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OVERALL AND COMPONENT AIRTIGHTNESS VALUES OF A FIVE-STORY APARTMENT BUILDING

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ABSTRACT

Fan pressurization and balanced fan pressurization tests were conducted on a five-story apartment building to determine its air leakage characteristics. The overall airtightness of the building envelope and the airtightness values of the exterior walls of three individual stories were obtained, as well as the airtightness values of interior partitions, stairwells, and floor/ceiling separations. The methods used to measure the airtightness values are described, and the test results are reported.

INTRODUCTION

The envelopes and interior partitions of apartment buildings are not airtight. The cracks and openings in them permit some air leakage into and out of a building. They also allow the indoor air to flow from one area to another inside the building. These airflows contribute to the building's heating and cooling load and also to the transport of pollutants inside. With a renewed demand for energy conservation and a growing concern for indoor air quality, there is an increased need to understand and control such airflows.

Several airflow models have been developed for predicting such air movement (Kurabuchi et al. 1990; Said 1990). One of the major problems in applying these models is the lack of air leakage characteristics for various types of buildings, particularly for the interior partitions of high-rise apartment buildings. This paper describes a project carried out to measure the airtightness values (air leakage rates measured by the fan depressurization method) of the exterior walls and interior partitions of a five-story apartment building. The methods used and the results obtained are presented.

TEST BUILDING

Figure 1 *Test building showing test setup for measuring airtightness of the building envelope*

The five-story masonry building was constructed in 1981 (Figure 1 and Table 1). The building has a basement, a ground floor, and four typical stories. The basement houses a party room, a laundry room, storage areas, a transformer vault, and a mechanical room. Approximately half the ground floor is occupied by commercial tenants and is separated from the rest of the building. The garbage room is also located on the ground floor. Each typical story (second through fifth floors) has 12 apartment units—six on each side of a corridor (Figure 2). The elevator shaft, enclosed garbage chute, and electrical/service room are located at the center of the corridor. There are two stairwells, one on each end of the building. The south stairwell has a hatchway to the outside.

The building has a central heating and ventilating system that supplies air to the corridor of each story through two supply air registers. There are no return air grilles in the corridor. Return air is drawn into the heating and ventilating system through a dampered opening in the outdoor air supply duct inside the basement mechanical room.

TABLE 1
Description of Test Building

Year Constructed:	1981
Year Tested:	1989
Height (stories):	5
Wall Construction	
Exterior Wall:	80 mm (3 in) Face brick
	25 mm (1 in) Air space
	200 mm (8 in) Concrete block
	38 mm (1.5 in) Rigid glass fiber insulation
	Metal Studs
	38 mm (1.5 in) Semi-rigid glass fiber insulation
	Vapor Barrier
	12 mm (0.5 in) Gypsum board
Internal Wall:	13 mm (0.5 in) Gypsum board
	92 mm (3.5 in) Metal studs
	38 mm (1.5 in) Insulation blanket
	13 mm (0.5 in) Gypsum board

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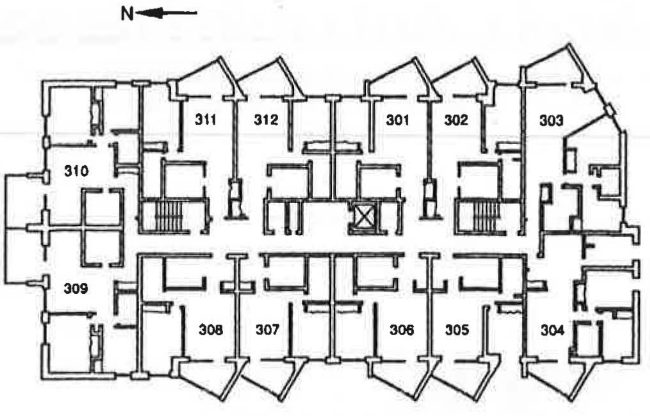


Figure 2 *Typical floor plan*

Each individual apartment unit is heated by a fan coil unit equipped with a hot water heating coil. There is no outdoor air supply to the fan coil unit or to individual apartment units. Ventilation air is drawn into the apartment unit from the corridor by discharging the indoor air to the outdoors through the kitchen and bathroom exhaust fans when they are operated by the occupants.

TEST METHODS

The test methods were modified from those developed previously (Shaw et al. 1973; Tamura and Shaw 1976; Shaw 1980; Shaw et al. 1990). A brief description of these methods is given below.

Airtightness Value of the Whole Building

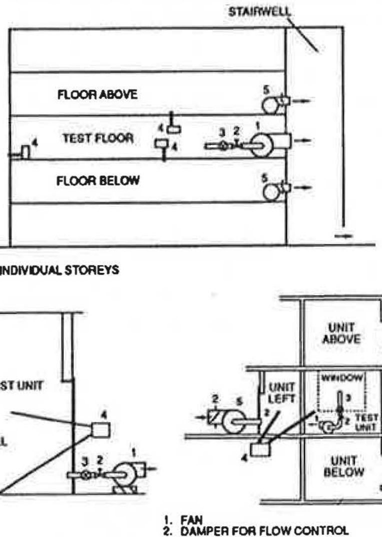
The overall airtightness value was measured using the fan depressurization method (Shaw 1980; Shaw et al. 1990). As shown in Figure 1, a large vane-axial fan was used to depressurize the test building. The fan airflow could be adjusted between 0 and 23 m^3/s (approximately 0 to 50,000 cfm). The fan inlet was connected by 12 m (39.3 ft) of 0.9 m (3 ft) diameter ducting to a plywood panel temporarily replacing a rear entrance door that connected to both stairwells. All interior doors to the stairwells were kept open to provide a free-flow path for the air drawn by the fan from the floor spaces through the stairwells to the outdoors. Because the building was fully occupied, for security reasons the entrance door to each apartment unit was kept closed during the test. A previous study conducted on a similar building had indicated that opening or closing the entrance door to each apartment unit had no effect on the measured overall airtightness values (Shaw 1980). During the test, the building's ventilation system was shut down (with fresh air intake dampers closed) and the dampers in all window air conditioners were closed. Also, the garbage room exhaust fan was shut off and the vent sealed, as was the vent to the transformer vault.

The airflow rate was measured upstream of the fan intake using a pair of total-pressure-averaging tubes. Airflow rate measurements are accurate to within 5% of the measured values, as determined during calibration by comparison with measurements using the pitot tube traversing method. 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 as specified by the manufacturer). The average of the pressure differences measured at the ground and roof levels was used to represent the mean pressure difference across the building envelope. Prior to and immediately after the test, the fan was sealed with a plastic sheet and the pressure differences across the envelope at the ground and roof levels were measured. These "base readings" were then averaged and subtracted from the test results to minimize weather effects (wind and stack action).

As an alternative to using a vane-axial fan, the supply fan of the building's heating and ventilating system can be used for the test in some cases (Shaw et al. 1973). To obtain meaningful results, the capacity of the supply fan should be sufficient to produce a minimum pressure difference across the building envelope of about 30 Pa. For conducting such a test, the heating and ventilating system is operated under 100% outdoor air by closing both the main return (and exhaust, if any) dampers. Different airflow rates, which are needed to produce four or five different pressure differences across the building envelope, can be obtained by adjusting the outdoor or supply air damper. This method was also applied to measure the airtightness of the building envelope. Very poor results were obtained due to insufficient capacity of the supply fan of the building's heating and ventilating system.

Airtightness Values of Exterior Walls and Floor/Ceiling Separations of Individual Stories

The balanced fan depressurization technique was used to measure the airtightness values of exterior walls and floor/ceiling separations of individual stories (Shaw 1980). As shown in Figure 3a, a variable-speed fan was used as the primary depressurization apparatus for a selected test story. The fan airflow could be adjusted between 0 and 1.3 m^3/s (0 and 2,750 cfm). The fan inlet was connected by 7.3 m (24 ft) of 0.46 m (1.5 ft) diameter ducting to a plywood panel temporarily replacing a stairwell door on the test story. The outside stairwell door at the ground floor was kept open during the test to allow the air from the test story to exhaust directly to the outdoors. The airflow rate was measured upstream of the fan intake with a pair of total-pressure-averaging tubes.



(a) INDIVIDUAL STOREYS

(b) INDIVIDUAL APARTMENT UNITS

Figure 3 *Test setup for measuring airtightness values of building components*

The pressure differences across the exterior wall of the test story and across the two floor/ceiling separations were each measured using an electronic manometer with a strip chart recorder. Two balancing fans with manual dampers were similarly installed in the stairwell doors to the stories above and below. These fans were used to control the pressures in these two stories and thereby control the flow of leakage air through the floor/ceiling separations into the test story.

For measuring the airtightness value of the exterior wall, the pressures in the test story and the stories above and below were balanced using the two balancing fans (Figure 3a) to minimize the flow of leakage air through the floor/ceiling separations into the test story. For measuring the airtightness values of floor/ceiling separations, two additional tests were conducted immediately after the above test. During each test, only one balancing fan was used; therefore, the pressure difference across only one floor/ceiling separation was reduced to zero. The pressure difference across the other floor/ceiling separation was measured simultaneously with the pressure difference across the exterior wall. The measured leakage rates during this test, therefore, included the exterior wall leakage of the test floor and that of the unbalanced floor/ceiling separation. By subtracting from the result the exterior wall air leakage rate at the same pressure difference across the exterior wall (this component could be calculated from the results of the first test), the airtightness value of the floor and ceiling separation at the measured pressure difference across the separation could be determined.

Airtightness Values of Interior Partitions and Floor/Ceiling Separations of Individual Apartment Units

The balanced fan depressurization method was also used to obtain the airtightness values of interior partitions and floor/ceiling separations of individual apartment units (Shaw 1980). As shown in Figure 3b, a fan was used to depressurize a selected test apartment unit. The fan airflow could be adjusted between 0 and 320 L/s (approximately 0 and 680 cfm). The fan inlet was connected by 3 m (10 ft) of 0.2 m (0.65 ft) diameter ducting to a plywood panel temporarily replacing the entrance door of the test unit. All interior doors in the apartment unit were kept open and all exhaust fans (e.g., kitchen and bathroom exhaust fans) were turned off and their grilles sealed. The airflow rate was adjusted with a manual damper and measured upstream of the fan intake with a pair of total-pressure-averaging tubes. The pressure differences across the exterior wall and interior partitions were measured using an electronic manometer with a strip chart recorder.

In addition, four balancing fans with manual dampers were installed, one for each adjacent unit (Figure 3b). By adjusting the airflow rate through each balancing fan until the pressure difference across the corresponding partition wall or floor/ceiling separation was reduced to zero, the air leakage through that component could be reduced to zero. Ideally, a fifth balancing fan could be used to balance the pressures between the corridor and the test apartment unit, thereby eliminating the leakage of air through the corridor wall. In order to avoid occupant complaints, this application of a fifth balancing fan was not carried out. As a result, the exterior wall airtightness values of individual apartment units were not measured.

Six tests were conducted, one after the other. The first test was a simple fan depressurization test in which all four balancing fans were off and sealed. The results were, therefore, the overall airtightness values of the test apartment unit (excluding its entrance door, which was replaced by a sheet of plywood for installing the pressurization fan). In the second test, all four balancing fans were used to reduce the pressure differences between the test unit and its four adjacent units to zero. The results were the combined airtightness values of the exterior wall and the corridor partition (excluding the entrance door) at measured pressure differences across the exterior wall.

Four more tests were conducted immediately after the second test. The test procedures were similar to those for individual stories; i.e., in each test, only one balancing fan was shut down and sealed and the pressure differences across the unbalanced component and across the exterior wall were measured simultaneously. The results of these four tests and those obtained from the second test were used to determine the airtightness values for the unbalanced building component using the same method as described for the floor/ceiling separations of individual stories.

Airtightness of Stairshafts

The method for stairwell leakage determination has been reported by Tamura and Shaw (1976). Similar to the test for the whole building (Figure 1), the fan with a maximum capacity of 1.3 m^3/s (2,750 cfm) was ducted to a plywood panel temporarily replacing an outside stairwell door. All other doors to the stairwell were kept closed (but not sealed).

The airflow rate was measured upstream of the fan intake using a pair of total-pressure-averaging tubes. The pressure differences across the stairwell wall were measured at the ground, third, and fifth floors by inserting the probe into the stairwell through the crack around the door. Again, an electronic manometer with a strip chart recorder was used. The measured values were averaged to represent the mean pressure difference across the shaft. Base readings to correct for weather effects (wind and stack action) were conducted as described for the measurement of overall airtightness value.

RESULTS AND DISCUSSION

The airtightness of the building, three individual stories, ten individual apartment units, and two stairwells was measured. The measured results are presented below.

Airtightness Value of the Whole Building

Figure 4 shows the overall airtightness values per unit area of exterior wall. Also shown are the results obtained with the alternate method of using the building's heating and ventilating system to pressurize the building interior. The results indicate that at the maximum flow rate of 1,280 L/s (2,700 cfm) available from the HVAC system, the pressure difference across the building envelope was about 3 Pa (0.012 in. of water), which was inadequate to produce meaningful results.

For comparison, the measured overall airtightness values of three other apartment buildings are also shown in Figure 4 (Shaw 1980; Shaw et al. 1990). Buildings A, D, and V are 5, 14, and 17 stories high, respectively. The results indicate that the overall airtightness value of the test building is almost the same as that of Building V and is about 60% and 100% greater than those of Buildings A and D at 50 Pa (0.2 in. of water) and 10 Pa (0.04 in. of water), respectively.

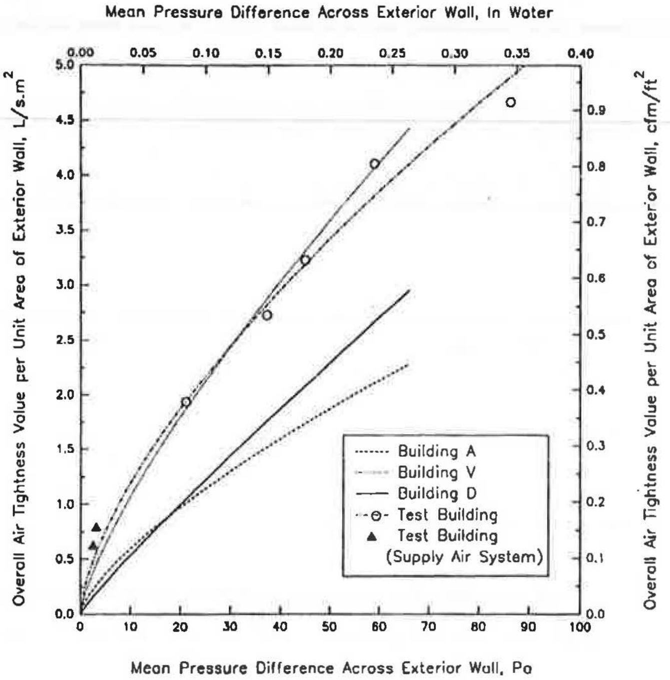


Figure 4 ***Overall airtightness values***

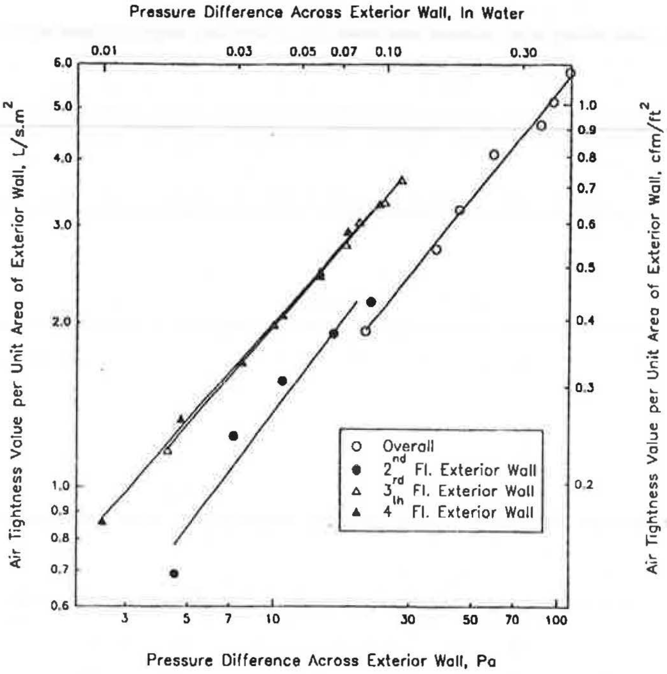


Figure 5 ***Overall and individual floor exterior wall airtightness values***

Airtightness Values of Individual Stories

Exterior Walls Figure 5 shows the airtightness values of the exterior walls of the second, third, and fourth stories. Again, the plotted results were normalized by the exterior wall area of the individual stories. As shown, the airtightness value of the second story was about 25% smaller and, therefore, more airtight than that of the other two stories. Such a variation in results was likely caused by the conditions of windows and patio doors, which varied from apartment unit to apartment unit. For comparison, the overall airtightness value of the whole building was also included in Figure 5. The overall airtightness value per unit area of exterior wall was about the same as that of the second floor and was smaller than those of the other two stories. One reason for the discrepancy was that a significant part of the ground floor, occupied by commercial tenants, was separated from the building (i.e., no doors connecting the commercial units to the building). As a result, the exterior wall airtightness value of the ground floor would be smaller than that of the upper floors. This, in turn, would result in a smaller overall airtightness value for the whole building.

Floor/Ceiling Separations Figure 6 shows the airtightness values of floor/ceiling separations for the ground/second, second/third, and third/fourth floors. All results were normalized by the floor area of the individual stories. The data showed a relatively high degree of scatter when compared with the results for the exterior wall airtightness determinations. This was probably because the exterior wall airtightness values were approximately nine times greater than those of the floor/ceiling separations. As the airtightness values of floor/ceiling separations were obtained indirectly by subtracting the exterior wall leakage from the overall value, a small error in these measurements would result in a large error in the airtightness values of floor/ceiling separations.

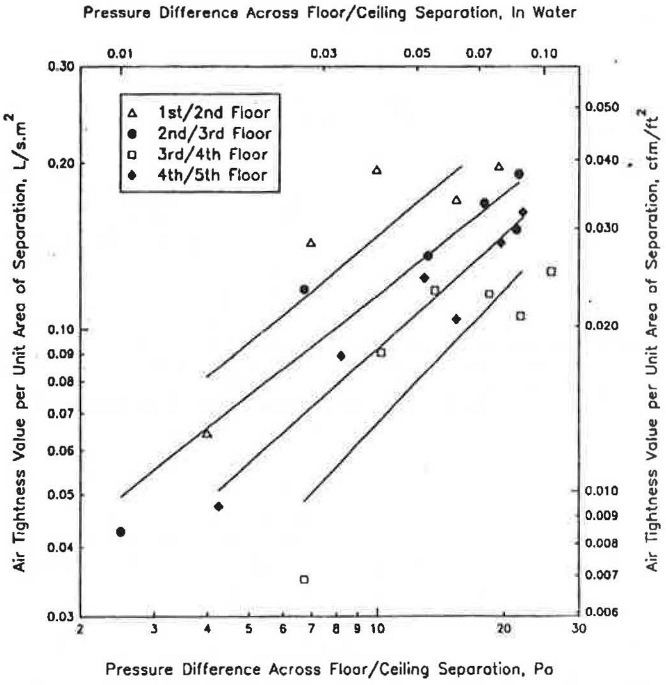


Figure 6 ***Airtightness values of floor/ceiling separation for individual stories***

Individual Apartment Units Ten apartment units on the third story were tested. Of the ten, permission was obtained to test six apartment units extensively to determine the airtightness values of individual interior partitions, floor/ceiling separations, and the exterior wall (which includes the corridor wall leakage). In addition, the overall airtightness values of these units were also measured independently. Figure 7 shows typical results of one of these series of tests. The sum of the individual component air leakage rates was approximately equal to the indepen-

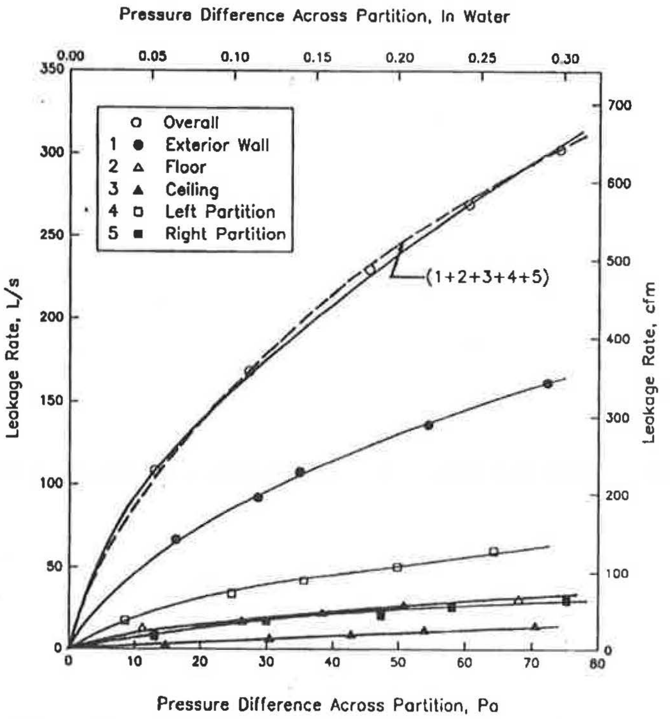


Figure 7 *Overall and partition air leakages for apartment 307*

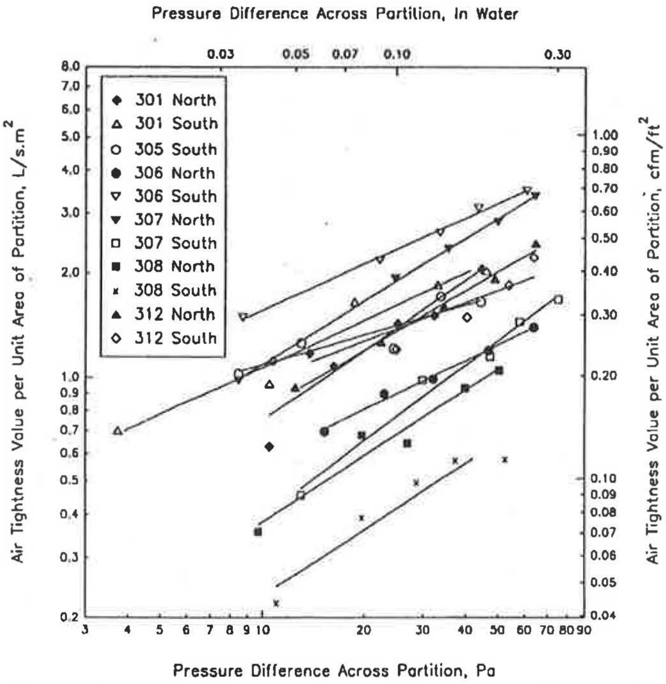


Figure 8 *Airtightness values of interior partition for individual apartment units*

dently measured overall value. Similar results were also obtained for the other five tested apartment units.

Figure 8 shows the airtightness values for the interior partitions. The results were normalized by the areas of the partitions. As shown, the measured airtightness values for interior partition walls at 50 Pa (0.2 in. of water) varied from 0.65 (Unit 308 South) to 3.1 L/s·m² (Unit 306 South) (0.13 to 0.61 cfm/ft²).

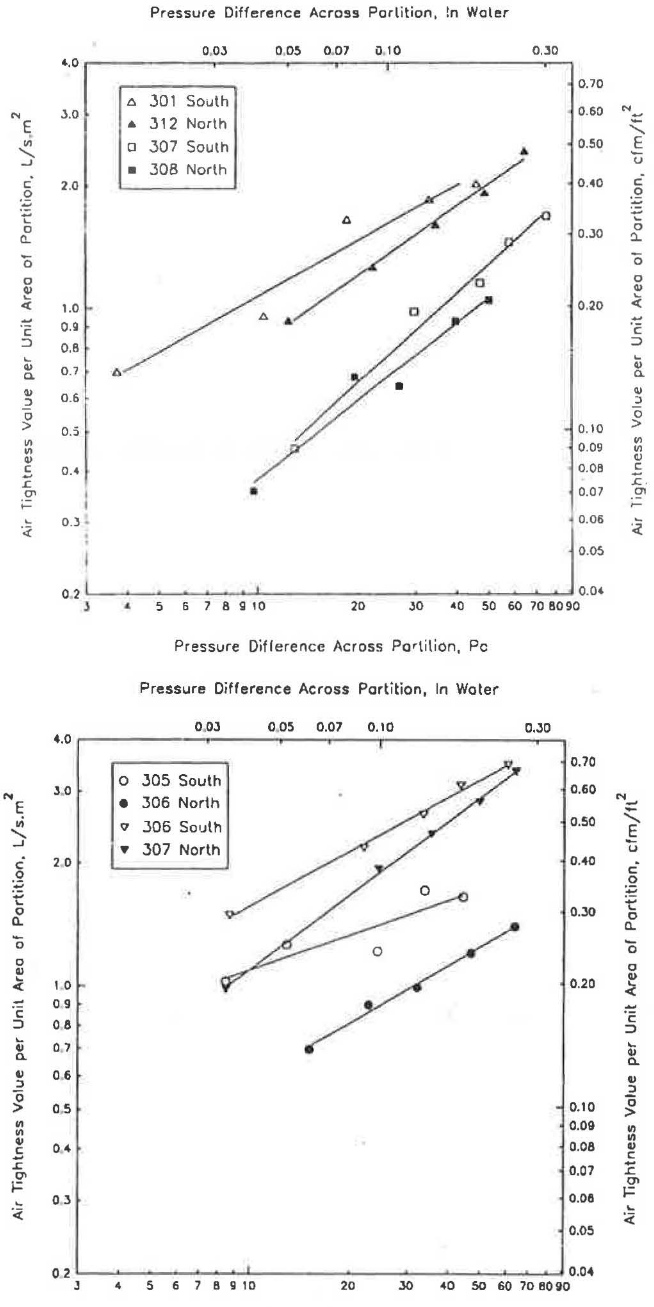


Figure 9 *Repeatability of airtightness measurements for interior partitions*

Four partitions were each measured twice during this series of tests, as these partitions are each shared by two adjacent apartment units. The two results of each of the four partitions are shown in Figure 9. As shown, except for the partition between apartment units 305 and 306, the results of the two tests agreed within 20% of each other at pressure differences greater than 20 Pa (0.08 in. of water). The discrepancy was likely caused by having obtained the airtightness result indirectly by taking the difference between the overall value and the overall value less that of the test component. As both values were much larger than the airtightness value of the partition, a small error in these measurements would result in a large error in the final result.

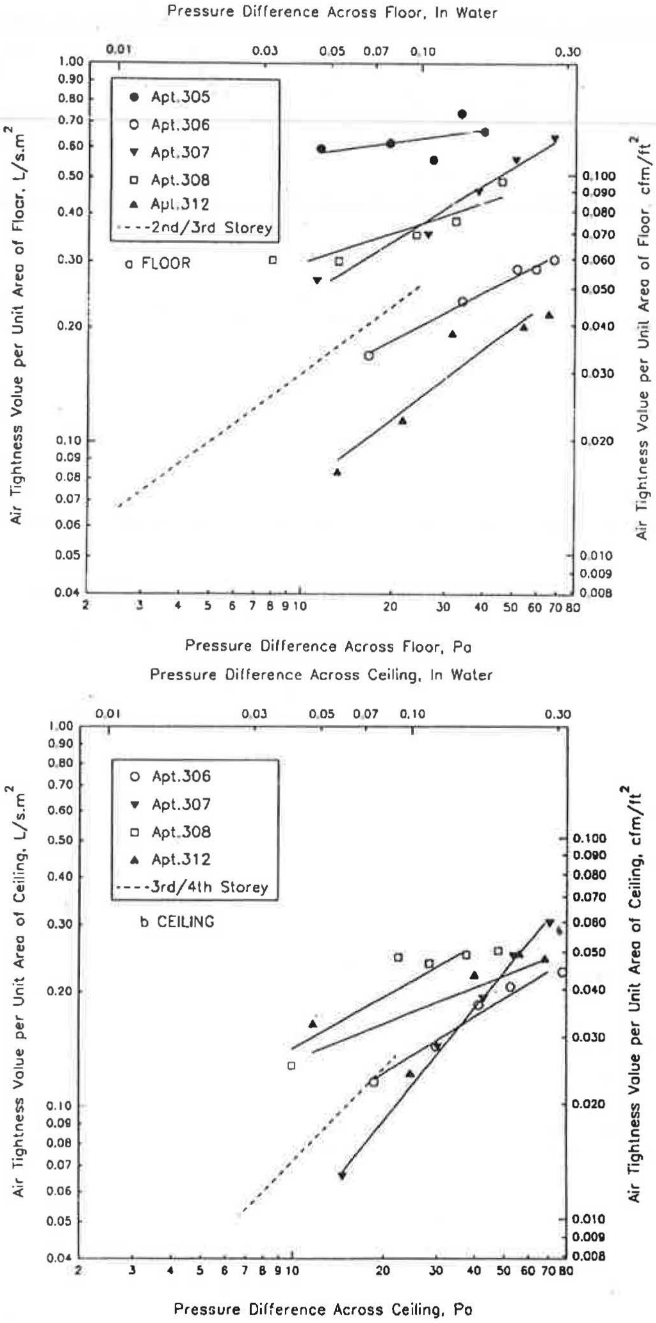


Figure 10 *Airtightness values of floor and ceiling for individual apartment units*

Figures 10a and 10b show the airtightness values of floor and ceiling separations, respectively, for individual apartment units. The results also indicate that the measured airtightness values for floor/ceiling separations at 50 Pa (0.2 in. of water) varied from 0.18 (Unit 306) to 0.68 L/s·m² (Unit 305) (0.035 to 0.13 cfm/ft²). The ceilings for this story seem to be much more airtight than the floors. The measured floor and ceiling airtightness values for the third story also indicated the same trend. No obvious reason could be found to explain the difference.

Stairwells The airtightness of two stairwells is shown in Figure 11. The south stairwell, which contains the roof access hatch, was approximately 40% leakier than the north stairwell.

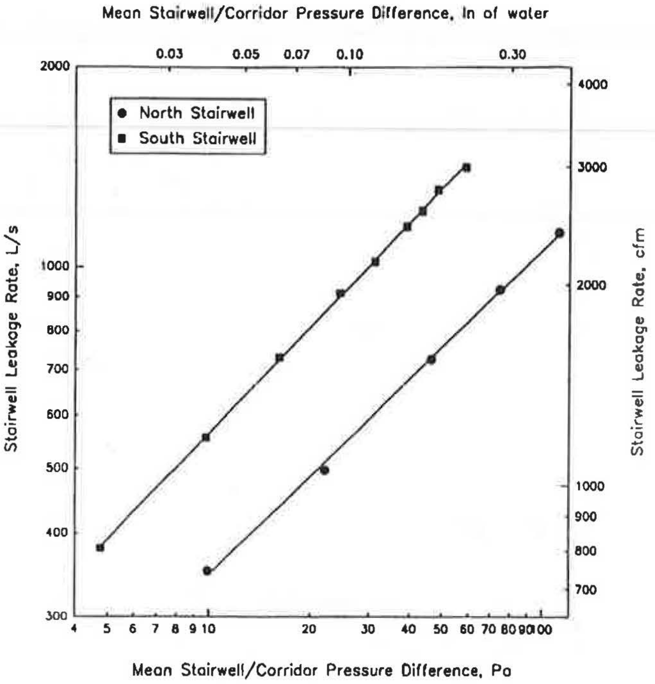


Figure 11 *Airtightness values for stairshafts*

Possible Applications of the Data

Strictly speaking, these kinds of data are valid only for the buildings or components tested. For applications where an accurate estimate of the air leakage characteristics of a specific building is needed (e.g., airflow model validation), the only way to obtain the data is by measurement. It is not likely that a correlation between airtightness values and designs of wall construction can be developed (Shaw and Jones 1979). This is because most wall construction consists of a vapor barrier and a painted interior finish (e.g., a painted drywall). As such a combination is much more airtight than other materials (e.g., bricks or concrete blocks), the airtightness value of a wall assembly is dependent on how well the vapor barrier/interior component is installed. Therefore, the materials used to construct the exterior portion of a wall assembly would not likely have a significant influence on its air leakage characteristic. As indicated in Figure 4, the overall airtightness values of four buildings with different wall constructions are not very different from each other.

The leakage data, while specific to the building tested, can be used for design purposes (e.g., estimating air infiltration rates for sizing HVAC equipment or predicting air leakage rates through interior partitions for designing smoke control systems). For such applications, the designers need a complete data set, such as the one reported for conducting sensitivity studies.

SUMMARY

The airflow capacity of the building's heating and ventilating system was insufficient to be used for measuring the airtightness value of the building envelope. Before planning to use the building's HVAC system for such measurements, it is advisable to measure the maximum airflow rate and the maximum pressure difference it can develop across the envelope.

Because windows and doors are not uniformly distributed in the building envelope, tests to measure the overall airtightness value (conducted on the whole building) and the exterior wall airtightness values of individual stories often produce different results. For this building, the overall airtightness value for the whole building at 50 Pa was 3.1 L/s·m² (0.6 cfm/ft²). The measured exterior wall airtightness values for individual stories at 50 Pa (0.2 in. of water) varied from 4.0 to 5.1 L/s·m² (0.79 to 1.0 cfm/ft².

The measured airtightness values for the building components of individual apartment units varied from component to component. For this building, the measured airtightness values for interior partition walls and floor/ceiling separations at 50 Pa (0.2 in. of water) varied from 0.65 to 3.1 L/s·m² (0.13 to 0.61 cfm/ft²) and 0.18 to 0.68 L/s·m² (0.035 to 0.13 cfm/ft²), respectively.

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