No. 2573

WIND AND TEMPERATURE INDUCED PRESSURE DIFFERENTIALS AND AN EQUIVALENT PRESSURE DIFFERENCE MODEL FOR PREDICTING AIR INFILTRATION IN SCHOOLS

DR. C.Y. SHAW, P.Eng.

ABSTRACT

Wind induced pressure differences have been measured across the exterior walls of 2 schools; one is surrounded by houses and trees and the other is partially shielded from wind. These schools were selected from a total of 11 schools whose air leakage characteristics had been previously studied.

The measured pressure differences across the exterior walls were analyzed and the corresponding air infiltration rates were calculated. These were used to evaluate the equivalent uniform pressure differentials caused by wind. Similarly, the equivalent uniform pressure differentials caused by stack action were also calculated using a computer model. It was shown that these equivalent pressure differentials could be summed and used with the air leakage data obtained by fan pressurization method to predict air infiltration rates for schools under various conditions of wind and stack action.

INTRODUCTION

In the autumn of 1975, the Division of Building Research, National Research Council of Canada, was invited to participate with the Carleton Board of Education in a program to reduce energy use in their schools. Since air infiltration has always been recognized as one of the major factors affecting energy consumption of buildings, an air leakage study on schools was carried out. This study included the measurements of air leakage characteristics using the fan pressurization method[1] and pressure differences across the exterior walls caused by wind and stack action. These data provide a basis for calculating air infiltration rates for schools.

Air leakage tests conducted on 11 schools[1] having various wall constructions and energy consumptions have been reported by Shaw and Jones[1]. Pressure differentials were subsequently measured on 2 of the 11 schools for a period of 8 months. In addition, a computer building model was used to calculate the pressure differentials caused by stack action. Finally, an equivalent pressure difference method for calculating air infiltration rates was derived from these results.

DESCRIPTION OF TEST SCHOOLS

Two schools as shown in Fig. 1 were selected for the study. School C is situated in a mature suburban residential area and is surrounded by houses and trees. School Q is also situated in a suburban residential area but is only protected by houses on the north and south sides. In addition, it is partially shielded from wind by another school on the west but is fully exposed on the east. The shapes of both schools are irregular as shown in Figs. 2a and 2b. A brief description of the 2 schools is given in Table 1.

C. Y. Shaw, Research Officer, Energy and Services Section, Division of Building Research, National Research Council of Canada, Ottawa, Ontario K1A 0R6.

where C_{we} is the equivalent pressure difference coefficient caused by wind. Its values are shown in Fig. 6 and can be approximated by the same expression as Eq 2. The appropriate coefficients for the two schools are also given in Table 2. Similarly, in the absence of wind, a uniform equivalent pressure differential caused by stack action, ΔP_{se}, is

$$\Delta P_{se} = \left[\frac{1}{CA} \sum_{i=1}^{4} \sum_{j=1}^{5} C\, A_{ij} (\Delta P_{sj})^n \right]^{\frac{1}{n}} \quad (7)$$

The values of ΔP_{se} are shown in Fig. 7. They can also be curve fitted to the form[2]

$$\Delta P_{se} = 117 \frac{(\beta H)^{1+n}}{1+n} \left(\frac{1}{T_o} - \frac{1}{T_i}\right) \quad (8)$$

where β is the ratio of the height of the neutral pressure level and the building height, H. The value of β is 0.7 for both schools. Also, in Eq 8, ΔP_{se} is in pascals, H is in meters, T_i and T_o are inside and outside air temperatures in Kelvins. The constant 117 becomes 0.84 if the units change to inches of water for pressure differentials, feet for building height and Rankines for air temperatures.

Finally, a uniform equivalent pressure differential caused by the combined action of wind and stack action, ΔP_e, is obtained by adding the 2 pressure differentials together. Hence,

$$\Delta P_e = \frac{1}{2} \rho V^2 C_{we} + \Delta P_{se} \quad (9)$$

In Eq 9, C_{we} is based on the local wind speed. If the meteorological wind speed is used for V the values of C_{we} obtained from Fig. 6 should be multiplied by a factor of 0.7. The air infiltration, I, can now be calculated from Eq 3 which is rewritten as

$$q = \frac{I}{A} = C\ (\Delta P_e)^n \quad (10)$$

Eq 6,8,9 and 10 are the basic equations of the equivalent pressure difference model for predicting air infiltration rates. To use these equations it is necessary to know the appropriate values for C, n, β and C_{we}. The best way to determine these values is to measure them directly. This is not difficult to do as C, n and β are easily and accurately measurable. C_{we} can be calculated from Eq 1 and 6 using the pressure differences across the exterior walls measured during mild weather, but an estimate of C_{we} requires a large amount of data due to its variation with wind direction. However, a fairly good approximation of air infiltration rates may be obtained for design purpose from the following values.

	Class	$m^3/s \cdot m^2\ (Pa)^{0.65}$	$cfm/ft^2\ (in.\ of\ water)^{0.65}$
C	Tight	2.4×10^{-4}	1.7
	Average	4.0×10^{-4}	2.8
	Loose	5.6×10^{-4}	4.3
n	0.65 for all classes of construction		
β	0.7		
C_{we}	0.07 for protected site		
	0.15 for a more exposed site		

The values of C and n were based on air leakage data from 11 schools[1] (Fig. 8) where air leakage through walls was assumed to be 80% of the overall leakage (average of the two schools). The value of β was based on the data of the 2 schools; the values of C_{we} were also calculated from the results of the 2 schools with the effect of wind direction averaged (arithmetic mean of C_{we}).

NOMENCLATURE

A	total area of exterior walls
A_{ij}	area of the j^{th} section of the i^{th} wall; i = 1, 2, 3, and 4
C	flow coefficient per unit area of exterior walls; see Eq 3
C_{dpi}	pressure difference coefficient caused by wind for the i^{th} wall; see Eq 1 and 2.
C_{we}	equivalent pressure difference coefficient caused by wind; see Eq 6
I	air infiltration rate; see Eq 4
n	flow exponent; see Eq 3
$\overline{\Delta P}$	uniform pressure difference across a building enclosure induced by an air leakage testing fan; see Eq 3
ΔP_e	uniform equivalent pressure difference across a building enclosure caused by combined action of wind and stack action; see Eq 9.
ΔP_i	pressure difference across the i^{th} wall
ΔP_{se}	uniform equivalent pressure difference across a building enclosure caused by stack action; see Eq 7 and 8
ΔP_{sj}	pressure difference across exterior walls at the j^{th} level caused by stack action
ΔP_{we}	uniform equivalent pressure difference across a building enclosure caused by wind; see Eq 5
ΔP_{wi}	pressure difference across the i^{th} wall caused by wind
q	air infiltration or air leakage rate per unit area of exterior walls; see Eq 10
Q	air leakage rate
T_i	absolute inside air temperature
T_0	absolute outside air temperature
V	wind speed at 15 m (49 ft) above ground
β	ratio of height of neutral pressure level and building height
Θ	wind angle measured counterclockwise from the true north
ρ	air density

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ACKNOWLEDGEMENT

The author is indebted to the Carleton Board of Education for cooperation in making this study possible. He gratefully acknowledges, also, the contribution of D.G. Stephenson and G.T. Tamura in the preparation of the paper and the assistance of R.G. Evans and R. Plouffe in taking the field measurements.

This paper is a contribution of the Division of Building Research, National Research Council of Canada, and is published with the approval of the Director of the Division.

TABLE 1

Description of Test Schools

School		C	Q
Year Tested		1977	1977
Year Constructed		1972	1968
Floor Area, m^2 (ft^2)		3003 (32331)	3219 (34650)
Floor Height, m (ft)		4 (13.0)	3.8 (12.5)
Volume, m^3 (ft^3)		11900 (420303)	12263 (433125)
a. Exterior Wall Area m^2(ft^2)	side 1	341 (3671)	500 (5382)
	side 2	341 (3671)	486 (5231)
	side 3	341 (3671)	486 (5231)
	side 4	341 (3671)	343 (3692)
	Total	1364 (14684)	1815 (19536)
Window Type		Fixed Sealed Domes, Fixed & Openable Sealed Double Glazing	Fixed Sealed Domes, Fixed & Openable Sealed Double Glazing
Window Area/Wall Area		0.062	0.102
Openable Window/Wall Area		0.008	0.040
Typical Wall Construction		10.2 cm Split Black Face 5.1 cm Air Space 15.2 cm Conc. Blk & Foamed in Place Insul	10.2 cm Face Brick 5.1 cm Foamed Insulation 20.3 cm Conc. Blk
No. of Exterior Doors	Vestibule	3 sgle, 2 dble	14 sgle, 1 dble
	No Vestibule	2 sgle, 3 dble	6 sgle
HVAC System		Gas Centralized All Air H/V Systems with Roof-Top A.H. Units	#2 oil & Elect Centralized All-Air H/V System with convector or unit ventilator in Perimeter Room

Notes: a. Including Window

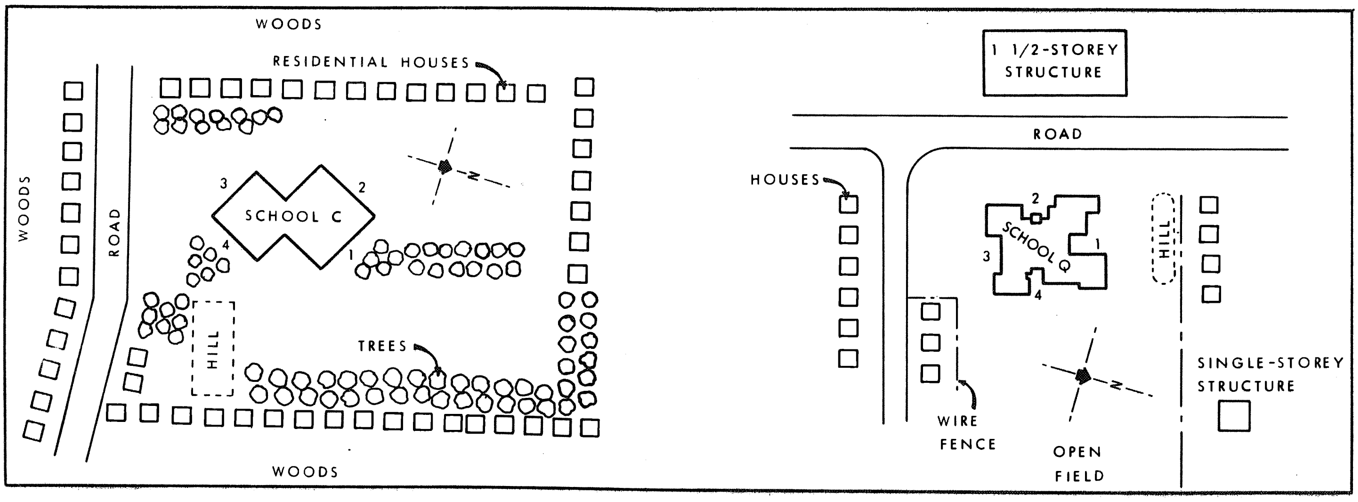

Fig. 1 Test sites

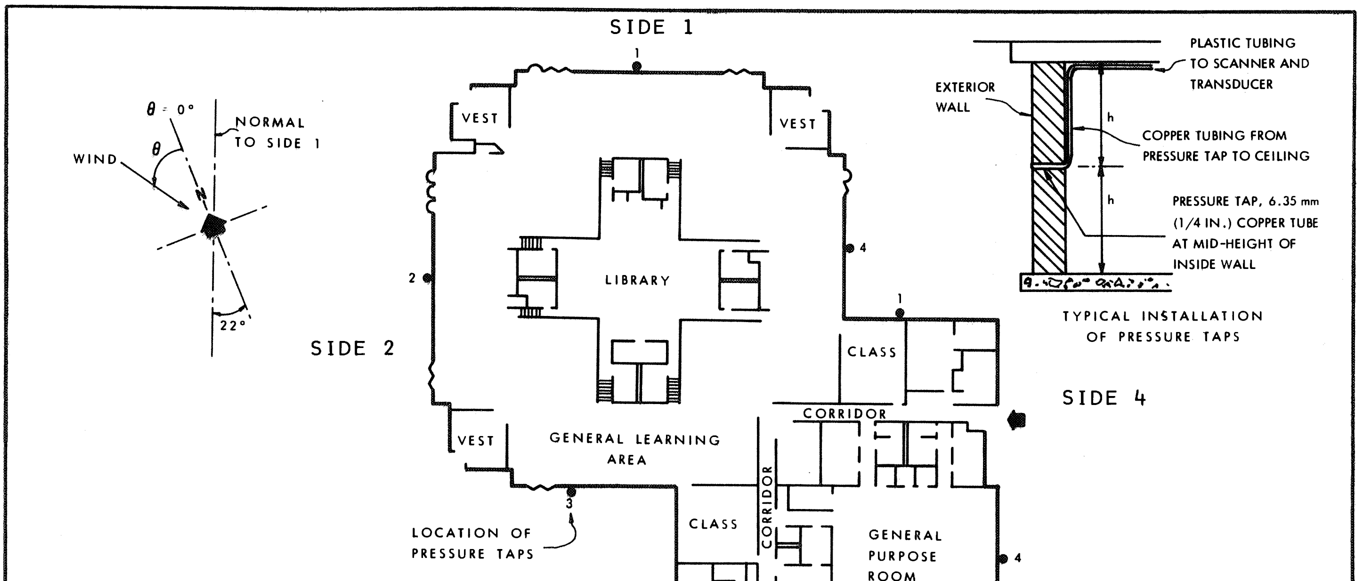

Fig. 2 Plan and location of pressure taps for School C

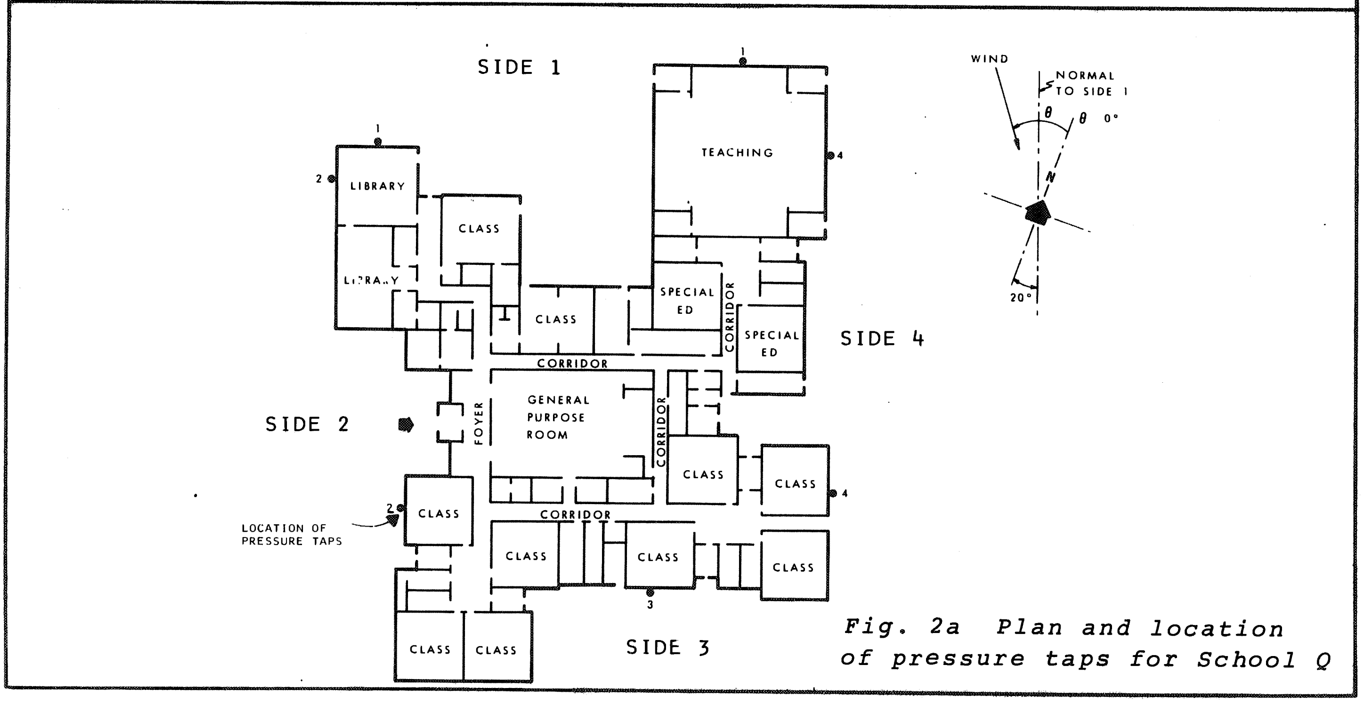

Fig. 2a Plan and location of pressure taps for School Q

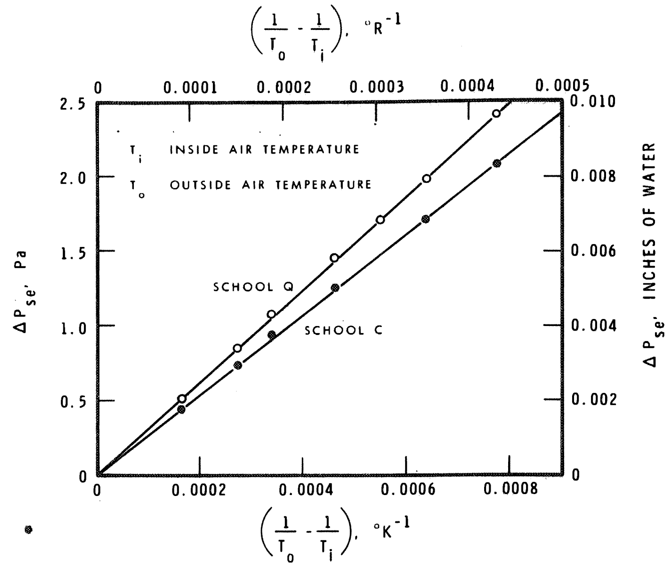

Fig. 7 Equivalent pressure differentials due to stack action

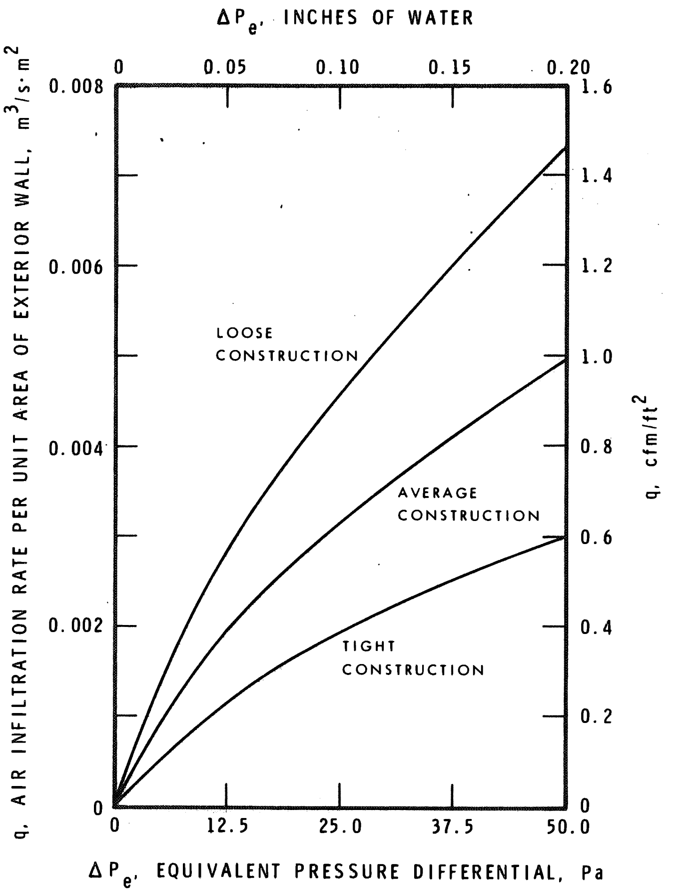

Fig. 8 Generalized air infiltration rates for schools

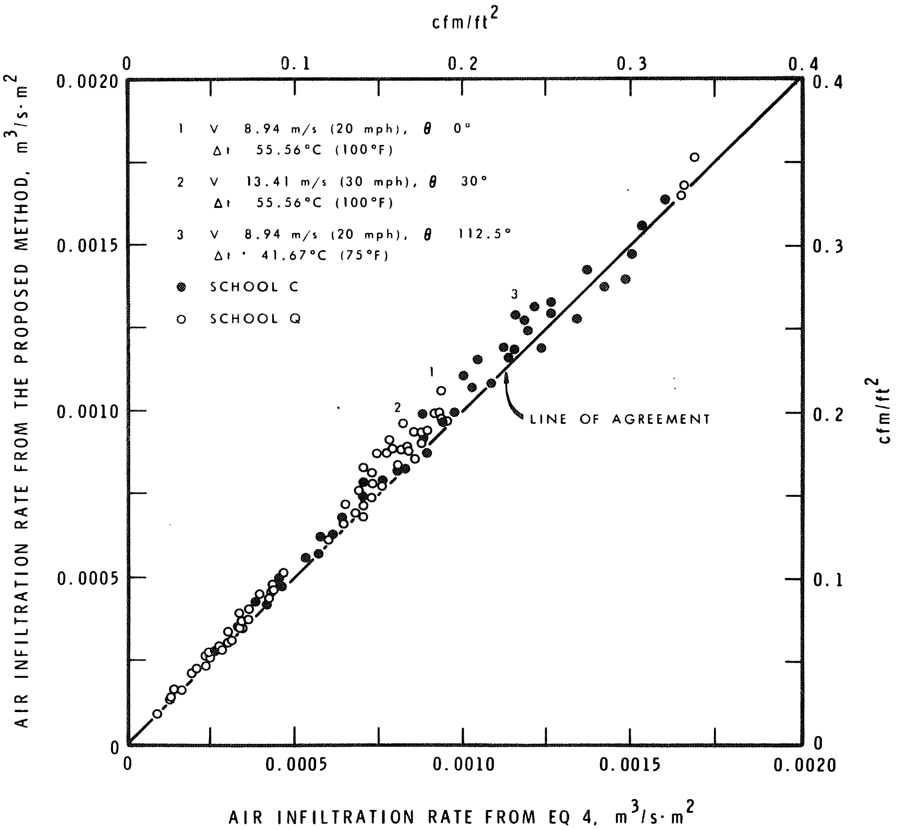

Fig. 9 Comparison of calculated air infiltration rates using Eq 4 with those using the proposed method