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METHODS FOR CONDUCTING SMALL-SCALE PRESSURIZATION TESTS AND AIR LEAKAGE DATA OF MULTI-STOREY APARTMENT BUILDINGS

by C.Y. Shaw

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SOMMAIRE

Nous avons fait une étude expérimentale pour mettre au point des méthodes de réalisation d'essais de pressurisation à petit échelle, destinés à déterminer les caractéristiques des fuites d'air dans les immeubles à appartements à plusieurs étages, lorsqu'il est impossible de faire une mesure des fuites à pleine échelle. Ces méthodes nécessitent l'utilisation d'un ventilateur portatif pour créer une force de suction ou de pression à l'intérieur d'un local hermétiquement fermé et englobant le périmètre d'une zone d'essai comme par exemple le mur extérieur d'une chambre ou une fenêtre. Pour réduire au maximum les fuites d'air latérales dues au mouvement de l'air dans les cavités d'un mur, la pression dans le local de mesure est réglée à la même valeur que la pression dans les salles qui l'entourent. En utilisant ces méthodes, on a mesuré le débit de fuite d'air des murs extérieurs de cinq immeubles de cinq à vingt étages de hauteur. On a également mesuré le débit de fuite d'air des principales sources de fuites dans des immeubles quelconques, pour déterminer leur contribution au débit total de l'air s'échappant par les murs. En outre, on a mesuré le débit de fuite d'air dans un immeuble de cinq étages dans lequel la porte d'entrée de chaque appartement est soit fermée, soit ouverte, pour étudier l'influence des murs des couloirs sur l'ensemble des fuites d'air de l'immeuble.

No. 2570

METHODS FOR CONDUCTING SMALL-SCALE PRESSURIZATION TESTS AND AIR LEAKAGE DATA OF MULTI-STOREY APARTMENT BUILDINGS

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

ABSTRACT

An experimental study has been made to develop methods for conducting small-scale pressurization tests to determine the air leakage characteristic of multi-storey apartment buildings where a full-scale air leakage measurement cannot always be performed. These methods require the use of a portable fan for developing a suction or pressure inside a test chamber which is sealed around the perimeter of a test area such as the exterior wall of a room or a window. To minimize the lateral air leakage due to air movement in the cavities of a wall construction, the pressure in the test chamber is balanced with those in the surrounding rooms.

Applying these methods, the air leakage rates through the exterior walls were measured in five buildings ranging from 5 to 20 storeys high. Air leakage rates through major leakage sources were also measured in selected buildings to determine their contribution to the total leakage of wall assemblies. In addition, the overall air leakage rate was measured in a 5-storey building with the entrance door to each apartment unit open and closed to investigate the influence of corridor walls on the overall building air leakage characteristic.

INTRODUCTION

High-rise apartments represent a large group of buildings whose heating demands make up a major part of their annual energy consumption and where substantial savings can be achieved by applying appropriate energy conservation measures. Without exception, however, a major problem encountered in evaluating various conservation measures is the lack of air leakage characteristics of these buildings for heating load prediction. Therefore, the Division of Building Research, National Research Council of Canada, initiated a program in the spring of 1978 to conduct air leakage measurements for this type of building. The results are presented in this paper.

A high-rise apartment is different from other types of tall buildings in that it is divided into small units connected by a common corridor on each floor, and it is normally serviced by a common ventilation system for supply of fresh air into the corridors and exhaust air from each unit. Owing to the limited capacity of the ventilation system and the large building volume, the usual pressurization method[1] for measuring the overall air leakage rate cannot be applied. Thus, there is a need for methods that can be applied to measure the air leakage rate through part of a building shell, such as the exterior wall of a room or a window. Field studies were conducted to develop such methods and, applying these methods, air leakage data for five apartment buildings (see Table 1) were obtained. In addition, the overall air leakage rate of a 5-storey building was measured using a large fan mounted on a trailer.

TEST METHOD

Fig. 1(a) shows the experimental set-up for measuring the air leakage rate through an entire wall assembly of a room (Direct Method). As shown, a portable fan with a maximum capacity of 200 ℓ/s at 2000 Pa (424 cfm at 8 in. of water) was used for this purpose. The fan intake was

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connected to an airtight test chamber by a duct of about 3 m (9.8 ft) in length and 0.2 m (8 in.) in diameter. The test chamber was made of plywood panels covered with polyethylene sheets and was sealed around the perimeter of the test wall with tapes. To facilitate sealing the top, the test chamber was slanted towards the wall.

The air flow rates of the fan were adjusted with a manual damper and measured with a laminar flow element (MERIAM LFE ELEMENT; accuracy of 5% of measured values). The pressure difference across the middle of the wall was measured with a diaphragm-type pressure transducer (static error band of 5% full scale) and a digital voltmeter. The pressures in the test chamber and the adjacent rooms were balanced with fans (Fig. 1(b)) to minimize the flow of leakage air through the four boundaries of the test area into the test chamber. The flows through these balancing fans were also controlled by individual manual dampers. As shown in Fig. 1(b), a minimum of four balancing fans were required for wall air leakage tests.

The air leakage rate through a wall assembly can also be obtained by measuring the air leakage rate through each component that makes up a wall. For an apartment building, they are usually windows, balcony doors, window sills, and floor-wall joints. Two methods, Direct and Indirect, can be used either independently or jointly for the purpose. Fig. 2 shows the arrangement required to apply the Direct Method. They are very similar to the one for walls, except for the size of the test chamber and the requirement for pressure balancing. It was found that a heavy-duty shop vacuum cleaner would have enough capacity to meet the flow requirements and also to produce the head required by the laminar flow element. Except for balcony doors and windows, the pressure in the test chamber and that in the test room should be properly balanced with a portable fan to minimize lateral air leakage. The experimental set-up for the Indirect Method is identical to that shown in Fig. 1(a). The air leakage rate through one particular component is obtained by comparing the flow rates measured before and after it is sealed.

In addition, an overall air leakage test was conducted on Building A using the method developed for schools[1]. The fan used was a vane axial type with variable pitch blades that can be adjusted manually to obtain flow rates between 0 and 23 600 ℓ/s (0 and 50 000 cfm). The fan intake was connected by a duct of about 15 m (49.2 ft) in length and 0.92 m (3 ft) in diameter to an entrance where the door was replaced by a plywood panel. All inside stair doors were kept open during the tests to allow a free flow of air from the floor spaces to the fan. Air flow rates were measured upstream of the fan intake using total pressure averaging tubes[1]. The pressure differences across the four exterior walls were measured at the middle of each wall at three levels using the same pressure transducer.

Most tests were conducted under the suction condition. For comparison, some components were tested both under suction and pressurization. To minimize wind influence on pressure measurements, all tests were conducted when the meteorological wind speed was lower than 15 km/h (9.3 mph)[2].

VALIDATION OF TEST METHOD

A series of validation tests was conducted to verify the test methods and to demonstrate the necessity of pressure balancing. The result of validation tests for the Direct Method for measuring wall air leakage is shown in Fig. 3. It indicates that the air leakage values of the wall assembly of Building C obtained by the Direct Method is within 5% of that obtained by summing the independently measured air leakage values of the floor-wall joint, window and window sill of the same wall. Likewise, as shown in Fig. 4, an agreement in results within 15% was also obtained for validation tests on floor-wall joints and window sills.

In conducting the air leakage test, the pressure in the test chamber was balanced either with that in the adjacent rooms or with that in the test room by adjusting the air flow rate of the balancing fan. It was found that even with a manual damper, these pressures could be balanced within ±2.5 Pa (0.01 in. of water) without difficulty.

The effect of pressure balancing is illustrated in Fig. 4 showing the air leakage rates through both the window sill and the floor-wall joint. It indicates that a substantial reduction in the air leakage rate resulted from pressure balancing which reduced the lateral air leakage into the test chamber via the cavities in the wall. This hypothesis is at least partially supported by the fact that the air leakage rate obtained with pressure balancing is within 15% of that by the Indirect Method (Fig. 4). The effect of pressure balancing was further investigated by conducting air leakage tests on the floor-wall joint of Building M where the air leakage rate through the carpet could be eliminated. Fig. 5, which gives the results of four tests, indicates that when the pressures were balanced, identical air leakage rates were obtained before and after removing the carpet (Curves 1 and 2). If, however, the pressures were not balanced, an increase in the air leakage rate was observed, the amount of increment depending on whether the carpet was removed from the floor (Curves 3 and 4). The differences between Curves 4 and 3, and between Curves 3 and 2 are approximately the air leakage rates through the carpet and other sources (e.g., window sill as indicated by the heavy dotted line).

Finally, the effect of pressure balancing between test chamber and adjacent rooms is illustrated in Fig. 6. The results indicate that the air leakage through a wall assembly measured without pressure balancing brings about an increase in flow up to 73% (Building T) of that with pressure balancing. An inspection of the test rooms indicated that Buildings T and M were the only two whose partition walls were penetrated by heating pipes. Since these walls were used as the two side panels of the test chamber in these tests, the openings around the heating pipes of Building T, which could not be properly sealed, were mainly responsible for the large increase in the air leakage rates.

RESULTS AND DISCUSSIONS

Applying the developed test methods, air leakage rates through wall assemblies were measured in five apartment buildings. Except for Buildings A, M and T, the exterior walls of two rooms of each building were tested for air tightness. The air leakage characteristics of windows of the five buildings and those of the sliding glass balcony doors of one additional building (Building W) were also studied. Also, the overall air leakage rate of the entire building was measured in Building A with the entrance door to each apartment unit open and closed. These results were analyzed and presented for opaque walls consisting of window sills and floor-wall joints, the sliding glass balcony doors, and windows including window frame-wall joints. Fig. 7 shows the air leakage data of the opaque walls. Their values vary not only from building to building with similar wall design (e.g., Buildings C and V), but also vary from room to room in the same building. Also shown in this figure is the air leakage characteristics of a 33-cm (13-in.) unplastered brick wall obtained from the ASHRAE Handbook of Fundamentals[3]. It indicates that, except for Building M, the air leakage values of the opaque walls of the test buildings are within ±50% of that of the unplastered brick wall.

The air leakage rates through the four types of windows are shown in Fig. 8(a) and 8(b). In this paper, the air leakage through a window frame-wall joint is credited to the window instead of the wall. The reasons are twofold: firstly, it will considerably reduce the work in field testing and secondly, it is more appropriate to do so in modeling air leakage characteristics of buildings. Air leakage values of windows as shown in Fig. 8(a) and 8(b) vary widely from building to building. Even in the same building these values can be different by a factor of 2. There is no clear evidence to indicate that one window design gives a tighter window than another. Nor is there any correlation between air leakage characteristics and ratio of openable area to total window area (e.g., Building T with fully openable windows has a lower leakage rate than Building A, which has partially openable windows).

ASHRAE Standard 90-75 on energy conservation in new building design[4] recommends that the maximum air leakage rate through windows should be 0.77 ℓ/s·m at 75 Pa (0.5 cfm/ft at 0.3 in. of water). This value does not include the air leakage through a window frame-wall joint whereas the measured values in our study did include this leakage. Even so, one-third of the 17 test window units (including window frame-wall joints) had air leakage values below the suggested limit, suggesting that it is possible to design, manufacture, and install windows to meet the leakage specification of the Standard.

Tests were also conducted on three buildings to investigate the difference in air leakage characteristics under suction and pressurization. It was found that for floor-wall joints, there was no appreciable difference in the test results whereas for windows, the air tightness value obtained under one condition was, at most, 12% higher or lower than the other.

Fig. 9 shows the air leakage rates of the eight residential-type sliding glass doors (excluding frame-wall leakage). As shown, there are 6 out of 8 doors whose air tightness values are lower than the 2.5 ℓ/s·m^2 at 75 Pa (0.5 cfm/ft^2 at 0.3 in. of water) maximum recommended by ASHRAE Standard 90-75. All these doors are double doors with the outer door acting as a storm door. Hence, tests were also conducted with the outer door open to study the effect of the storm door. The results indicate that with both doors closed, a reduction in the air leakage rate (ranging from 15% to 32%) was obtained.

The contribution of major building components to the total air leakage rate of wall assemblies was studied in selected buildings. Fig. 10 shows that at a pressure difference of 75 Pa (0.3 in. of water), windows including window frame-wall joints can be the main contributing component which may account for as high as 70% of the total leakage. Next are floor-wall joints and window sills which can account for 50% and 30% of the total air leakage respectively. The air leakage rate of the ceiling joint was measured in one building (Building M) as this is the only building having smoothly plastered ceilings. As shown, there was no measurable air leakage through the ceiling joint of this building.

Finally, the overall air leakage rate was measured in Building A with the entrance door to each apartment unit open and then closed. As shown in Fig. 11, there is no appreciable difference in the overall air leakage rate whether the door is open or closed. Fig. 11 also shows that the overall air leakage characteristics of Building A are similar to the average air leakage values of the 7 tall office buildings, all having open floor arrangements[2].

CONCLUSIONS

Air leakage characteristics of the exterior walls of multi-storey apartment buildings can be obtained by conducting small-scale pressurization tests using the methods outlined in this paper. These methods were validated by comparing the overall leakage values and the sum of the independently obtained component leakage values.

It was found that air leakage rates through opaque walls were similar to those of a 33-cm (13-in.) unplastered brick wall obtained from laboratory tests. It was also found that one-third of the 17 windows tested as installed met the 0.77 ℓ/s·m of sash crack at 75 Pa (0.5 cfm/ft at 0.3 in. of water) maximum value recommended by ASHRAE Standard 90-75. The air leakage data of the 8 balcony doors tested as installed indicated that three-quarters of them also met the requirement of the 2.5 ℓ/s·m^2 at 75 Pa (0.5 cfm/ft^2 at 0.3 in. of water) maximum air leakage rate recommended by the same Standard.

Air leakage rates through various building components were measured in selected buildings. The results indicated that floor-wall joints, windows, and window sills are the three major air leakage sources in exterior walls. The results obtained from one building indicated that there is no measurable leakage through ceiling joints.

Opening or closing the entrance door to each apartment unit was found to have no effect on the air tightness values of Building A. This finding suggests that the air leakage rates of apartment buildings are mainly governed by the resistance of the exterior walls. Further studies are required in this area.

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2. Tamura, G.T. and Shaw, C.Y., "Studies on Exterior Wall Air Tightness and Air Infiltration of Tall Buildings," ASHRAE Transactions 1976, Vol. 82, Pt. I, p. 122-134.

3. ASHRAE HANDBOOK of Fundamentals, Table 3, Chap. 21, 1977, ASHRAE, Inc., N.Y.

4. ASHRAE Standard 90-75, "Energy Conservation in New Building Design," 1975, ASHRAE, Inc., N.Y.

ACKNOWLEDGEMENTS

The author is indebted to A. Zdanowicz of the Ontario Housing Corporation, F. Monopoli and W. Forrester of the University of Ottawa, and the Board of Directors of the Ambleside I for granting permission to conduct the tests, and to the managers of the test buildings for their assistance during the tests. The author wishes to thank Dr. D.G. Stephenson and G.T. Tamura for their valuable comments during the review of this paper. The author also wishes to acknowledge the assistance of R.G. Evans and Miss R. Plouffe in the field tests.

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TABLE 1 Description of Test Buildings

Building	A	C	M	T	V
Year Constructed	1978	1978	1965	1972	1978
Year Tested	1978	1978	1978	1978	1978
Height (Storeys)	5	10	20	15	12
Dimensions of Test Wall Assembly m (ft.)	3.14 W x 2.44 H (10.3 x 8.0)	3.05 W x 2.44 H (10.0 x 8.0)	1.88 W x 2.41 H (6.17 x 7.92)	4.34 W x 2.48 H (14.25 x 8.13)	3.02 W x 2.41 H (9.92 x 7.92)
Dimensions of Test Window m (ft.)	1.52 W x 1.22 H (5.0 x 4.0)	1.62 W x 1.62 H (5.33 x 5.33)	0.91 W x 1.42 H (2.98 x 4.67)	3.94 W x 1.37 H (12.92 x 4.5)	1.93 W x 1.57 H (6.33 x 5.15)
Window Type	Fixed and Openable;Sealed Double Glazing	Fixed and Openable; Sealed Double Glazing	Openable; Sealed Double Glazing	Openable; Sealed Double Glazing	Fixed and Openable; Sealed Double Glazing
Openable/ Total Window Area	50%	38%	100%	100%	63%
Wall Construction	10.2 Cm (4 in.) Clay Brick, 15.3 Cm (6 in.) Conc. Block, Parging, Bldg. Paper, 8.9 Cm (3.5 in.) Batt Insulation, Vapour Barrier, Gypsum Board	22.9 Cm (9 in.) Conc. Brick, 5.1 Cm (2 in.) Rigid Insulation, Dry Wall	Outer Shell: 15.3 Cm (6 in.) Clay Brick - for main wall; or 10.2 Cm (4 in.) P/C panel - for wall below window Inner Shell: Parging, Bldg. Paper 5.1 Cm (2 in.) Batt Insulation, Vapour Barrier, Plaster	15.3 Cm (6 in.) Pre-poured Conc. Spandrel Panel, 5.1 Cm (2 in.) Insulation, Vapour Barrier, Dry Wall	10.2 Cm (4 in.) Face Brick, 10.2 Cm (4 in.) Conc. Block, Parging, 6.4 Cm (2.5 in.) Rigid Insulation, Gypsum Board

Note: Bldg. W is not included as it was tested for balcony door only

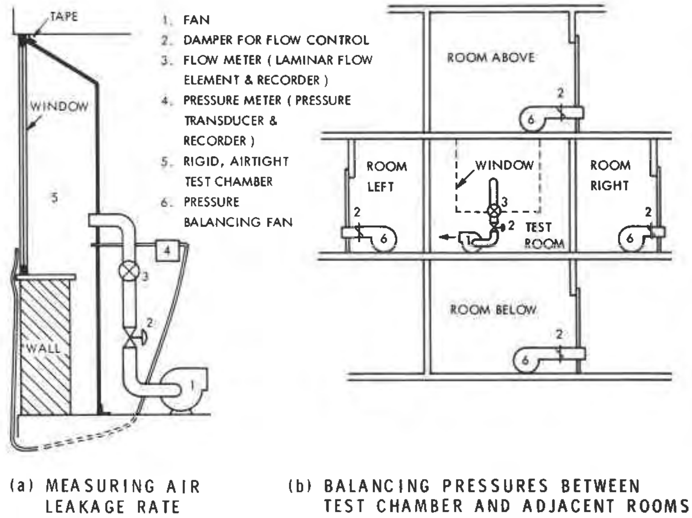

Fig. 1 Experimental set-up for measuring air leakage rate through wall assembly

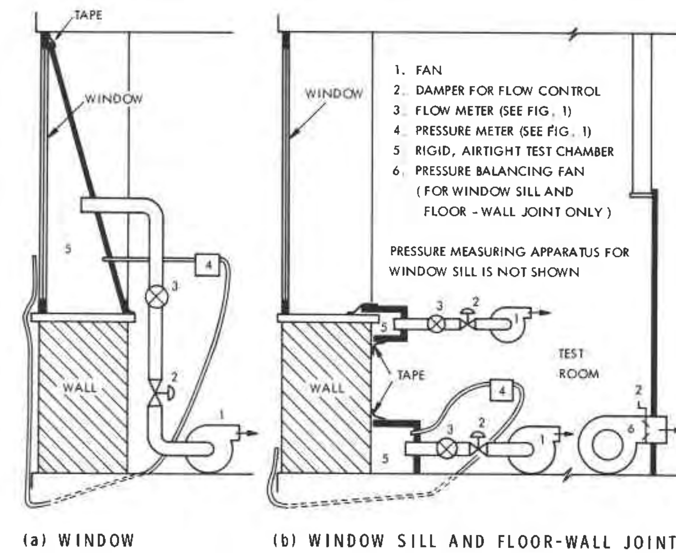

Fig. 2 Experimental set-up for air leakage rate through building components

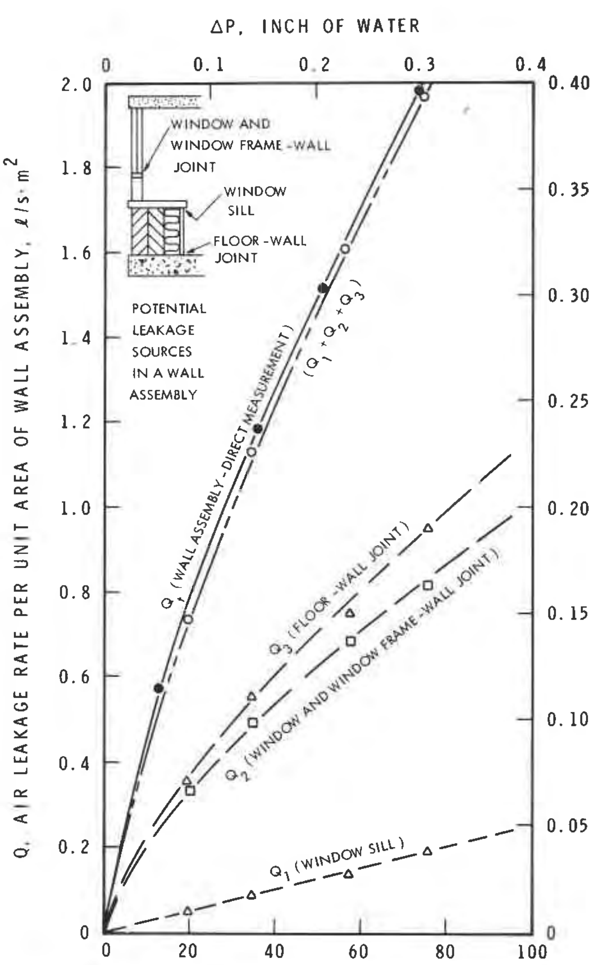

Fig. 3 Comparison of air leakage rates through wall assembly of Building C obtained by direct measurement and measurements of building components

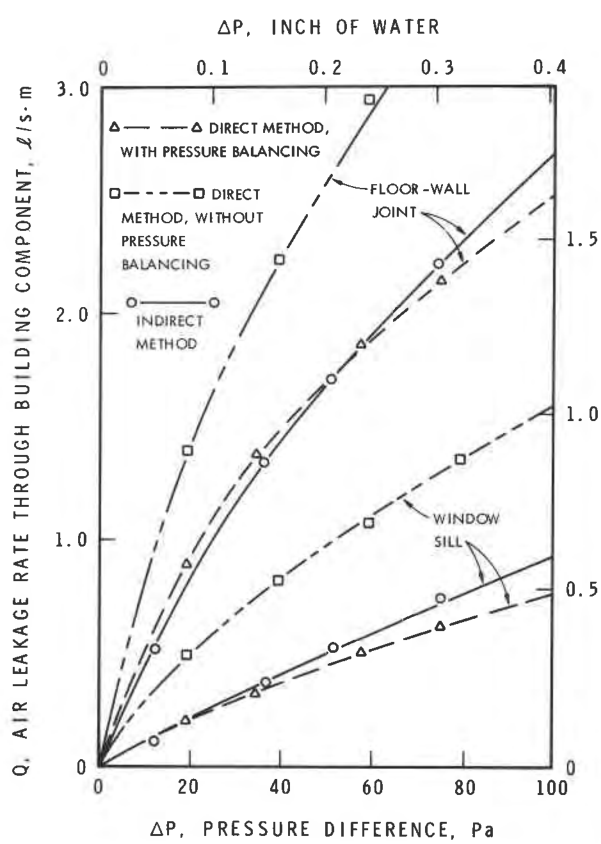

Fig. 4 Comparison of air leakage rates through window sill and floor-wall joint of Building C obtained by Direct and Indirect Methods

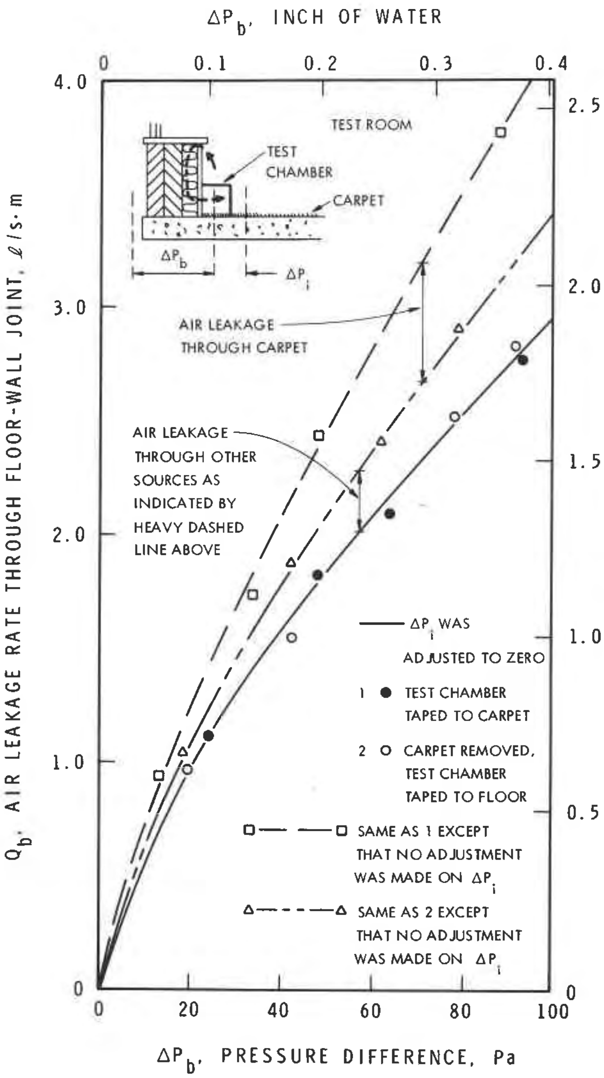

Fig. 5 Effect of pressure balancing on air leakage rates

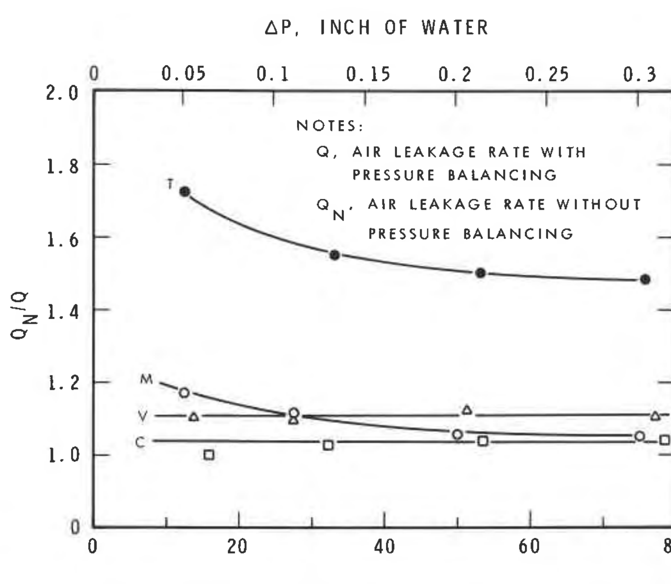

Fig. 6 Effect on air leakage rates with and without pressure balancing

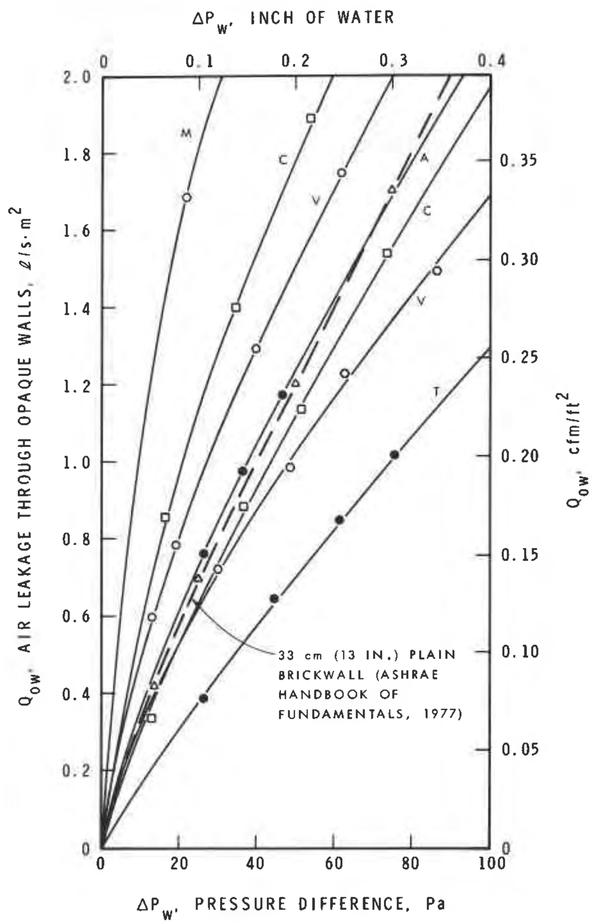

Fig. 7 Air leakage rates through exterior walls excluding windows and doors

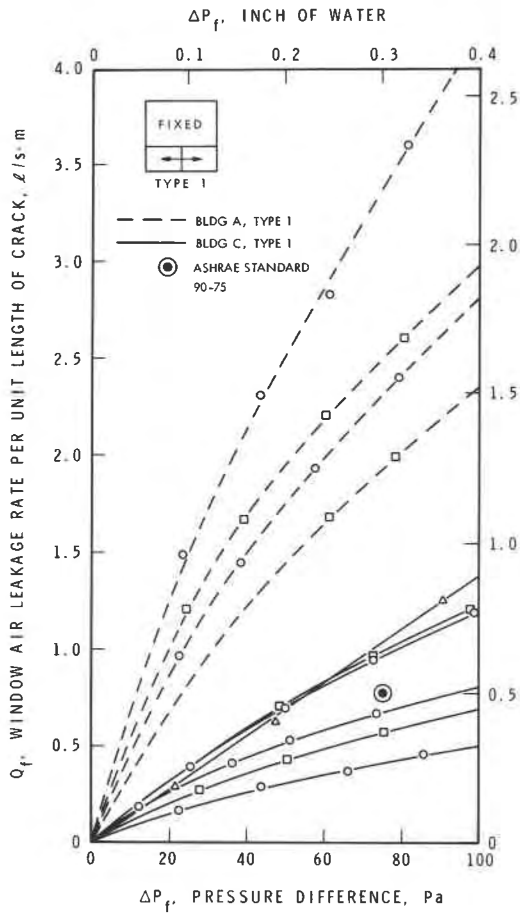

Fig. 8(a) Air leakage rates through windows including window frame-wall joints (Buildings A and C)

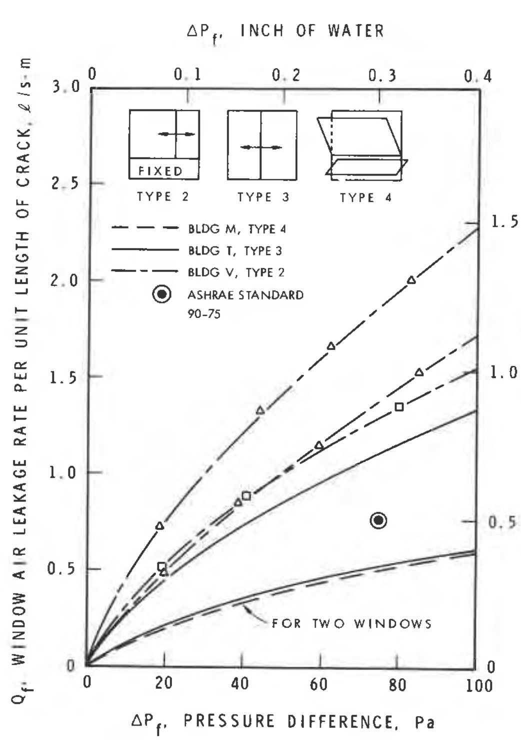

Fig. 8(b) Air leakage rates through windows including window frame-wall joints (Buildings M, T and V)

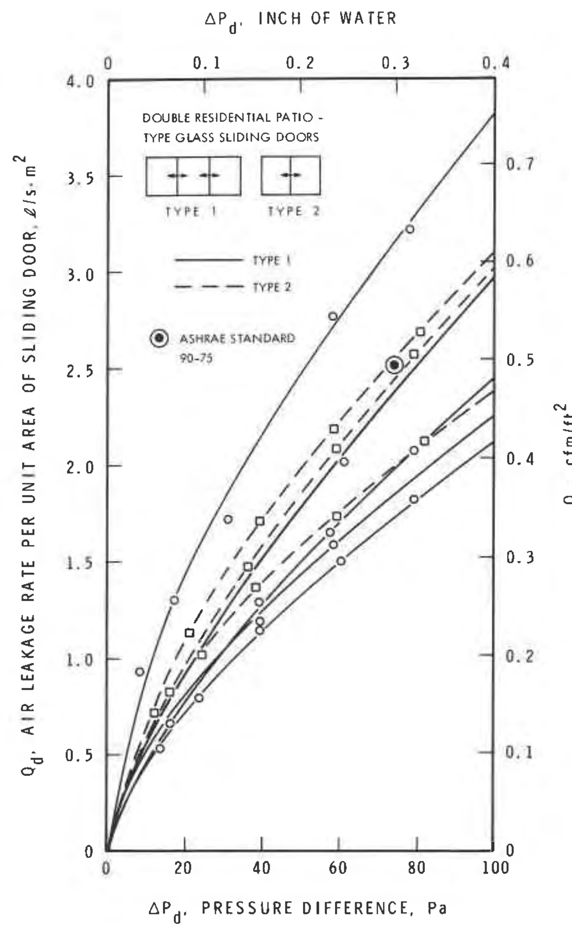

Fig. 9 Air leakage rates through balcony sliding doors

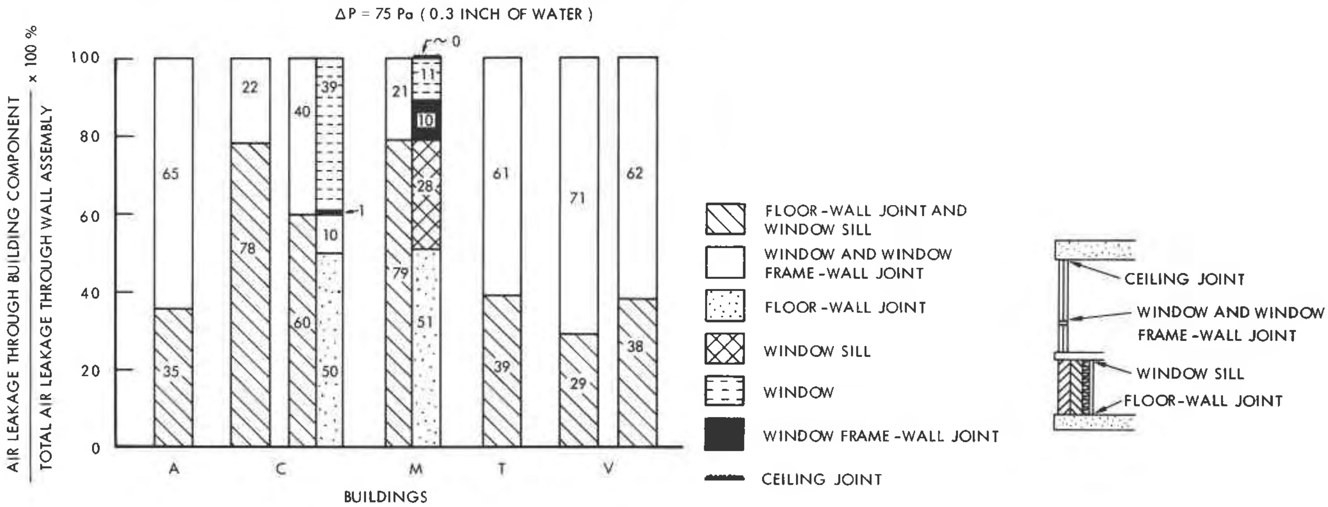

Fig. 10 Contribution of various building components to total air leakage rate

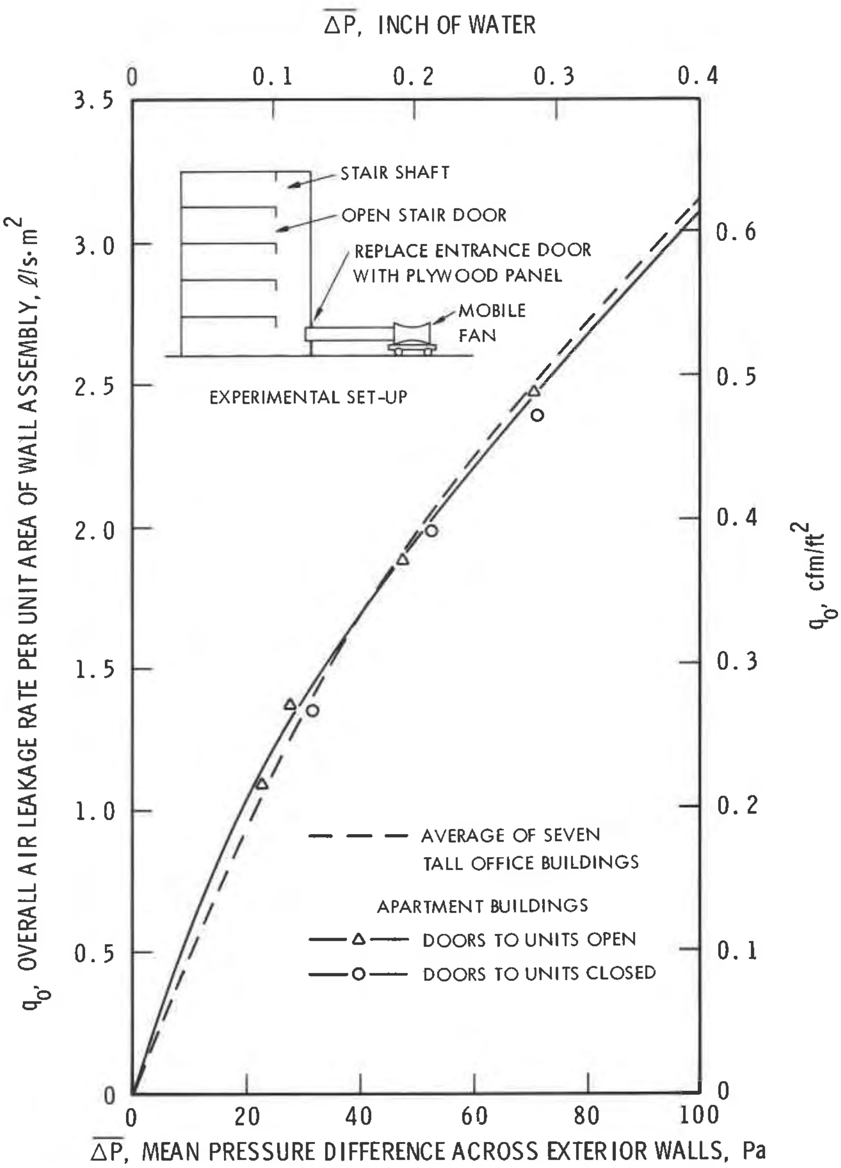

Fig. 11 Overall air leakage rates per unit area of wall assembly of Building A

DISCUSSION

RICHARD GOLE, Partner, H.H. Angus & Assoc. Ltd., Don Mills, Ontario, Canada: How was the outside mounted fan used for pressurizing the building?

C.Y. SHAW: The test method is described in the fourth paragraph under the heading "Test Method."

GOLE: What area and/or volume was the subject building?

SHAW: The volume of Building A is about 10 419 m^3 or 368 000 ft^3.

GOLE: What degree of pressurization was achieved?

SHAW: Up to 100 Pa or 0.4 in. of water.

GOLE: Test results indicated values of infiltration of components (pressurized and non-pressurized); where was the differential considered?

SHAW: See Fig. 1 and 2. The pressure differential is the pressure difference across the test component, i.e., the pressure difference between the outside and the inside of the test chamber.

JAMES E. GRIFFITH, Sr. Resch. Engr., PSE&G Resch. Corp., Maplewood, NJ: Are you taking concurrent tracer gas data to relate actual air changes per hour to the individual leakage rates?

SHAW: We will conduct air infiltration measurements using the tracer gas decay method in some of the test buildings.

ROBERT A. MACRISS, Assoc. Dir. R&D, Inst. of Gas Technol., Chicago, IL: Why is it necessary to perform structural component air-leakage tests at the site rather than in the laboratory? As the Swedish Building Institute has done for many years, such tests can be made in the laboratory with great precision, at cost-effective levels as compared to testing in the actual 10-story or taller structure.

SHAW: It is not economical to conduct laboratory tests on building components such as wall assemblies or floor-wall joints because they are too expensive to construct even if one can realistically duplicate factors such as workmanship and aging. Even for windows, there is no reason to believe it is more expensive to test them at the site than in the laboratory. Nor is there any reason to suggest that the laboratory test will give better results than the field test. Furthermore, it is possible that one has to substantiate the laboratory measurements with the field data. For example, it is always necessary to support the wind tunnel measurements on building models with the field data.

DAVID T. HARRJE, Princeton Univ., Center for Energy & Env. Studies, Princeton, NJ: Have you made a comparison of the window leakage rate in these commercial types as installed compared to factory values? Such comparisons were made in a residential windows study reported by Weidt and Selkowitz at the recent ASHRAE/DOE Conference on Thermal Performance of the Exterior Envelopes of Buildings.

SHAW: No.