. These effects relate to variations with direction of the vertical profile or gradient of the wind and to the shielding effect of adjacent buildings. In wind tunnel studies⁵ a significant reduction of wind pressure on a model of a 100-ft high building was noted when a shielding building of equal height was as far away as 15 times the building width.

Differences in wind effect can best be seen by summing the pressure coefficients on windward and leeward sides, as shown in Table III. These coefficients are indicative of the total pressure difference acting across the building. It will be noted that there is some directional effect on the pressure coefficients for the upper level of Building A. Values for winds from the east are lowest, due to the shielding effect of high buildings in that direction (see Fig. 4). There is no direct shielding from the other directions and differences are related to variations in the wind profile. The high values for north winds are probably associated in some way with the small mountain to the north. At the intermediate level of Building A, east and south walls are shielded while the north and south are relatively exposed.

The coefficients for Building B are generally lower than those for Building A at the upper level,

mainly because of B's lower height. The value in Table III for the north direction is greatest (as it is in Building A); whereas that for the west is smallest because of high buildings to the west and north-west. At the intermediate level there is some shielding in all directions, the effect being greatest for east and west winds. At the street level, the pressure differences are unpredictable; significant pressure differences occur with winds from the north and also from the southwest (see Table II), whereas values are smaller for the other directions.

It will be noted, using values from Tables I and II, that the ratio of pressure coefficients for windward sides to corresponding ones for the leeward sides is quite variable with elevation and direction. This implies differences in the ratio of infiltration and exfiltration. For example, if it is assumed that the effective area of leakage openings in the exterior wall is uniformly distributed at the perimeter of Building A, a simple calculation utilizing the wind pressure coefficients indicates an approximate balance of infiltration and exfiltration at the 545-ft level with wind from the north or west. A similar calculation for the intermediate level indicates greater exfiltration than infiltration. This suggests that there may be a vertical flow of air within the building induced by wind action; or that the single pressure tap in each wall does not provide a good indication of the average pressure difference. There is also the possibility that this apparent effect is due to limitations in the method of analysis; for

example, the assumption that the pressure differences due to the ventilation system are constant for a particular mode of operation may not be entirely valid.

ON-SITE VS METEOROLOGICAL WIND VELOCITY

The wind pressure coefficients in Tables I and II are referenced to the wind velocity measured on site. The wind data generally available, however, is that obtained at the local meteorological station.

The ratios of the wind velocity at the site (800 ft above street level on top of Building A) and at the meteorological station (33 ft above ground) were calculated for each wind direction from the hourly average values. As an example, a plot of the records for wind from the west direction is shown in Fig. 7. The calculated ratio for this direction is 1.60.

Fig. 8 shows the variation of the ratio of on-site to meteorological wind speed (R_v) with wind direction. Wind velocities varied from 0 to 30 mph at the meteorological station in the records selected for analysis. The on-site anemometer was located well

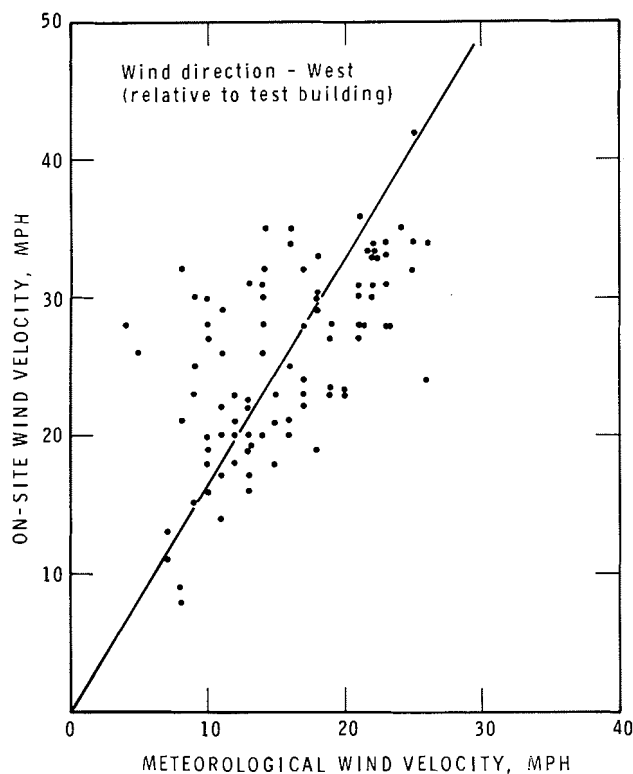


Fig. 7 Comparison of on-site and meteorological wind velocity

above adjacent buildings; the variation in the ratio with direction is therefore caused by differences in the general characteristics of the surroundings at the two locations. Relatively high values of R_v were obtained for the west, southwest and northeast direction. The lower values of R_v for the north and northwest directions are caused by the low mountain to the north of Building A (see Fig. 1). The lower values of R_v for the east and southeast directions can possibly be attributed to the effect of the cluster of tall buildings located east of Building A. The low value of R_v for the south direction may be due to some shielding of the anemometer by the 10-in. diameter radio mast. The anemometer was located on a 5-ft arm attached to the north side of the mast.

The wind velocity profile in the vertical direction can be approximated by the following equation⁵:

$$\frac{V}{V_r} = \left(\frac{h}{h_r} \right)^k \quad (8)$$

where

V = mean wind speed at height h above ground

V_r = mean wind speed at the reference height h_r above ground

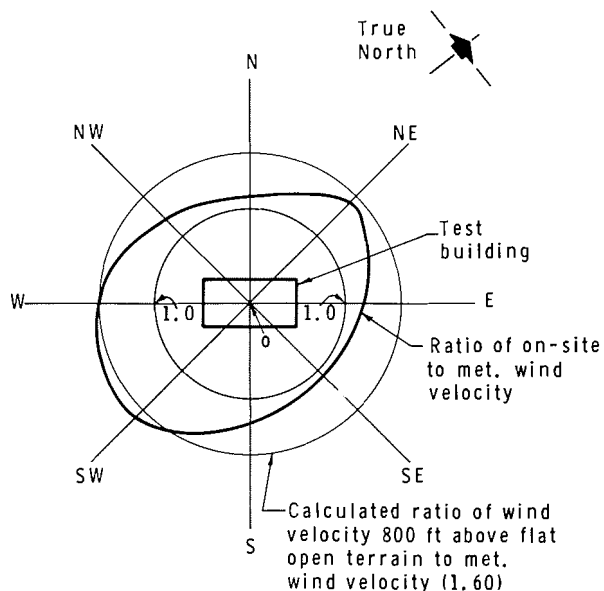
k = exponent.

The value of the exponent can be taken as $1/7$ for flat open country¹. The ratio of mean wind velocity at 800 ft and that at 33 ft, for an exponent of $1/7$ is also shown in Fig. 8. If the exponent of $1/7$ applies to the terrain at the meteorological station, the mean wind velocities 800 ft above ground at the two locations are approximately the same with wind from the northeast, west and southwest directions.

Wind pressure coefficients in Tables I and II can be computed in terms of meteorological wind records using Eq 7 and the information in Fig. 8. This will obviously alter the relative value of the coefficients because of variations in the ratio of on-site to meteorological wind speed.

SUMMARY

Coefficients describing the pressure differences due to wind action have been obtained for selected points across the walls of two tall buildings in the center of a large city. The coefficients were quite



Note:
On-site wind - 800 ft above street level
Meteorological wind - 33 ft above ground
level at airport

Fig. 8 Ratio of on-site wind velocity to meteorological velocity

variable with location, because of variations with direction of the vertical wind velocity gradient and the shielding effect of adjacent buildings.

The pressure coefficients were based on wind speeds measured at the site. These velocities in turn were related to the wind velocities measured at the meteorological station 8 miles away. This relationship is variable with direction and depends upon the general characteristics of the terrain, including buildings, at the two locations.

The results emphasize the difficulty of predicting the specific values of pressure differences due to wind to be expected with a particular building; and the difficulty, therefore, of making accurate predictions of corresponding air infiltration and exfiltration.

In the analysis of the pressure records, pressure differences due to wind action were isolated from those caused by the combined effect of chimney

action and the effect of the mechanical ventilation system operation. These latter values agreed reasonably well with the values of pressure differences measured during calm periods. This suggests that the resultant pressure difference across the exterior wall can be approximated by the summing of the pressure differences caused by the various forces.

During periods of moderate wind velocity and low outside temperature, the pressure differences caused by chimney action constitute a significant part of the resultant pressure differences across the upper and lower levels of a tall building.

ACKNOWLEDGEMENT

The authors are very much indebted to the building owners, Dorchester Commerce Realty Ltd., and Dorchester University Holdings Ltd., for the permission to use their buildings for this study. The cooperation received from their building managers, superintendents and operating personnel during the instrumentation of the buildings is greatly appreciated. The authors acknowledge the contributions made by R. G. Evans, who assisted in the field measurements, and by J. G. Arseneault, who prepared the computer programs for the analysis of the pressure records.

REFERENCES

1. A. G. Davenport, Wind Loads on Structures, Technical Paper No. 88 of the Division of Building Research (NRC 5576), Ottawa, Canada.
2. G. T. Tamura and A. G. Wilson, Pressure Differences Caused by Chimney Effect in Three High Buildings, ASHRAE TRANS., V. 73, Part II, 1967, pp. II. 1.1 - II. 1.10.
3. ASHRAE HANDBOOK OF FUNDAMENTALS, 1967, Chapter 25, Infiltration and Ventilation, p. 406.
4. J. Johnston, Econometric Methods, McGraw-Hill Book Company Inc., 1963, pp. 221.228.
5. A. Bailey and N. F. G. Vincent, Wind-Pressure on Buildings including Effects of Adjacent Buildings Journal of the Institution of Civil Engineers, Vo. 19-20, 1942-43, pp. 243-275.

DISCUSSION

RICHARD E. BARRETT (Columbus, Ohio): It would be interesting if the authors could build a scale model of this and surrounding buildings and conduct a study of wind pressures as measured in a wind tunnel. Although wind tunnel studies are becoming more common for large buildings, there has been little effort to correlate wind tunnel data to actual measurements on large buildings because measurements are not generally made after the building is constructed. Measurements on buildings are difficult enough to obtain and further problems are encountered in identifying the pressure components solely associated with wind.

The authors of this paper have already accomplished the difficult task of making pressure measurements on the buildings and factoring out the wind pressures. It seems that, if these results are to be of maximum usefulness in the engineering of future buildings, a corresponding wind tunnel study is desirable.

G. T. TAMURA: Wind pressure patterns for the two test buildings reported in this paper are in general agreement with those reported in many publications dealing with model studies in wind tunnels. A comparison of the values of wind pressure coefficients, however, is difficult because of the variation in the wind velocity profile, location of reference pressure, building height and shape and the type of

wind tunnel used in the various studies.

A paper entitled "Wind Pressure Measurements on a Full-Scale High-Rise Office Building" by W. A. Dalgleish et al (International Research Seminar on Wind Effects on Buildings and Structures held at the National Research Council, Ottawa, September, 1967) describes the results of pressure measurements on Building B of this paper. Because of their interest in wind pressure from the structural load aspect of a building, the number and location of pressure taps, method of recording and analysis of wind pressure records were different from the ones described in this paper. Where the pressure taps were located in the same region of the exterior wall, the comparison of the two values of wind pressure coefficients indicated reasonable agreement.

The paper by A. Dalgleish et al also describes the results of model studies of the same building in a boundary layer type wind tunnel in which the surrounding terrain including buildings as well as the test building were modeled. The results of the wind tunnel measurements indicated good correlation with those of the field measurements. For further studies on wind effect related to air leakage of buildings, we are also exploring the possibilities of model tests in a boundary layer type wind tunnel.
