National Research Council Canada
Conseil national de recherches Canada

PREDICTING AIR LEAKAGE FOR BUILDING DESIGN

BY

G. T. TAMURA

REPRINTED, WITH PERMISSION, FROM
VOLUME 1/1 OF THE PREPRINT PAPERS OF THE 6TH CIB CONGRESS
THE IMPACT OF RESEARCH ON THE BUILT ENVIRONMENT
HELD IN BUDAPEST, 3 - 10 OCTOBER 1974
P. 368 - 374

TECHNICAL PAPER NO. 437
OF THE
DIVISION OF BUILDING RESEARCH

OTTAWA

PRICE 10 CENTS

NRCC 14747

Predicting air leakage for building design

G. T. TAMURA
National Research Council of Canada
Division of Building Research
Ottawa, Canada

Summary

Air leakage through the building envelope is an important consideration in the control of air conditions in buildings. It also affects the way that smoke or other contaminants migrate within the building and hence directly influences the design of systems that are intended to control or inhibit the movement of contaminants. Tests have been carried out on contemporary high-rise buildings to obtain data on their air leakage characteristics. Field studies have been complemented by the development of a computer program for calculating the air flow rates and pressure distributions that may occur under various combinations of wind and stack effects. These studies are described and the implications of the results on building design are discussed.

Air leakage that takes place across the building enclosure has a number of important implications in the design of a building. It contributes to the heating, cooling and moisture loads that must be handled by the air-conditioning system. The air movement inside a building as a result of air leakage through the exterior walls not only spreads odours but, in the event of fire, contributes to the spread of smoke and toxic gases.

The current practice of calculating loads in multistorey buildings caused by air leakage appears to be based primarily on the judgment and experience of the designer. This is due to the limited available data on the values of air tightness of wall construction and the complexity of calculating the rates of air leakage under various outside conditions. This led to a lack of appreciation of the contribution of air leakage to the total load on a building.

Research efforts were directed toward developing (1) information on the degree of resistance to air leakage provided by the exterior walls and the interior separations of modern high-rise buildings [1–4]; and (2) a computer program to determine the rates and pattern of air flow and, in the case of fire, smoke flow in a building [5].

1. Determination of Air Leakage Values

There are published data on the air leakage characteristics of residential windows, doors, and simple frame and brick walls [6]. There is no information, however, on the air leakage characteristics of contemporary wall constructions such as curtain walls and spandrel panels with fixed glazing.

A test method was developed, therefore, to measure the air leakage characteristics of exterior walls and was applied to four tall buildings in the Ottawa area [1]. This method involved pressurizing the building by using the supply fans of the central air-conditioning system and recording the supply air flow rates and the resultant pressure differentials across the enclosure. The test data were analyzed to separate the leakage flow through the typical wall area from those through the bottom and top of the pressurized enclosure.

The results of measurements on four of the test buildings are given in Fig. 1. The building height varied from 11 to 22 storeys. As shown in the graph, air leakage rates for these buildings varied from 0.00127 to 0.00244 m^3/s per square meter of exterior wall area at 75.0 N/m^2. The air leakage rates are comparable to those of an 0.33-m unplastered brick wall based on laboratory test [1] (also shown in Fig. 1). These values are much higher than the maximum value of 0.000306 m^3/s per square meter called for by the standard of the National Association of Architectural Metal Manufactures (NAAMM) in the USA.

The air leakage characteristics of interior separations such as walls of elevator and stair shafts and floor construction of several buildings have been measured. Initial measurements conducted on the 9- and 17-storey buildings are reported in [2].

2. Mathematical Model

The study of the rates of air leakage and flow patterns of multi-storey buildings for various assumed conditions was conducted with the use of a mathematical model.

The basic components of the model are illustrated in Fig. 2. It consists of leakage openings from outside to each floor area (A_w), from each floor area to the floor above (A_f), and from each floor area to the vertical shafts (A_s). Each shaft may have two vents to the outside which may be located at any floor level. The effects of the air handling systems are incorporated by specifying the net quantity of air supplied to each vertical shaft and each floor area.

The set of equations describing the building is obtained by writing a mass flow balance equation for each floor space and each shaft. This results in a set of simultaneous nonlinear equations. The outside pressures, which depend on the outside temperature and wind condition, are input data; the unknown variables are then the floor and shaft pressures. An iterative technique is used to solve for all unknown inside pressures. With all pressures known, pressure difference and air leakage rate across each separation are calculated. A computer program was prepared to carry out these calculations [5].

3. Heat Loss Caused by Stack Action

Fig. 3 shows the air flow pattern in a 20-storey building with air leakage characteristics of the building components based on measured values for an outside temperature of −18°C and no wind [2]. The leakage area for the outside wall (A_w) was based on 0.00306 m^3/s per square meter of outside wall area at 75.0 N/m^2 pressure difference. Air flows into the building through the outside wall below the neutral pressure plane, up through floors and vertical shafts, and out through the outside wall above the neutral pressure plane, of the building. The total infiltration rate into the building is 9.30 m^3/s; of this, 8.95 m^3/s flows into the vertical shaft and the remainder through openings in the floor construction. Most of the upward flow occurs through openings in the vertical shafts.

The magnitude of the sensible heating load due to infiltration caused by stack action relative to the overall heating load for various wall leakage values is shown in Fig. 4. The infiltration and transmission heating loads were based on an outside temperature of −18°C, and inside temperature of 24°C, and zero wind velocity. The overall heat transfer coefficient assumed for the wall was 1.70 W/m^2 degree C; with values of 0.85 for the insulated walls and 3.12 for the double glazed windows, the windows constituting 40 per cent of the total wall area.

The percentage heating load due to infiltration increases with building height as well as with increasing wall leakage values; the leakage rates can be much higher than 0.00306 m^3/s per square meter for walls of masonry construction and openable windows [4]. For walls with leakage values similar to those of the four buildings that have been tested, the infiltration heating load constitutes 20 to 40 per cent of the total heating load for building heights of 20 to 60 storeys. For walls with leakage values conforming to the NAAMM Standard, the heating load component due to infiltration is minimal.

Wind action in combination with stack action will increase the infiltration heating load above those indicated in Fig. 4. Pressurization of a building as a result of more air supplied than exhausted by the air handling systems will decrease heating load caused by infiltration although there is an offsetting penalty of heating the extra outside air supply. The heating load caused by stack action occurs mainly on the lower storeys (Fig. 3).

It is evident that attention should be paid in the design and construction of exterior walls to minimize heating loads as well as other loads associated with air leakage.

4. Smoke Movement

Heat generated by a fire in a building can cause smoke to spread to adjacent spaces. External conditions can also cause smoke to move from the fire area to other parts of a building. The smoke flow pattern can be deduced from the air flow pattern such as that caused by stack action (illustrated in Fig. 3). Computer studies indicate that stack action results in the greatest vertical air flow rate and thus the greatest potential for smoke spread from floor to floor in the event of fire. Under certain conditions, wind action can cause smoke to move vertically upward within a building, but its principal effect is to cause air or smoke to move in a horizontal direction towards leeward and side walls.

Fig. 5 shows calculated values of maximum smoke levels caused by a fire on the first floor of the 20-storey building shown in Fig. 3. A smoke level of unity is assumed for the fire floor. Under severe fire conditions, a smoke level 1 per cent of that of the fire floor can be considered a critical level of safety for the occupants. In the steady-state case considered, the entire building is contaminated, except floors 3 to 10. The time to reach these conditions depends on the leakage rates through the various compartments. Calculations of smoke concentrations for the transient case indicate that 5 minutes after the development of fire the vertical shafts, such as elevator and stair shafts, can be contaminated and after 15 minutes the upper floors can become untenable (2). This is particularly significant for occupants of high rise buildings as they cannot be evacuated in a short time.

One of the basic approaches to smoke control involves modifying the air flow pattern in such a way that smoke from the fire region is prevented from spreading to critical areas. This may be achieved by such measures as pressurizing and venting vertical shafts, providing protected vestibules, and venting the fire region (7). To design a smoke control system using such techniques requires a knowledge of the air leakage characteristics of the various parts and would be facilitated by the use of a mathematical model such as the one described in this paper.

References

[1] SHAW, C. Y., SANDER, D. M., TAMURA, G. T.
Trans. ASHRAE, 1973, 79, Part II.

[2] TAMURA, G. T.
Trans. ASHRAE, 1969, 75, Part II, 81

[3] TAMURA, G. T., WILSON, A. G.
Trans. ASHRAE, 1967, 73, Part II, p. II.1.1 II.1.

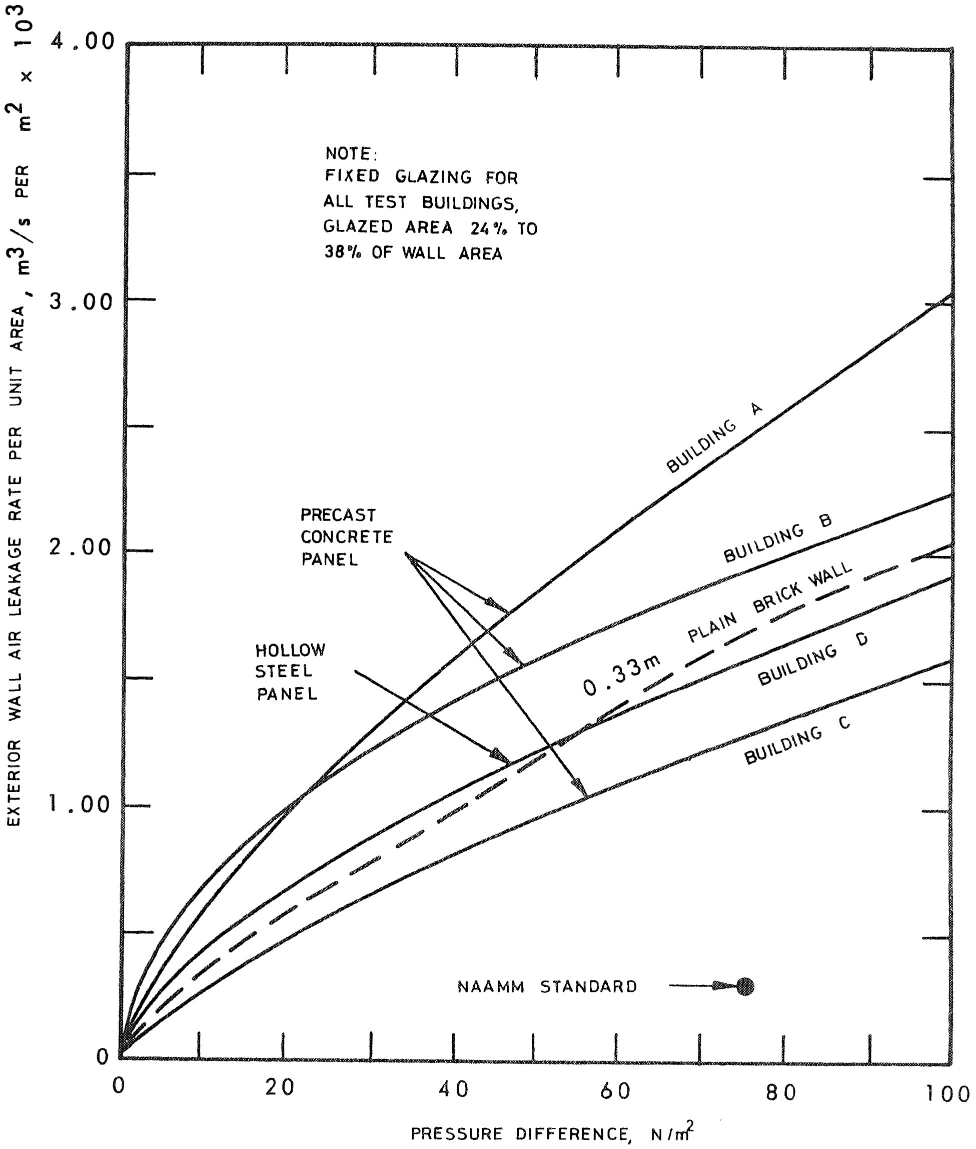
[4] TAMURA, G. T., WILSON, A. G.
Trans. ASHRAE, 1966, 72, Part I, 180.

[5] SANDER, D. M., TAMURA, G. T.
Fortran IV Program for the Simulation of Air Movement in Multi-Storey Buildings. NRC, Div. Bldg. Res., 1973. CP 35.

[6] ASHRAE Handbook of Fundamentals, 1972.
Chapter 19.

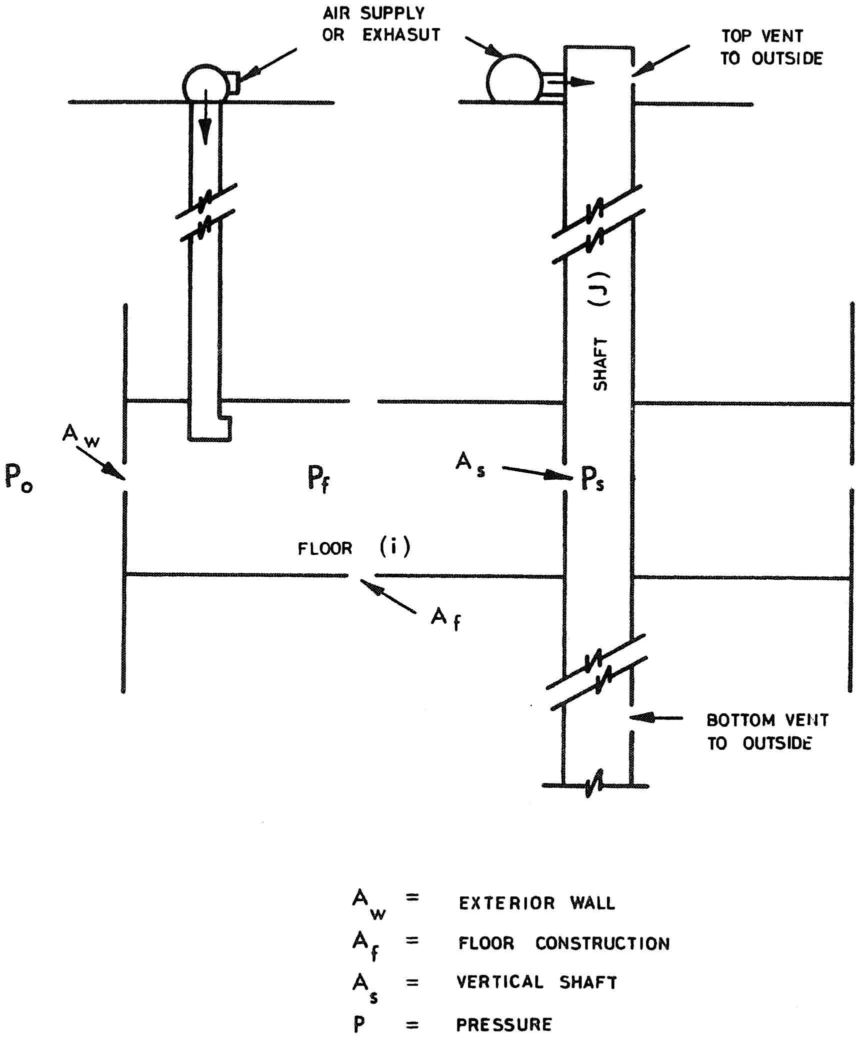
[7] TAMURA, G. T., MCGUIRE, J. H., WILSON, A. G.
Air-Handling Systems for Control of Smoke Movement. Proc. ASHRAE Symposium, Fire Hazards in Buildings, 1970.

* * *



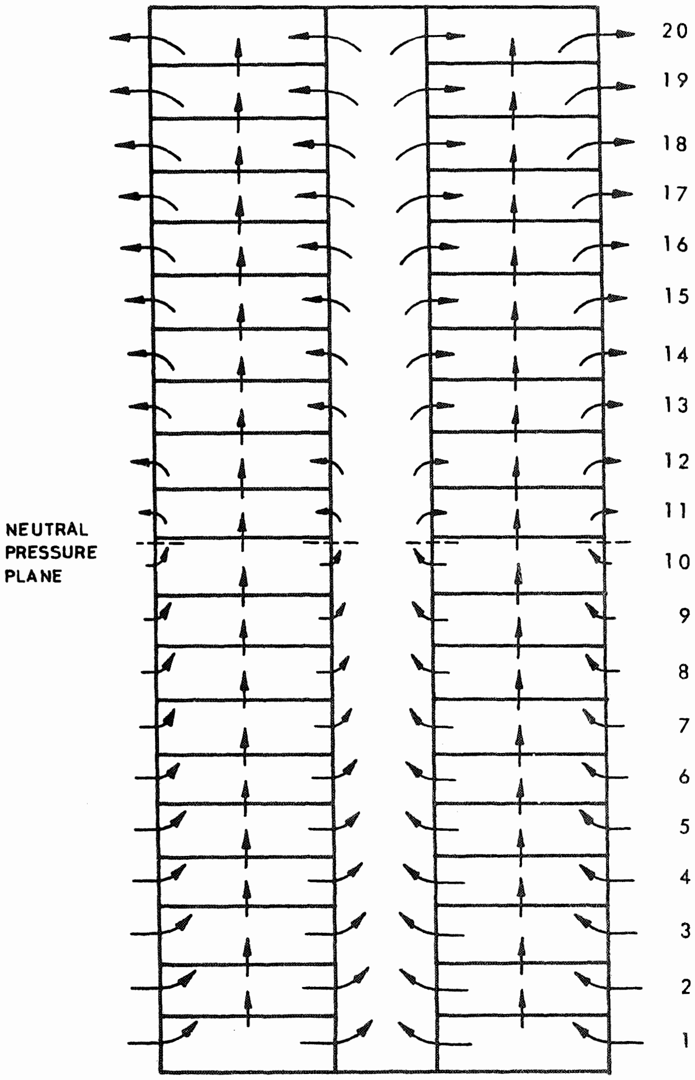
1

Air leakage rates of exterior walls



2

Mathematical model



NOTE: ARROWS ARE NOT TO SCALE

TEMPERATURES OUTSIDE, -18°C
INSIDE, 24°C

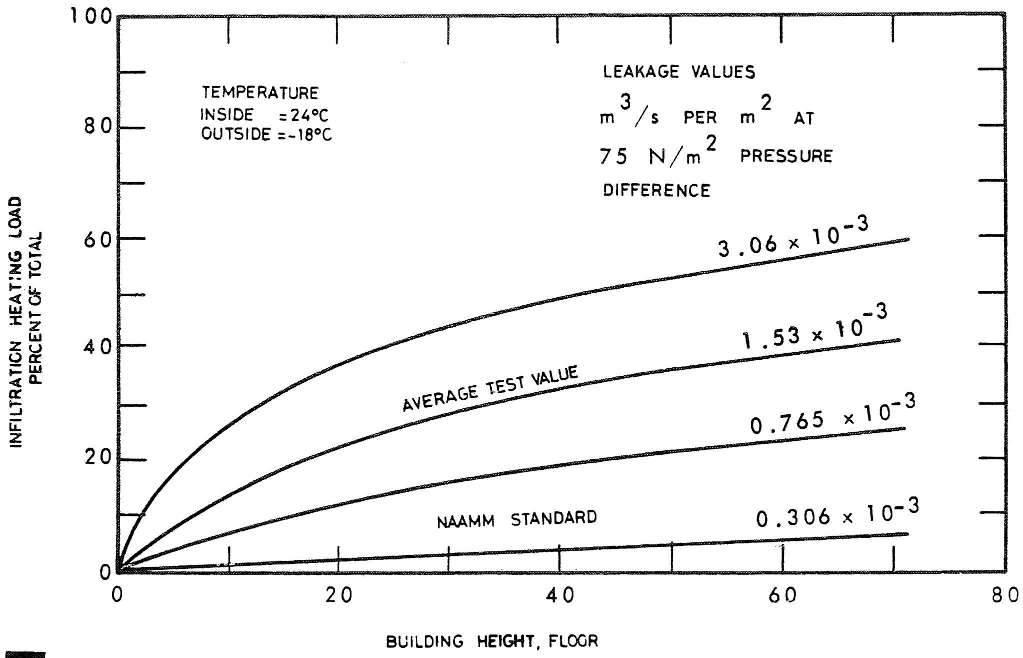
AIR LEAKAGE CHARACTERISTICS

$A_w = 0.24\ m^2$; $A_f = 0.35\ m^2$

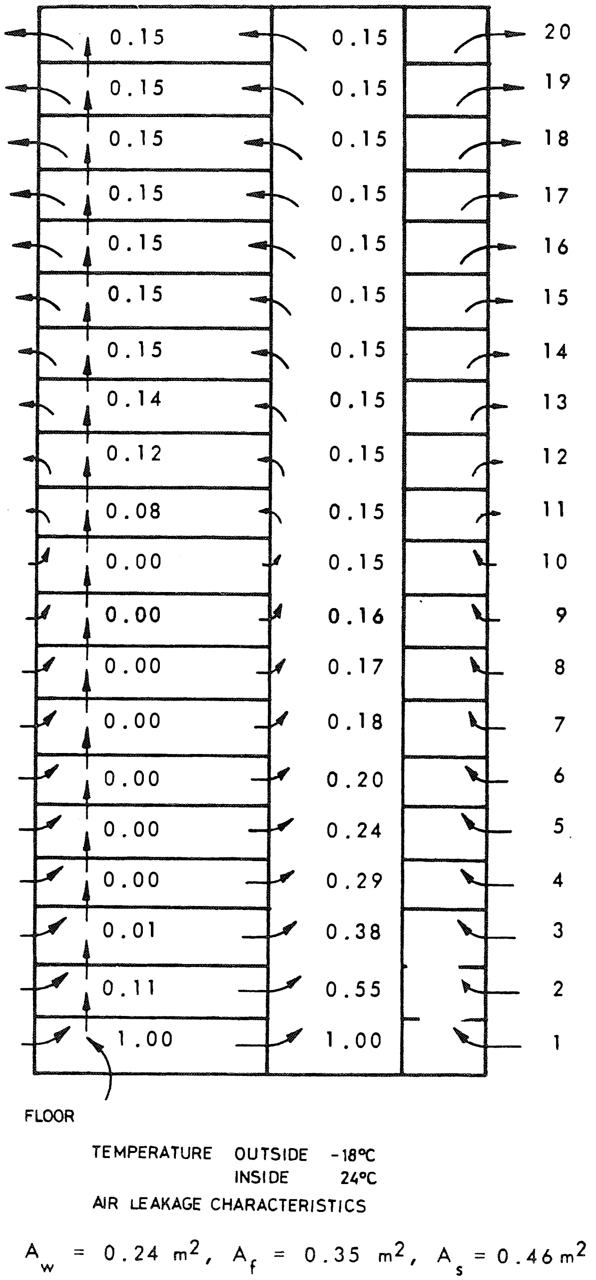
$A_s = 0.46\ m^2$

3

Air flow pattern caused by stack action



4



5

4

Infiltration heat loss vs building height

5

Smoke concentration pattern caused by fire in first floor and stack action (steady state conditions)