National Research Council of Canada

Conseil national de recherches du Canada

STUDIES ON EXTERIOR WALL AIR TIGHTNESS AND AIR INFILTRATION OF TALL BUILDINGS

by G.T. Tamura and C.Y. Shaw

Reprinted from
ASHRAE Transactions
Vol. 82, Part 1, 1976
p. 122-134

DBR Paper No. 706
Division of Building Research

Price 25 cents OTTAWA NRCC 15732

SOMMAIRE

Les auteurs présentent des valeurs mesurées d'étanchéité à l'air pour huit tours de bureaux (murs-rideaux et vitrages scellés). Ces valeurs sont de beaucoup supérieures aux valeurs mentionnées dans norme industrielle. Une équation permettant de calculer la vitesse totale de pénétration due à l'appel d'air est appliquée aux édifices à l'aide de valeurs mesurées de l'étanchéité à l'air des murs. Les auteurs examinent également le rôle que joue la pénétration de l'air dans la perte globale de chaleur, y compris la transmission et la ventilation mécanique.

No. 2388

STUDIES ON EXTERIOR WALL AIR TIGHTNESS AND AIR INFILTRATION OF TALL BUILDINGS

GEORGE T. TAMURA, P.E.
Member ASHRAE

CHIA Y. SHAW, P.E.

One of the functions of the exterior walls of buildings is to separate outdoor elements from the inside environment. Building envelopes are not normally completely air tight and they permit some flow of air into and out of them through joints and cracks in the wall fabric. This leakage of air contributes to heating and cooling loads and must be taken into account in any energy analysis of buildings and design of HVAC systems.

Infiltration rates depend primarily on the air leakage characteristics of exterior walls and to a lesser extent on those of interior separations such as floor construction, interior partitions and various service shafts. A reliable prediction of the infiltration rates of multistorey buildings is hampered, at present, by the scarcity of information on the actual air leakage characteristics of exterior walls.

The National Research Council of Canada has taken measurements of the air leakage characteristics of the exterior walls of eight multi-storey office buildings located in Ottawa, Canada. Varying in height from 11 to 22 stories, with curtain wall construction and fixed glazing, they were built during the sixties and early seventies. The results of the measurements are reported in this paper. A method for calculating infiltration rates caused by stack action has been developed and is applied to heat loss calculations using the measured wall leakage values.

EXTERIOR WALL MEASUREMENTS

The results of air leakage measurements of the exterior walls of four multi-storey buildings were reported by Shaw, Sander and Tamura.[1] This project was subsequently expanded to include four additional buildings, using the same test method (Table 1). Briefly, it involved pressurizing all typical floor spaces between the ground floor and the top mechanical floor, using 100% outside air for the central supply air systems with return and exhaust systems shut down. Supply air rates were varied and the concomitant pressure differences across the pressurized enclosure recorded. To ensure stable pressure differences across the building enclosure, the tests were conducted during unoccupied periods and when there was little or no wind.

Under steady-state condition the rate of supply of outside air equals the sum of the air leakage rates through the exterior walls of typical floors, bottom and top separations (Fig. 1). It can be expressed as follows:

$$Q_s = C_w \sum_{j=1}^{N} (A_w \Delta P_w^{\;n_w})_j + C_b A_b (\Delta P_b)^{n_b} + C_t A_t (\Delta P_t)^{n_t} \quad (1)$$

G.T. Tamura, Division of Building Research, National Research Council of Canada, Ottawa, Canada.
C.Y. Shaw, Division of Building Research, National Research Council of Canada, Ottawa, Canada.

where

Q_s = total outdoor air supply rate, cfm

n = flow exponent

C = flow coefficient, cfm/(sq ft)(in. of water)^n

ΔP = pressure difference, $P_i - P_o$, in. of water

P_i = inside pressure, in. of water

P_o = outside pressure, in. of water

A = area, sq ft

N = total number of floors with typical wall construction

subscripts

w = exterior wall

b = bottom separation

t = top separation

The values of Q_s, ΔP_w, ΔP_b and ΔP_t can be measured. By obtaining several sets of these values it is possible to determine the values of flow coefficients C_w, C_b and C_t and the flow exponents n_w, n_b and n_t, defining air leakage characteristics of the three separations. Details of test methods and data analysis are given in Ref 1.

TEST RESULTS

The values of flow coefficient and exponent, as defined in Eq 1 for the eight test buildings, are given in Table 2. Using these values, the over-all air leakage rates in terms of cfm per sq ft of outside wall area vs pressure difference were plotted on Fig. 2. These values, which include the air leakage rates through the top and bottom as well as through the exterior walls, are useful in estimating the supply air rates required for pressurizing a building. It should be noted that leakage values of the top separation, given in Table 2, include leakage flows through the closed exhaust dampers at the top of the return and exhaust systems (shut down during the tests).

The dependence of the exterior wall air leakage rates on pressure difference is shown in Fig. 3. These air leakage rates varied from 0.12 to 0.48 cfm per sq ft of wall area at a pressure difference of 0.30 in. of water pressure and constituted from 20 to 55% of the over-all air leakage rates of the test buildings. These values are well above the standard [2] specified by the National Association of Architectural Metal Manufacturers (NAAMM): 0.06 cfm per sq ft of wall area at the same pressure difference. The exterior facades of three of the test buildings, D, E and H, were constructed of metal panels; those of the remaining test buildings were of precast concrete panels. As the wall materials are relatively impermeable to air, it is probable that the air leakage rates depended mainly on the design of wall joints and the way they were put together. Buildings F and H, which were constructed with close supervision of workmanship on wall jointing to minimize air infiltration, gave the lowest leakage rates; and where joint seals appeared inadequate, remedial measures were taken.

CALCULATION OF INFILTRATION RATE CAUSED BY STACK ACTION

Air infiltration in a building is caused by both wind and stack action. The calculation of infiltration rates caused by wind is quite complex, for the wind pressure distribution over the surface of a building depends on wind speed and direction, building shape and the nature of the surrounding terrain, including adjacent buildings. The literature on wind pressures on actual and model buildings in boundary-layer wind tunnels is extensive. Pressure measurements have been made primarily to develop data for structural load calculations and not for infiltration calculations, which require more detailed data on wind pressures both horizontally and vertically. If wind pressure data for a building are available, infiltration rates caused by both wind and stack action can be calculated with the aid of a digital computer and an appropriate mathematical model.[3,4,5]

The infiltration rates caused by stack action alone, which tends to govern the infiltration rate of a multi-storey building during cold weather, can be calculated relatively easily. The derivation of the equation is as follows:
Theoretical pressure difference across exterior walls caused by stack effect is given by[6]

$$\Delta P = 0.52\ p\ h \left(\frac{\Delta T}{T_i T_o}\right) \qquad (2)$$

where

p = barometric pressure, lb/sq in.

h = vertical distance from neutral zone, ft

positive sign above neutral zone

negative sign below neutral zone

ΔT = temperature difference, $T_i - T_o$, F

T_i = absolute temperature inside, R

T_o = absolute temperature outside, R .

The neutral zone is the level at which inside and outside pressures are equal. Eq 2 indicates that ΔP and ΔT have the same signs for all locations above the neutral zone and, conversely, opposite signs below the neutral zone. Thus there will be infiltration through the walls of the lower storeys and exfiltration through the walls of the upper storeys when the temperature inside the building is higher than the air temperature outside. This means that air flows upward within the building during the winter months. The flow pattern is reversed during the summer months when the air temperature outside is higher than that inside.

Actual pressure difference depends on the resistances to flow of both the exterior and interior separations. It is less than the theoretical pressure difference indicated by Eq 2 because of the resistance to air movement associated with interior components such as partitions, floor constructions and walls of vertical shafts. The upward flow caused by stack action during cold weather takes place from floor to floor through openings in the floor construction and through vertical shafts. It can be expected that most upward flow will occur in the vertical shafts because their resistance (friction losses) will be considerably less than that associated with floors, which act as resistances in series. For this discussion, therefore, the floor construction is considered to be air tight.

With this assumption, the theoretical pressure difference given by Eq 2 is that between outside the building and inside a shaft at the same level. It is distributed across the exterior walls, interior partitions and the walls of vertical shafts. The manner of distribution depends upon the resistance of each of these separations in relation to that of the combined resistances at the same level. If the resistances of the exterior and interior separations are uniform from floor to floor, the ratio of actual (exterior walls) to theoretical pressure differences will be constant for the whole height of a building.

Eq 2 can be modified to take this into account

$$\Delta P = 0.52\ \gamma\ p\ h \left(\frac{\Delta T}{T_i T_o}\right) \qquad (3)$$

where

γ = ratio of actual to theoretical pressure difference.

If the exterior wall is much tighter than the interior separations, the value of γ will approach unity; if it is much looser, the value of γ will approach zero. The values for γ determined experimentally for a few multi-storey office buildings[7] ranged from 0.63 to 0.88.

The rate of airflow through an infinitesimal area of the exterior wall is given by

$$dQ_w = C_w dA_w (\Delta P)^{n_w} \quad (4)$$

where

dQ_w = air leakage rate through an area dA_w of the exterior wall, cfm

C_w = flow coefficient, cfm/(sq ft)(in. of water)^{n_w}

n_w = flow exponent

Combining Eq 3 and 4 gives

$$dQ_w = C_w \left[0.52\ \gamma\ p\ h \left(\frac{\Delta T}{T_i T_o}\right)\right]^{n_w} Sdh \quad (5)$$

where

S = perimeter of the building, ft.

For a building with a constant cross-sectional area and a uniform distribution of leakage openings with height, an equation for the total air infiltration rate can be obtained by integrating Eq 5 from the ground level to the neutral zone. The neutral zone level can be expressed as βH where β is the ratio of the height of the neutral zone and the building height H in ft.

Thus,

$$Q_w = C_w S \left[0.52\ \gamma\ p \left(\frac{\Delta T}{T_i T_o}\right)\right]^{n_w} \frac{(\beta H)^{n_w + 1}}{n_w + 1} \quad (6)$$

where

Q_w is the total rate of infiltration for the whole building.

As this equation assumes a wall with a uniform air leakage characteristic, a separate infiltration heat loss calculation using Eq 3 and 4 should be made for the exterior walls of the ground floor since their air leakage values tend to be higher than those of other floors.

INFILTRATION HEAT LOSSES CAUSED BY STACK ACTION

From Fig. 3, air leakage values for a tight, average and loose wall were assigned arbitrarily for heat loss calculation. A flow exponent, n_w, of 0.65 was assumed for these walls (it varied from 0.50 to 0.75 for the test buildings). The flow coefficients were assumed as follows:

Wall Tightness	Air Leakage Rate, cfm/sq ft at 0.3 in. water	Flow Coefficient, C_w cfm/(sq ft)(in. water)$^{0.65}$
NAAMM	0.06	0.13
tight	0.10	0.22
average	0.30	0.66
loose	0.60	1.30

These values will probably apply to exterior walls of curtain wall construction with fixed glazing but not to exterior walls of masonry construction. Measurements on one building [8] of the latter construction indicated that its leakage rates are considerably higher than those shown on Fig. 3.

The equation for infiltration rate, Eq 6, can be simplified for practical purposes by assuming the following: $\gamma = 0.80$, $p = 14.7$ psia, $T_i = 530R$, $n_w = 0.65$, $\beta = 0.50$. Substituting these values in Eq 6

$$Q_w = 0.00974\ C_w S \left(\frac{\Delta T}{T_o}\right)^{0.65} (H)^{1.65} \quad (7)$$

The sensible heat load due to infiltration is given by [8]

$$Y = 1.08\ Q_w \Delta T \tag{8}$$

where

Y = sensible heat loss, Btu/hr

Substituting Eq 7 in Eq 8 gives

$$Y = 0.0106\ C_w S \left(\frac{1}{T_o}\right)^{0.65} ([\Delta T]H)^{1.65} \tag{9}$$

The latent heat loss when indoor humidity ratio is to be maintained at a constant level is given by [9]

$$Z = 4800\ Q_w (W_i - W_o) \tag{10}$$

where

Z = heat required to increase moisture content of infiltration air from W_o to W_i, Btu/hr

W_i = humidity ratio of indoor air, pounds of water per pound of dry air

W_o = humidity ratio of outdoor air, pounds of water per pound of dry air

Substituting Eq 7 in Eq 10 gives

$$Z = 50.9\ C_w S \left(\frac{\Delta T}{T_o}\right)^{0.65} H^{1.65} (W_i - W_o) \tag{11}$$

Infiltration rates were calculated for the four air leakage values and various building heights using Eq 7, expressed in air changes per hour and assuming a floor plan 150 ft sq. A temperature difference of 70 F was assumed between indoor and outdoor air. The results of these calculations (Fig. 4) indicated that air change rates increase with building height as well as with increasing wall leakage values.

These values may be compared with the outdoor air requirement for ventilation. ASHRAE STANDARD 62-73 [10] gives the minimum required ventilation air without tempering or filtering as 15 cfm per person for general office space (0.15 cfm per sq ft, based on 10 persons per 1000 sq ft of floor area). This represents 0.9 air change per hour. As this value is much higher than the values shown on Fig. 4, it appears that air infiltration by itself will not usually satisfy the ventilation requirement.

The sensible and latent infiltration heat losses were calculated using Eq 9 and 11, assuming an indoor-outdoor temperature difference of 70 F, a humidity ratio for indoors of 0.0047 lb of water per lb of dry air (70 F, 30% RH) and one for outdoors of 0.0006 lb of water per lb of dry air (0 F, 80% RH). The results of the calculation given in Btu per hour per square foot of wall area are shown in Fig. 5 for various building heights. For this example, the latent heat losses are 28% of the sensible heat losses.

In Fig. 6, the infiltration heat losses (sensible plus latent) are compared with the total heat losses through the exterior walls (infiltration plus transmission). The over-all U value was assumed to be 0.30, with values of 0.15 for the insulated walls and 0.55 for double-glazed windows, which constituted 40% of the total wall area. Transmission heat loss was 21.0 Btu/(hr)(sq ft) at a temperature difference of 70 F. For a building with an average wall leakage value, the percentage of total heat loss contributed by air infiltration varied from 22 to 46% for building heights of 200 to 1000 ft, respectively; these values are reduced to 9 to 22% for buildings with relatively air-tight walls. As infiltration heat losses increase with building height, the significance of air tightness for walls of tall buildings is apparent.

The ventilation requirement for general office space of 15 cfm of outdoor air per person demands an outdoor air supply of 0.56 cfm per sq ft of outside wall area, assuming a floor dimension of 150 by 150 ft and floor height of 10 ft. Using Eq 8 and 10, the heat loss (sensible plus latent) was 53.6 Btu/(hr)(sq ft) of wall area at a temperature difference of 70 F

5 D.M. Sander and G.T. Tamura, "Simulation of Air Movement in Multi-Storey Buildings," presented at Second Symposium on the Use of Computers for Environmental Engineering Related to Buildings, Paris, 13-15 June 1974.

6 ASHRAE HANDBOOK OF FUNDAMENTALS, Chapter 19, "Infiltration and Natural Ventilation," 1972.

7 G.T. Tamura and A.G. Wilson, "Pressure Differences Caused by Chimney Effect in Three High Buildings," ASHRAE TRANSACTIONS, vol 73, part II, 1967, pp. II. 1.1 - II. 1.10.

8 G.T. Tamura and A.G. Wilson, "Pressure Differences for a Nine-Storey Building as a Result of Chimney Effect and Ventilation System Operation," ASHRAE TRANSACTIONS, vol 72, part I, 1966, pp. 180-189.

9 ASHRAE HANDBOOK OF FUNDAMENTALS, Chapter 21, "Heating Load," 1972.

10 ASHRAE STANDARD 62-73, "Standards for Natural and Mechanical Ventilation," 1973.

ACKNOWLEDGEMENTS

The authors are indebted to the Department of Public Works, Carleton University, and Campeau Corporation for cooperation in making this study possible; also to the operating personnel of the test buildings for their assistance during the tests. The authors wish to acknowledge the assistance of R.G. Evans in the field tests and in the processing of test results. This paper is a contribution from the Division of Building Research, National Research Council of Canada, and is published with the approval of the Director of the Division.

and humidity ratio, indoors, of 0.0047 lb of water per lb of dry air and, outdoors, of 0.0006 lb of water per lb of dry air. This heating load imposed by ventilation air has been compared with those of transmission and infiltration through a wall of average air tightness in Fig. 7. It may be seen that the ventilation heating load is the largest component of the total heating load (infiltration plus transmission plus ventilation). For a 200-ft high building it constitutes 67% of the total heating load, whereas infiltration heating load is only 7%. ASHRAE Standard 62-73 permits reduction in the ventilation air to 5 cfm per person (0.05 cfm per sq ft of floor area) if the air is tempered and filtered. This reduction in ventilation air results in heat losses due to ventilation and infiltration of 40 and 12% of the total heat loss, respectively. During unoccupied periods with no ventilation air, the infiltration heat loss is 22% of the total for walls of average air tightness and 9% for tight walls.

These calculations recognized stack action alone at a given inside-outside temperature difference. It is probable that infiltration rates of tall buildings depend primarily on stack action during cold weather and average wind velocity. The infiltration rates calculated in the previous examples would have been somewhat higher if wind action had also been considered. A complete analysis would involve integration of heat losses over the seasons, taking into account both wind and stack action.

HEAT LOSSES CAUSED BY BUILDING PRESSURIZATION

HVAC systems are sometimes designed and operated to minimize air infiltration, particularly at the entrance level, by means of building pressurization. Its effect is to increase the inside pressures and thereby lower the level of the neutral zone. If the neutral zone is lowered to ground level, air infiltration is eliminated but air exfiltration is increased. The required rate of supply of outside air to achieve this can be calculated from Eq 6 ; for this, the value of β, the ratio of the neutral zone height to building height, is taken as unity. The ratio of total exfiltration rate with pressurization ($\beta = 1.0$) to infiltration rate without pressurization ($\beta = 0.5$) is about 3.2; i.e., the outside supply air rate required to pressurize a building fully is 3.2 times the infiltration rate. This value would be greater if the exfiltration rate through the top of the building were also considered. Reducing infiltration rate by pressurization incurs a high heating cost penalty. It is more economical to pressurize the ground floor only, provided the ground floor enclosure is reasonably air tight.

CONCLUSIONS

1. The air leakage rates of the exterior walls of eight test buildings varied considerably, with values of 0.12 to 0.48 cfm per sq ft of wall area at a pressure difference of 0.30 in. of water. They were much above that specified by an industry standard of 0.06 cfm per sq ft of wall area at the same pressure difference.

2. For a wall with average air tightness and U value of 0.30 Btu/(hr)(sq ft)(F), the percentage of total heat loss through the walls contributed by infiltration during cold weather varied from 22 to 46% for building heights of 200 to 1000 ft, respectively; these values are reduced to 9 to 22% for buildings with relatively air-tight walls. They indicate the necessity of assuring relatively air-tight walls for tall buildings.

3. Air infiltration alone cannot be relied upon to provide an adequate amount of outdoor air for ventilation of buildings with curtain wall construction and fixed glazing. The heating load caused by ventilation air was found to be a major component of the total heating load.

4. Reducing air infiltration by mechanically pressurizing a building can mean a high heating cost penalty.

REFERENCES

1 C.Y. Shaw, D.M. Sander, G.T. Tamura, "Air Leakage Measurements of the Exterior Walls of Tall Buildings," ASHRAE TRANSACTIONS, vol 79, part 2, 1973, pp. 40-48.

2 National Association of Architectural Metal Manufacturers, Metal Curtain Wall Manual, Specifications, pp. 4-9, December 1962.

3 P.J. Jackman, "A Study of the Natural Ventilation of Tall Office Buildings," Journal of the Institute of Heating and Ventilating Engineers, vol 38, August 1970, pp. 103-118.

4 R.E. Barrett and D.W. Locklin, "Computer Analysis of Stack Effect in High-Rise Buildings," ASHRAE TRANSACTIONS, vol 74, part II, 1968, pp. 155-169.

5 D.M. Sander and G.T. Tamura, "Simulation of Air Movement in Multi-Storey Buildings," presented at Second Symposium on the Use of Computers for Environmental Engineering Related to Buildings, Paris, 13-15 June 1974.

6 ASHRAE HANDBOOK OF FUNDAMENTALS, Chapter 19, "Infiltration and Natural Ventilation," 1972.

7 G.T. Tamura and A.G. Wilson, "Pressure Differences Caused by Chimney Effect in Three High Buildings," ASHRAE TRANSACTIONS, vol 73, part II, 1967, pp. II. 1.1 - II. 1.10.

8 G.T. Tamura and A.G. Wilson, "Pressure Differences for a Nine-Storey Building as a Result of Chimney Effect and Ventilation System Operation," ASHRAE TRANSACTIONS, vol 72, part I, 1966, pp. 180-189.

9 ASHRAE HANDBOOK OF FUNDAMENTALS, Chapter 21, "Heating Load," 1972.

10 ASHRAE STANDARD 62-73, "Standards for Natural and Mechanical Ventilation," 1973.

ACKNOWLEDGEMENTS

The authors are indebted to the Department of Public Works, Carleton University, and Campeau Corporation for cooperation in making this study possible; also to the operating personnel of the test buildings for their assistance during the tests. The authors wish to acknowledge the assistance of R.G. Evans in the field tests and in the processing of test results. This paper is a contribution from 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 Buildings

Building	A	B	C	D	E	F	G	H
Year constructed	1970	1964	1970	1971	1968	1973	1974	1974
Year tested	1970	1971	1971	1971	1974	1974	1974	1974
No. of typical floors	9	17	20	20	21	16	25	20
Floor plan (ft x ft)	166x210	88x140	126x146	75x93	83x158	83x183	123x143	126x146
Floor height (ft)	13	11	10.6	10.5	10.4	10.6	10.6	10.6
Wall area per floor (sq ft)	9,776	5,016	5,766	3,528	5,013	5,656	5,639	5,766
Window area (% wall area)	38	33	30	26	35	52	26	40
Window type	Fixed sealed double glazing	Openable sealed double glazing (key locked)	Fixed sealed double glazing	Fixed sealed double glazing	Fixed sealed double glazing	Fixed sealed double glazing	Fixed sealed double glazing	Fixed sealed double glazing
Wall construction	Precast concrete 8-in. tile 2-in. insulation air space 6-in. tile plaster	Precast concrete panel 2-in. insulation	Precast concrete panel air space 1-in. insulation 1/2-in. cement 6-in. concrete block plaster	Metal panel air space 2-in. insulation 20-in. concrete	Metal panel 2-in. insulation	Precast concrete panel 1-in. insulation	Precast concrete panel 1-in. insulation	Metal panel 2-in. air space 3.5-in. insulation

TABLE 2

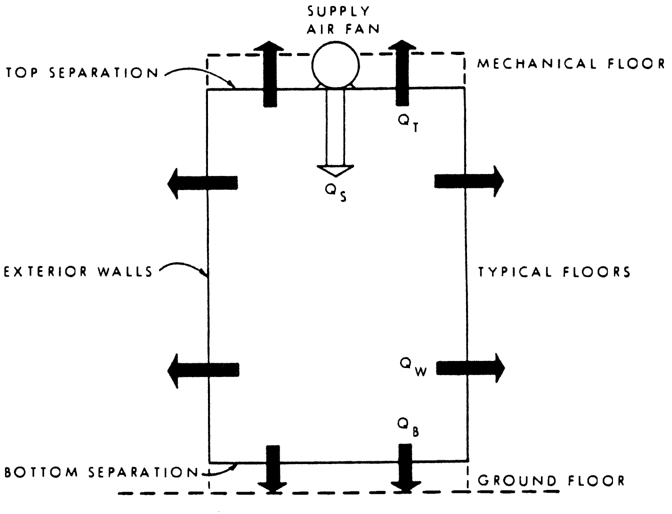
Flow Coefficients and Exponents of Test Buildings

Test Building	Outside Wall C_w	n_w	Bottom Separation C_b	n_b	Top Separation C_t	n_t
A	1.12	0.70	3.21	0.70	0.85	0.60
B	0.69	0.50	0.44	0.70	3.42	0.50
C	0.62	0.75	1.27	0.50	5.69	0.70
D	0.76	0.65	0.27	0.50	7.20	0.50
E	0.48	0.50	0.21	0.70	4.35	0.50
F	0.30	0.50	1.01	0.50	2.38	0.50
G	0.84	0.65	0.11	0.70	6.82	0.65
H	0.20	0.50	6.55	0.70	2.90	0.50

C_w in cfm/(sq ft of wall area)(in. of water)^{n_w}

C_b in cfm/(sq ft of floor area)(in. of water)^{n_b}

C_t in cfm/(sq ft of floor area)(in. of water)^{n_t}



$$Q_S = Q_W + Q_B + Q_T$$

Q_S = OUTSIDE SUPPLY AIR
Q_W = LEAKAGE FLOW THROUGH WALLS
Q_B = LEAKAGE FLOW THROUGH BOTTOM SEPARATION
Q_T = LEAKAGE FLOW THROUGH TOP SEPARATION

Fig. 1 Flow balance under wall leakage tests

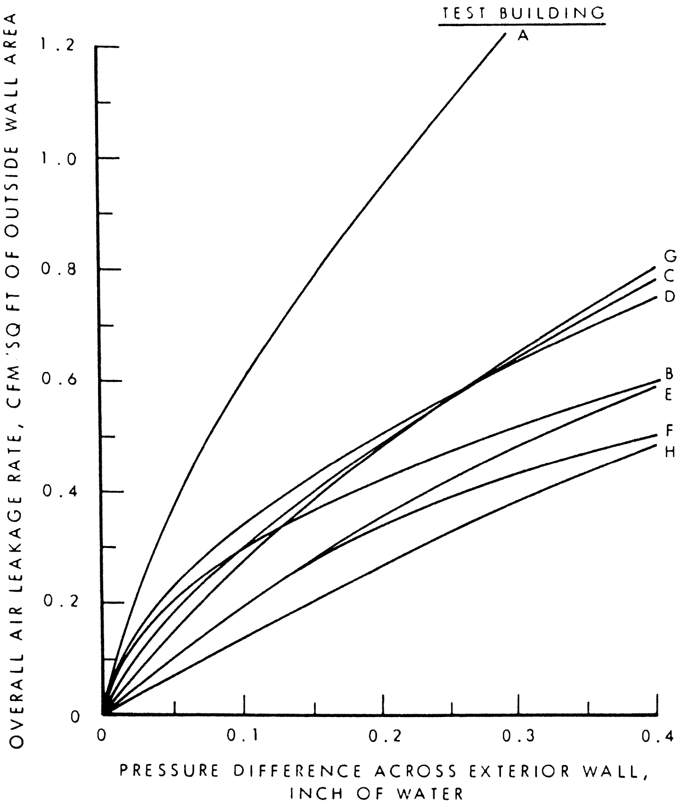
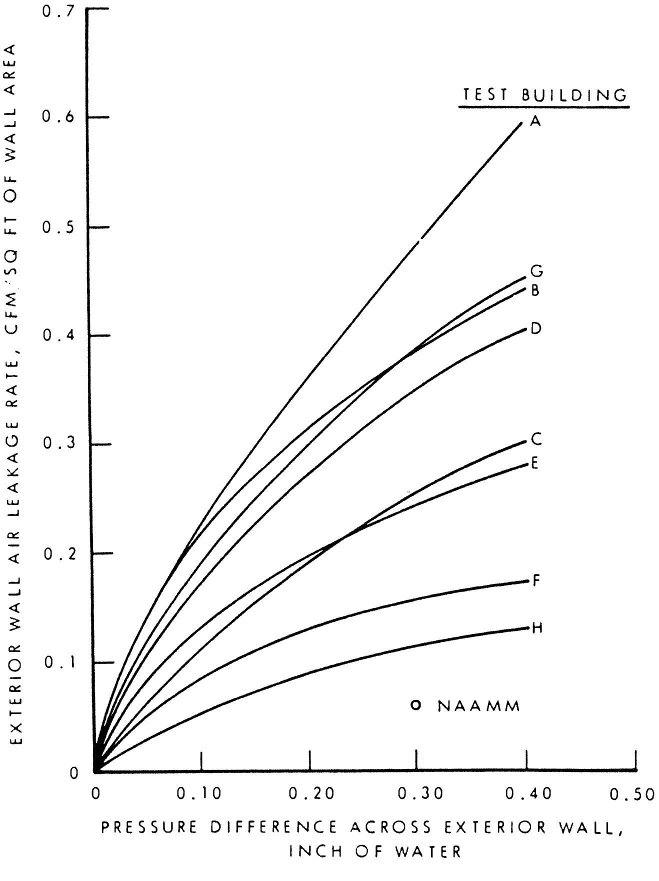


Fig. 2 Over-all air leakage rates of pressurized enclosure

Fig. 3 Air leakage rates of exterior walls



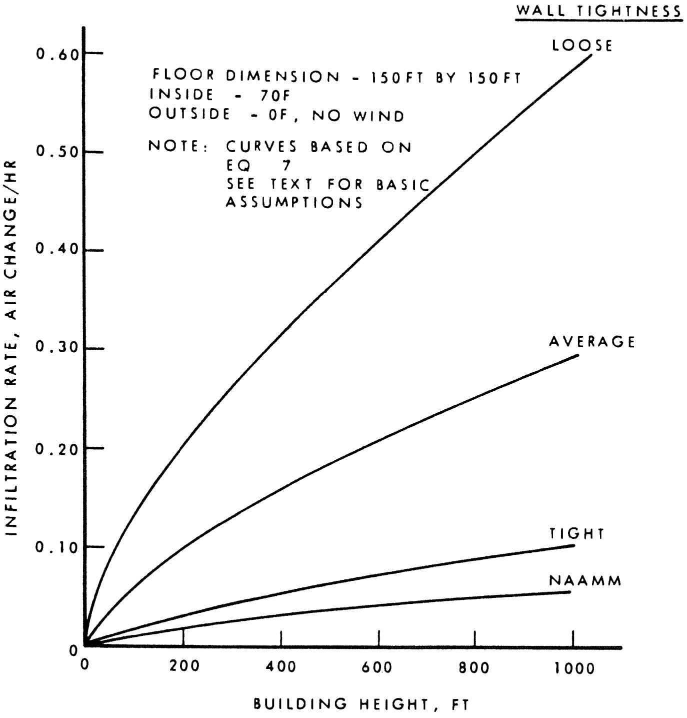


Fig. 4 Infiltration rate vs building height

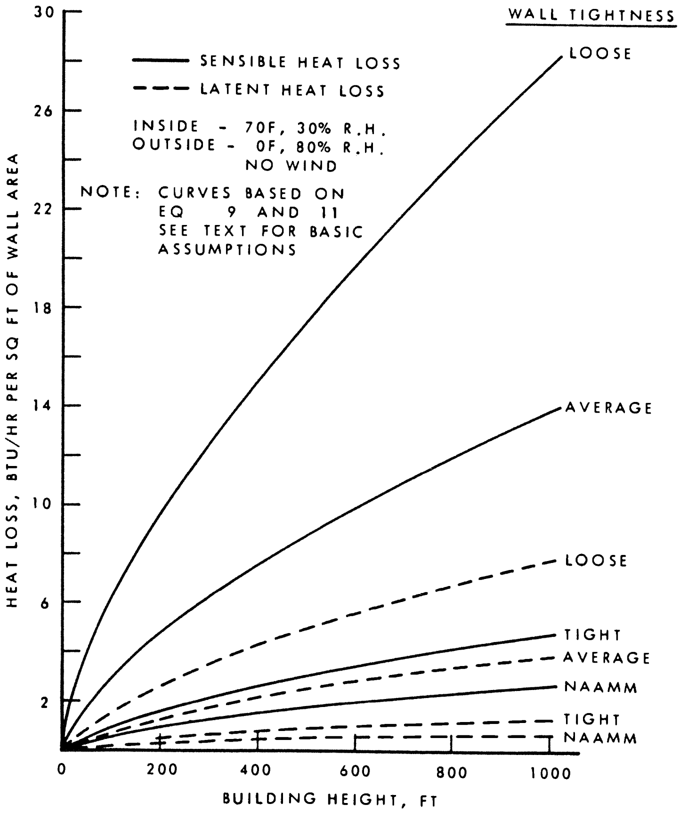


Fig. 5 Sensible and latent heat losses caused by infiltration

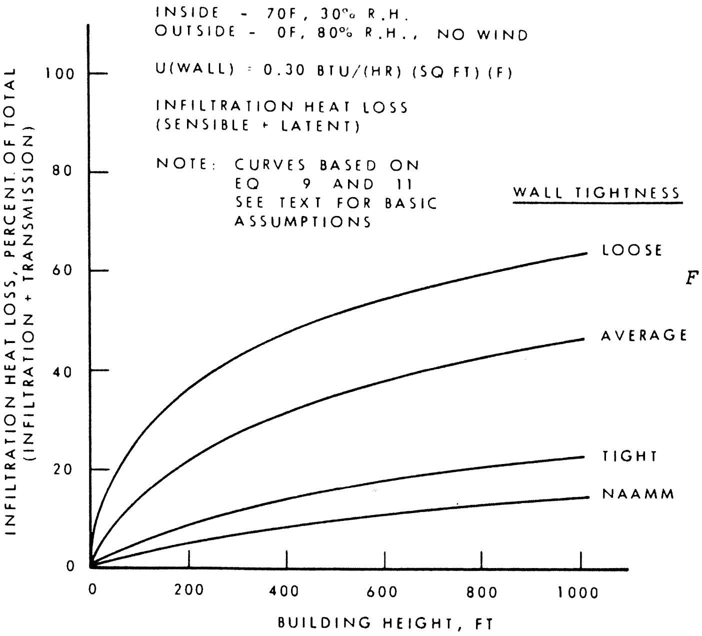


Fig. 6 Comparison of infiltration heat loss with transmission heat loss

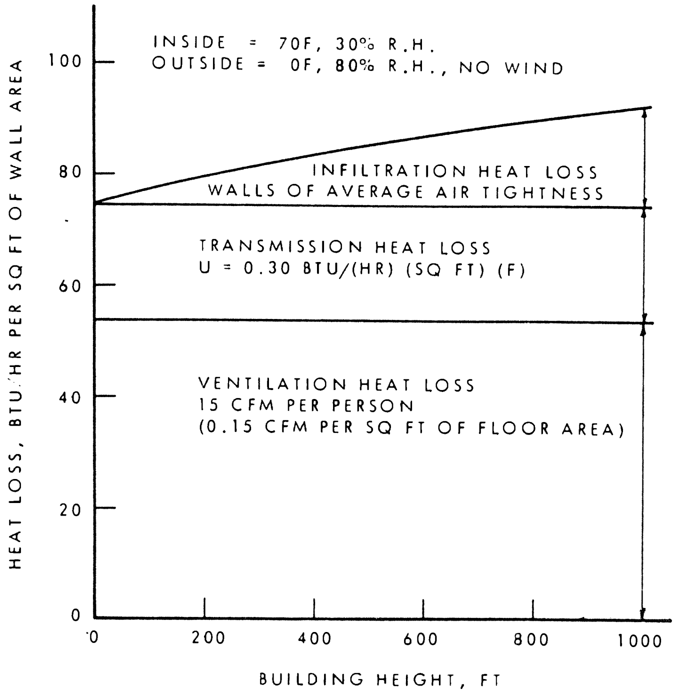


Fig. 7 Comparison of ventilation heat loss with infiltration and transmission heat losses

DISCUSSION

DAVID T. HARRJE, Senior Research Engineer and Lecturer, Princeton Univ., Princeton, NJ: Has there been any attempt to use the central shaft with blowing downward at the neutral line to attempt to benefit both the upper and lower portions of the building through reduced air infiltration?

TAMURA: Computer studies on this approach to reduce infiltration are given in a paper entitled "Building Pressures Caused by Chimney Action and Mechanical Ventilation" by A.G. Wilson and myself (ASHRAE TRANSACTIONS, vol. 73, Part II, 1967). The reduction of pressure differences across the exterior walls would depend on the recirculation rate and the internal resistence of a building; inside pressures of a building with a low internal resistance will not be altered significantly to affect the pressure differences across the exterior walls.

It should be recognized that if both infiltration and exfiltration are eliminated by this means, then the pressure differences caused by stack action would be transferred from the exterior walls to the walls of vertical shafts which can give rise to difficulties in operating elevator and stair doors. It is probable that effective operation of this system with changing condition of wind and stack action would be difficult. The preferred approach to minimize infiltration is by contructing outside walls that are relatively air tight rather than by using ventilation fans as suggested or for building pressurization.

RONALD N. JENNER, NASA, Hampton, VA: In regards to infiltration due to wind on low-rise building, what does your study show?

TAMURA: It was stated that infiltration rates of high rise buildings depend primarily on stack action during cold weather and average wind velocity. It is expected that the effect of wind action compared to that of stack action would be greater for low-rise buildings than for high-rise buildings; that due to stack action, however, it should not be neglected as field studies indicate that even for houses its effect is significant.

Reprinted from ASHRAE TRANSACTIONS, Volume 82, Part 1, 1976, pages 122-134, by permission of the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. © Copyright 1977.