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METHODS FOR MEASURING AIR LEAKAGE IN HIGH-RISE APARTMENTS

by

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ABSTRACT

The balanced fan depressurization method has been modified to be applied to high-rise apartment buildings for measuring the overall air leakage and the wall air leakage of an apartment unit simultaneously. The method requires the use of two sets of fan pressurization apparatus. One is installed at the door of an apartment unit for measuring the air leakage rate of the exterior wall and a much larger apparatus is installed at an exterior door of the building for measuring the overall air leakage rate. The pressures between the test unit and the adjacent units are balanced to minimize the air leakage through the party walls by adjusting the air flow of the larger apparatus and the door openings of the adjacent apartments. The method was successfully applied to two high-rise apartment towers before and after they were retrofitted to improve air tightness of the envelope. In addition, the tracer gas decay method was applied to the same buildings to obtain the infiltration rates of selected apartment units.

The methods used to measure the air tightness values and the air infiltration rates, and the test results of the two apartment towers are discussed.

Keywords: Leakage, Pressure, Residential, Measurement, Fan, Tracer Gas.

INTRODUCTION

Two high-rise senior citizen apartment buildings, Buildings D and V, were experiencing significant deterioration of their exterior masonry. As air leakage was suspected as the major cause for the deterioration, the buildings were retrofitted to improve airtightness. To assess the effectiveness of the retrofit measures, the air leakage rates through the building envelope and through the exterior wall of one individual apartment unit in each building were measured both before and after the retrofit. The balanced fan depressurization technique [1] was modified to be able to measure the air leakage rates through the exterior wall of the individual apartment unit and through the envelope of the whole building simultaneously.

A method was developed, for use by building consultants and air sealing contractors, to estimate the air infiltration rate of an individual apartment unit based on its measured airtightness value and the pressure difference across its exterior wall. Tracer gas decay tests were conducted on two individual apartment units to determine the feasibility of the proposed method. This paper presents the test methods and results.

TEST BUILDINGS

Both buildings are constructed with reinforced concrete frames and double wythe brick masonry cladding. The exterior walls are 20.3 cm (8 in) thick masonry panels and are insulated on the inside. The 14-storey Building D was constructed in 1977. The 17-storey Building V, constructed in 1982, incorporates a cavity between the inner and outer wythes, in addition to the interior insulation. The two buildings are connected at the ground floor via a common foyer.

Each floor has seven apartment units on each side of a common corridor. Outdoor air is supplied to each corridor through a central supply-only ventilation system. Exhaust air leaves the building through the exhaust fans in the bath room and the kitchen of each apartment. Each building has two elevators and two stairwells. One stairwell in each building has an outside door at ground level.

TEST METHODS

Air Tightness Measurements

In each building, air tightness values of the building envelope and the exterior wall of one apartment unit were measured both before and after the retrofit. During the test of each building, the connecting ground-level door to the other building was sealed. The test methods are described below.

Overall Air Tightness

As shown in Figures 1 and 2, a large vane-axial fan was used to depressurize the test building. The fan airflow could be adjusted between 0 and 23 m^3/s (0 to 50,000 cfm). The fan inlet was connected by 12 m (40 ft) of 0.9 m (3 ft) diameter ducting to a plywood panel temporarily replacing the entrance door to a stairwell. All interior doors to the stairshaft were kept open to provide a free flow path for the air drawn by the fan from the floor spaces, through the stairshaft, to the outdoors.

The air flow rate was measured upstream of the fan intake using a pair of total pressure averaging tubes. Flow rate measurements are accurate to within 5% of the measured values. The pressure differences across the building envelope at both the ground and roof levels were measured using an electronic manometer with a strip chart recorder (accurate to within 5% of the measured values). The average of the two measured values was used to represent the mean pressure difference across the building envelope. Prior to and immediately after each test, the fan was sealed with a plastic sheet and the pressure differences across the envelope at the ground and top levels were measured. The two readings obtained at each location (one before and one after the test) were averaged to give the base readings of the pressure difference for the two locations. These base readings were then subtracted from subsequent pressure difference measurements to minimize weather effects (wind and stack action).

The two buildings were tested without their ventilation systems operating. The window air conditioners in Building D were removed for the tests. Those in Building V were left in place with their outdoor air dampers closed during the tests. In addition, all the windows in each building were closed tightly for each test.

Exterior Wall Air Tightness

Figure 2 is a schematic diagram of the test set-up to measure the air tightness of the exterior wall of an individual apartment and the air tightness of the whole building's envelope simultaneously. A small fan depressurization apparatus was connected to a plywood panel, replacing the apartment's entrance door, to draw outdoor air through the apartment's exterior wall, and exhaust it into the corridor. The entrance doors of the two immediately adjacent apartments were cracked open just enough to make the individual pressure differences between them and the tested unit approximately zero. This adjustment was made to minimize the air leakage through the common walls [1], and is fundamental to this technique. The pressure differences between the test unit and the units directly above and below were also measured during the tests to ensure that they were approximately zero. Under this 'balanced' condition, the air flow rate measured through the small fan depressurization apparatus is equal to the air leakage rate through the exterior wall of the test unit driven by the pressure difference across the exterior wall [1].

The air flow rates through the small fan were measured using a Meriam LFE laminar flow element accurate to within 5% of the measured values. The pressure differences across the exterior wall of the test unit and across the common walls it shares with the adjacent units were measured using an electronic micromanometer and a strip chart recorder. The accuracy of all pressure measurements is within 5% of the measured values.

Air Change Rate Measurement Method for Individual Apartment Units

The air infiltration rate in an individual apartment unit can be estimated with the following equation. It uses the measured air tightness value of the exterior wall and the pressure difference measured across it.

$$q = C \cdot (\Delta P)^n \qquad (1)$$

where,

q = air infiltration rate, L/s

C = flow coefficient, $L/(s \cdot Pa^n)$

ΔP = pressure difference across the exterior wall, Pa

n = flow exponent

In the above equation, the values of C and n for the test units were obtained from the fan pressurization tests described earlier. The pressure difference in this equation is that measured across the exterior wall of the apartment unit during normal operating conditions, i.e., during conditions under which the air infiltration rate is to be estimated.

The method was used to estimate the air infiltration rates in two apartments, one in each building. The pressure differences were measured with the same apparatus used for the fan pressurization tests. The outdoor pressure tap was installed on the exterior surface of the living room window and the indoor pressure tap was located near the centre of the test unit.

For comparison with the estimates, the air change rates in the test apartment units were measured using the tracer gas decay method, at the same time that the pressure differences were being measured. The tracer gas concentrations in the surrounding units and the pressure differences across the common walls were also measured during these tests. These data were used to estimate the flow rates and directions of any air exchange between the test unit and its surrounding units.

The tracer gas test procedure was as follows. A small amount of SF_6 gas was injected into the centre of the living room. A small desk fan was used to help mix the tracer gas with the indoor air. After allowing 30 minutes for mixing, 50 ml samples of the indoor air were collected manually, using a syringe, every 10 minutes at the centre of the room for at least one hour. A total of seven to ten samples were collected for each test.

Each sample is taken as follows. Just prior to the sample time, the 60 ml syringe is purged twice and then, at the sample time, used to draw in a 50 ml sample of air. The gas sample is then injected into a 20 ml evacuated glass test tube with a rubber septum-type stopper, of the same type used to collect blood samples in medical laboratories. In this way, the sample is stored under pressure. This pressure is relied upon to later drive the sample into an electron capture gas chromatograph for analysis.

The electron capture gas chromatograph was calibrated against gases with known concentrations. Four SF_6-air gas mixtures ranging from 1 ppb to 200 ppb were prepared in our laboratory for this purpose (the accuracy of the prepared gas mixtures could not be checked because no certified gas at such low concentrations is available.). To check the consistency of the preparation procedure, several gas mixtures of the same concentration were prepared using containers of different sizes so that different proportions of SF_6 and air were used. The agreement among these gases was within 5% of each other.

RESULTS AND DISCUSSION

Air Tightness Values

The overall air tightness values for both buildings, before and after the retrofit, are shown in Figure 3. The plotted results have been normalized by exterior wall area. The results indicate that the overall air tightness of each building was improved by the retrofit. They also show that Building V is leakier than Building D.

As the pressure difference across the envelope decreased with the building height due to the large flow resistance in the stairwell, the overall air leakage rate was presented in terms of the mean pressure difference across the envelope. The mean pressure difference was defined to be the average value of the pressure differences at the ground and top levels. To give some indication of the variation of the pressure differences along the building height, the pressure differences at the ground and top levels are given for a fan flow rate (air tightness value) which produced a mean pressure difference of about 50 Pa. For Building D (14 storeys), the air tightness value corresponding to a mean pressure difference of 53 Pa. was 2.25 L/s.m^2 (Fig. 3), and the pressure differences at the ground and top levels were 74 Pa. and 32 Pa. respectively. For Building V (17 storeys), the air tightness value, the mean pressure difference, and the pressure differences at the ground and top levels were 3.39 L/s.m^2, 50 Pa., 75 Pa. and 25 Pa. respectively.

The air tightness values of the exterior walls of the two individual apartment units are shown in Figure 4. The results indicate that, in both buildings, the improvement in the airtightness of the exterior wall of the tested apartment is much greater than that realized for the whole building. This suggests that the air leakage through the exterior walls for both buildings is not as important as that through their roofs and basements. Visual inspections suggest that some of the major leakage sites in the roof are the elevator shafts (and the smoke dampers in Building V).

A comparison between Figures 3 and 4 indicates that the normalized overall air tightness value was ~~greater~~ than the normalized exterior wall air tightness value. This is because the area of the exterior wall used to normalize the overall air tightness value includes the two side walls. The side walls (Figure 1) are expected to be much more air tight than the front and back walls because the window area to wall area ratio for the side walls is much smaller than that for the other walls. As well, the windows in the side walls are not openable.

Air Change Rates

Figure 5 shows the results of two typical tracer gas tests for each apartment unit, including the concentrations and pressure differences measured in the surrounding units. All four tests shown were made after the retrofits. Arrows are used to indicate the directions of the pressure differences between the test apartment units and their surroundings. The air infiltration rates were calculated from Eq.(1). The flow coefficients and exponents used for the calculation were 3.43 $L/s \cdot Pa^{0.61}$ and 0.61 for Apartment Unit 208, and 5.68 $L/s \cdot Pa^{0.5}$ and 0.5 for Apartment Unit 310. The results indicate that there were some inter-apartment air flows during these tests. A mass flow balance for the Unit Left apartment in Fig.5a, assuming an air infiltration rate of 19.6 L/s equal to that calculated in Unit 208, was made to estimate the air flow rate from Unit 208. The result of this mass flow balance indicated that the air flow rate from Unit 208 was about 0.1 L/s. Similar observations in the other adjacent units, for all the tests, suggest that these inter-apartment air flow rates were too small to be measured accurately.

The air infiltration rates of Apartment Units 208 (Building D) and 310 (Building V) were calculated based on the pressure differences across the exterior walls measured under various weather conditions. At the same times that the pressure differences were measured, the air change rates of the two apartment units were also measured using the tracer gas decay method. Although the measured air change rates included the effects of air inflows from the surrounding apartment units, the above discussion suggests that the contributions of the air inflows were negligible. Figure 6 shows a comparison between the calculated and the measured air infiltration rates. The results indicate that, for most cases, Eq.(1) estimates the air infiltration rate within 20%.

CONCLUSIONS

The balanced fan pressurization method was modified to measure the air leakage rates through the exterior wall of an apartment unit and through the entire building envelope simultaneously. This technique was successfully used to test two high-rise apartment buildings to assess the effectiveness of an air tightness retrofit.

A method was developed to estimate air infiltration rates of individual apartment units using measured air tightness values and measured pressure differences across the exterior walls. A comparison between the air infiltration rates calculated using this method and those measured by the tracer gas decay method indicates that, for most cases, the proposed method estimates the air infiltration rates within 20%.

ACKNOWLEDGEMENTS

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REFERENCES

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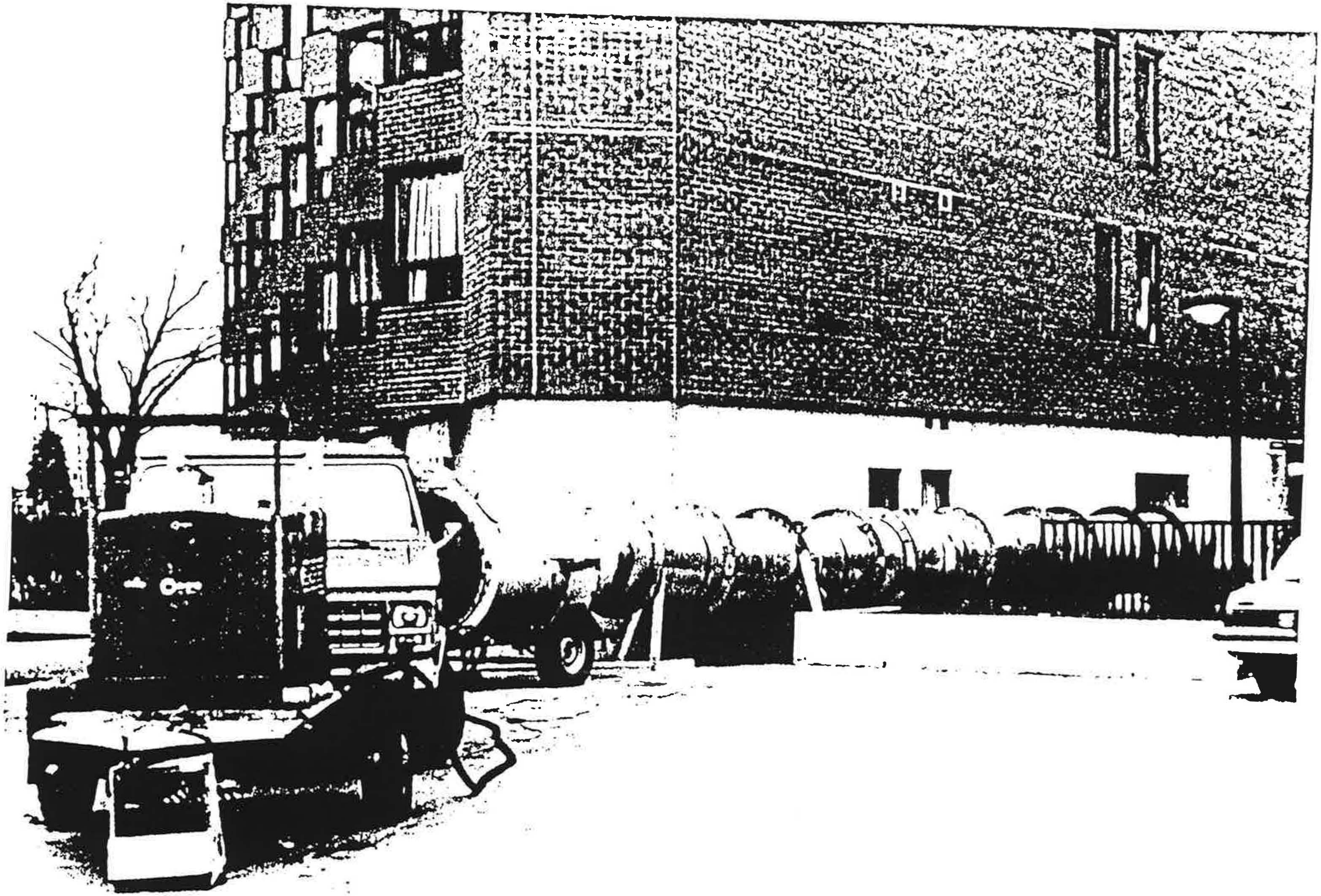

Figure 1 Building test set-up showing exhaust fan and duct connection

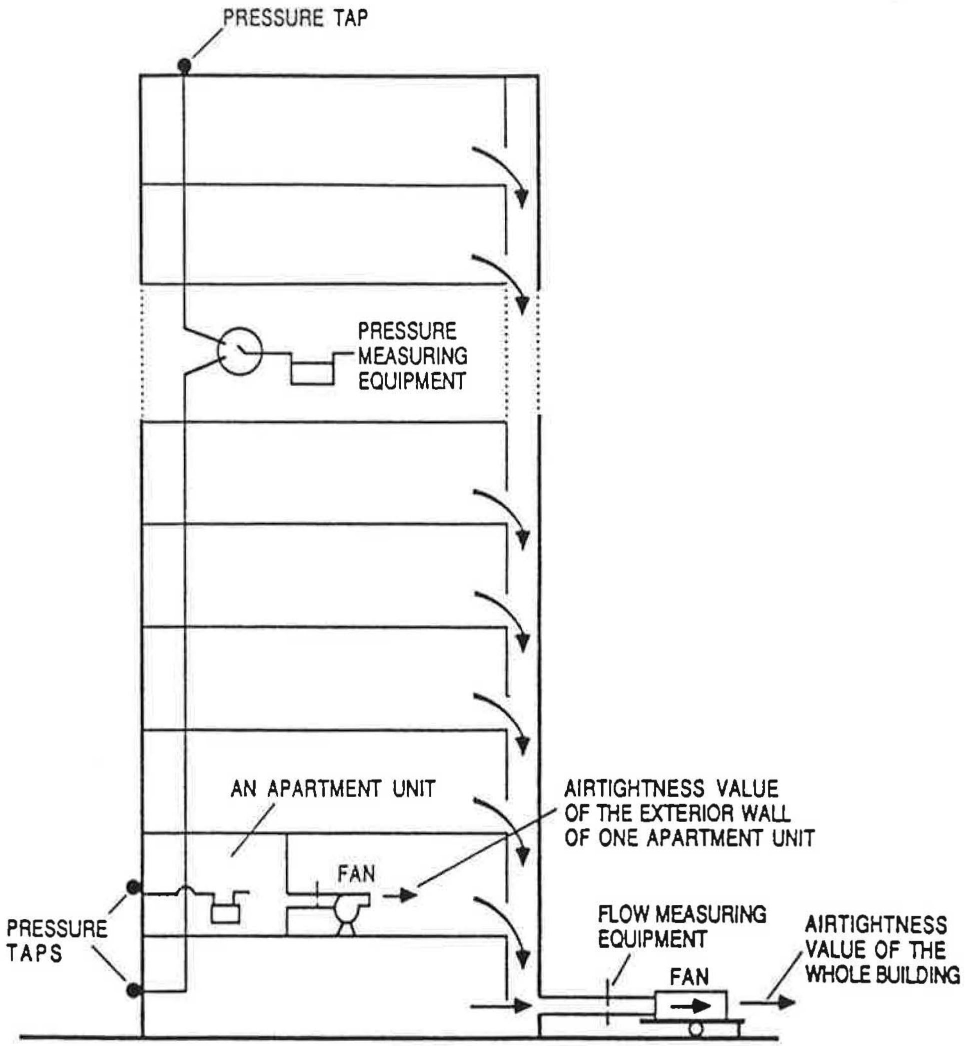

FIGURE 2

BUILDING TEST SET-UP SHOWING THE FAN PRESSURIZATION APPARATUS FOR MEASURING THE AIRTIGHTNESS VALUES OF THE WHOLE BUILDING AND AN APARTMENT

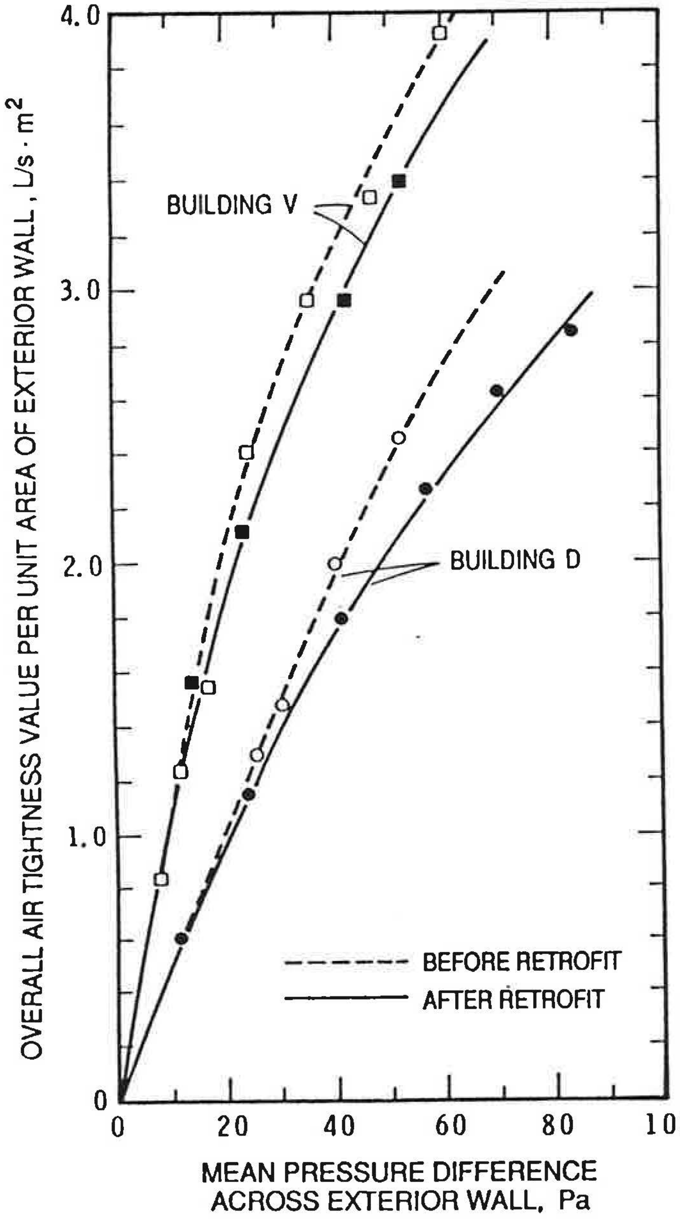

FIGURE 3

OVERALL AIR TIGHTNESS VALUE PER UNIT AREA OF EXTERIOR WALL

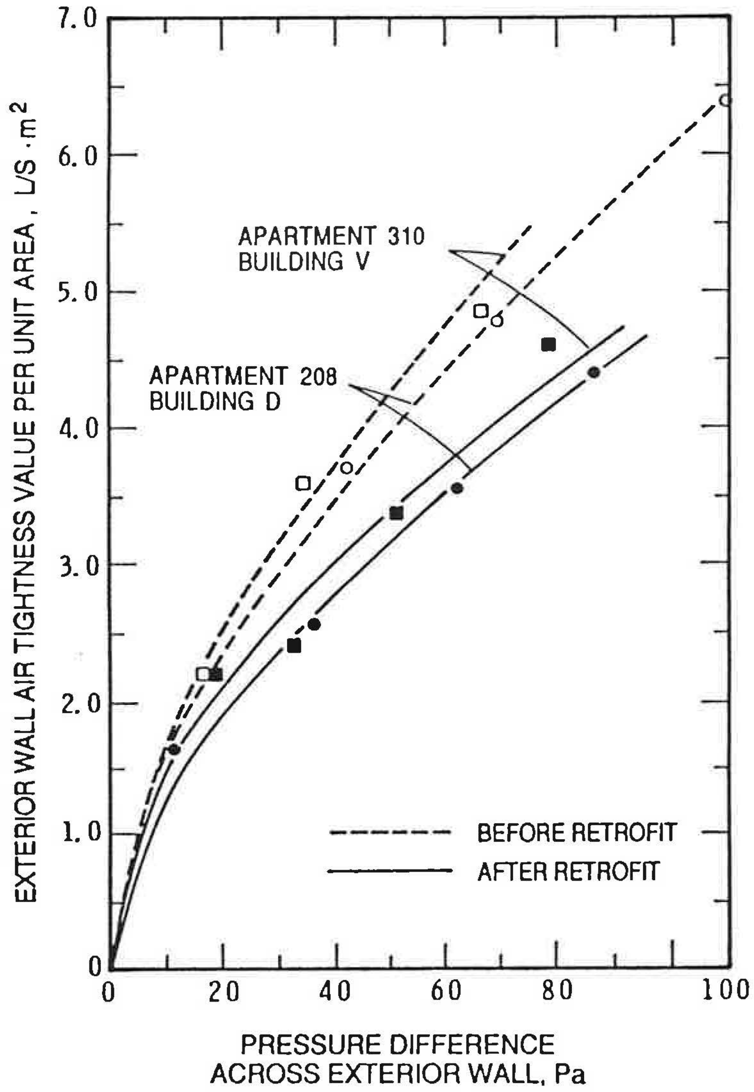

FIGURE 4

AIR TIGHTNESS VALUE OF EXTERIOR WALL PER UNIT AREA OF EXTERIOR WALL

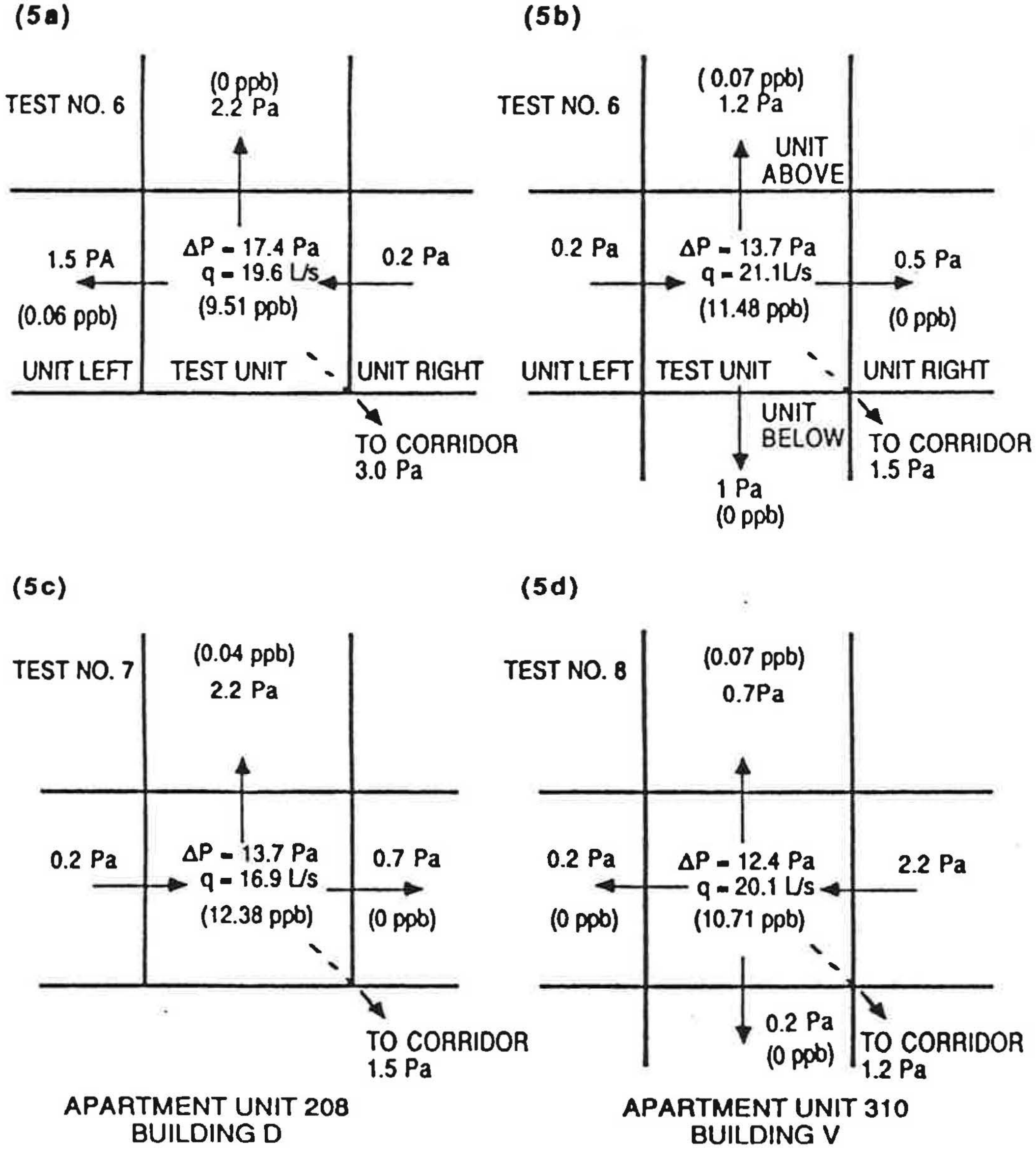

FIGURE 5

TRACER GAS CONCENTRATION, AIR FLOW DIRECTIONS AND CORRESPONDING PRESSURE DIFFERENTIALS

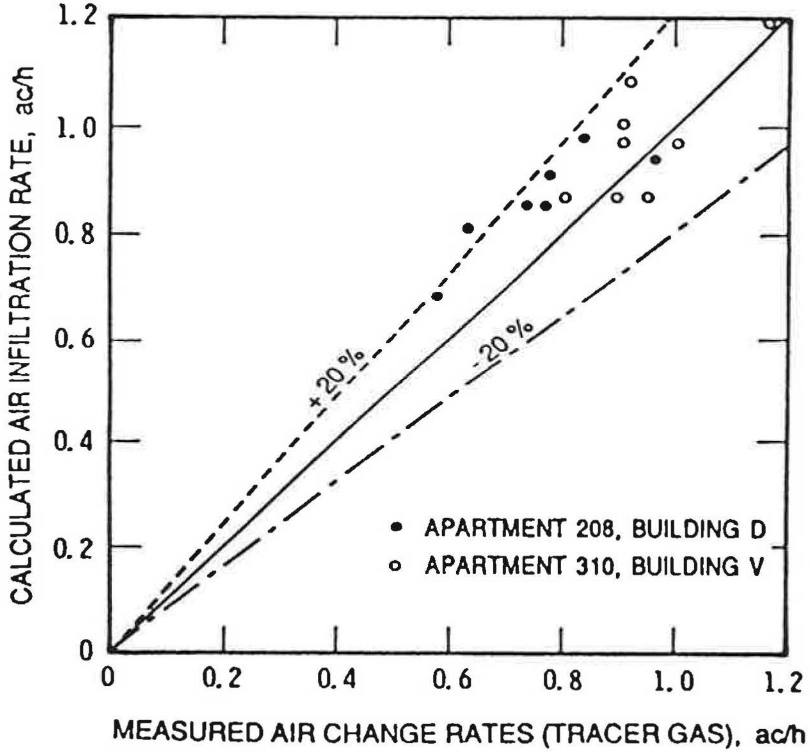

FIGURE 6

CALCULATED AIR INFILTRATION RATE vs MEASURED AIR CHANGE RATE