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AIRFLOW PATTERNS IN A FIVE-STOREY APARTMENT BUILDING

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1. SYNOPSIS

Tracer gas tests were conducted on a five-storey apartment building to determine the air and contaminant flow patterns within the building. The test method involves the injection of a small amount of tracer gas, SF_6, into a selected location to create a single source and monitoring the tracer gas concentrations at locations throughout the building. Based on the rates at which the tracer gas concentrations change at various locations, the air and contaminant flow patterns within the building can be determined. Several such tests were conducted. In each test, the tracer gas was injected into one of three locations: a garbage room on the ground floor, a party room in the basement and the supply air duct of the building's heating and ventilating system.

This paper presents the results of the tracer gas tests. It also includes measurements of the overall airtightness of the building envelope, the exterior wall airtightness values of three individual storeys, and the airtightness values of interior partitions, stairwells and floor/ceiling separations.

2. INTRODUCTION

Most high-rise apartment buildings have a central heating and ventilating system to supply outdoor air to the corridors and common areas only. Such a system is designed to pressurize the corridors and common areas of an apartment building which forces the air from the corridors into individual apartments and utility rooms. The intention is to prevent odours or contaminants generated in these areas from migrating to other areas. However, the pressures in the corridors are often inadequate for the system to function as designed. As a result, the air driven by stack action and/or wind can flow from one apartment to another and from one storey to another through corridors and vertical shafts. Non-uniform temperature distributions and odours are two common problems in high-rise apartment buildings caused by such air movement. With a renewed interest in energy conservation and a growing concern for indoor air quality, there is an increased need to understand and control such airflows.

An experimental study has been undertaken to determine the air leakage characteristics and airflow patterns of a 5-storey apartment building. The air leakage characteristics of the building envelope and its interior partitions have been discussed in another paper[1]. This paper presents the results of the airflow measurements. The objectives were to determine (a) the contaminant migration patterns from a source to other locations and (b) the outdoor air distribution through the central heating and ventilating system. In addition, the measured airtightness values of this building's exterior envelope and interior partitions are also included, so that the data can be used to check various airflow models which have been developed for predicting such air movement[2].

3. TEST BUILDING

The five-storey masonry building was constructed in 1981 (Figure 1 and Table 1). The building has a basement, a ground floor, and four typical storeys. 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 storey (second through fifth floors) has 12 apartments - 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 roof.

The building has a central heating and ventilating system that supplies air to the corridor of each storey through two supply air registers. There are no return air ducts, but there is a dampered opening in the outdoor air supply duct of the heating and ventilating system inside the basement mechanical room. Some indoor air can be drawn into the heating and ventilating system through this opening.

Each individual apartment is heated by a fan coil unit equipped with a hot water heating coil. There is no outdoor air supply to the fan coil units or to individual apartments. When the kitchen and/or bathroom exhaust fans are operated, some air is drawn into the apartment from outside and from the corridor as ventilation air.

4. TEST METHODS

Tracer gas tests were conducted to determine the air and contaminant flow patterns within the building. These tests involved the injection of a small amount of tracer gas, SF_6, into a selected location to create a source and monitoring of the tracer gas concentrations at locations throughout the building. For determining the distribution of the ventilation air, the tracer gas was injected into the building's heating and ventilating system. For monitoring the dispersion pattern of a contaminant, the tracer gas was injected into either the garbage room (a known source of contamination) or the party room (representing an atypical apartment).

Immediately after the injection, the tracer gas concentrations at each storey were measured at 10-minute intervals. The sampling locations, shown in Figure 2, were the centre of the corridor, the south stairwell, and two apartments at each side of the corridor. The measured tracer gas concentrations at each sampling location were plotted against time to indicate the magnitude and rate at which it dispersed to other locations.

5. RESULTS AND DISCUSSION

5.1 Air Leakage Characteristics

Fan pressurization and balanced fan pressurization tests[3,4] were conducted to obtain the air leakage characteristics of the building envelope and interior partitions[1]. The results indicated that the overall airtightness value for the whole building at 50 Pa (0.2 in. of water) was 3.1 L/s·m² (0.6 cfm/ft²). The exterior wall airtightness values for individual storeys 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 interior partition walls and floor/ceiling separations at 50 Pa 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. Table 2 presents the results in terms of flow coefficient, C and exponent, n as defined by the equation,

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

where,

q = airtightness value (air leakage rate), L/s

C = flow coefficient, $L/(s \cdot m^2 \cdot Pa^n)$

A = area of test component, m^2

ΔP = pressure difference across the exterior wall, Pa

n = flow exponent.

More than thirty interior partitions and floor/ceiling separations were tested; only the minimum, average and maximum airtightness values are reported in Table 2 for each of these two component types. These values were determined from the measurements using Eq.(1) with a typical flow exponent of 0.65.

5.2 Contaminant Dispersion

Figures 3 through 8 show how a contaminant, which was represented by the tracer gas, dispersed from the ground floor garbage room (located on the east side of the building) to other areas within the building. During the test, the building's heating and ventilating system operated normally, the outdoor air temperature was 11°C, and the wind speed about 17 km/h from the southeast first and then changed to the south shortly after the tracer gas injection. The results indicate that concentrations of the tracer gas in the corridor of every floor increased rapidly, while concentrations in individual apartments increased at a slower rate. The results suggest that the contaminant (tracer gas) in the garbage room moved upwards via the garbage chute mainly due to the action of stack effect. The contaminant then dispersed into the corridors and it was subsequently carried by the airflow from the corridors into individual apartments. The effect of wind on the tracer gas concentrations in individual apartments was minimal because of the wind direction (parallel to the exterior walls of the apartments).

The test was repeated in June to minimize stack effect. During the test, the wind blew from the south at 6 km/h and the outdoor air temperature was 22°C. As an example, Figure 9 shows the concentration profiles for the 3rd floor. Similar to the winter results (Figure 6), the contaminant dispersed rapidly into the corridors and more slowly into individual apartments. However, the concentrations in individual apartments were generally lower than the winter results, suggesting a reduced stack effect. The contaminant movement was probably due to the rise of warm contaminant-laden air from the garbage room up through the chute. The garbage room tends to be much warmer than the rest of the building and outdoors because it is located at the centre of the southwest (sunny) side of the building at ground level and has no windows.

Figure 9 also shows that at certain periods of time, the tracer gas concentration in Apt.311 was greater than that in the corridor. This was probably because the kitchen or bathroom exhaust fan was in operation during this period of time. As the sampling location for this apartment was closer to the garbage chute than that the corridor sampling point, the operation of the exhaust fans could produce such a situation.

Both the winter and summer test results suggest that the capacity of the building's heating and ventilating system is inadequate to pressurize the corridors sufficiently to prevent the air in the garbage chute from entering the corridors. Any contaminant generated in the garbage room will, therefore, migrate into individual apartments via mainly the garbage chute and the corridors. The extent and rate of this migration will depend on stack action and the use of exhaust fans in the apartments.

Another series of tests with the basement party room as the source location were conducted to investigate the contaminant dispersion pattern for a source location with no direct links to other floors (e.g., a garbage chute as in the previous case). The wind blew from the northwest at 24 km/h and the outdoor air temperature was -6°C during the winter test. As shown in Figures 10, 11 and 12, the tracer gas concentration in the basement corridor increased sharply immediately after the tracer gas injection. The concentrations in the corridors of the upper floors also increased, but at a lower rate. As the main return inlet for the building's heating and ventilating system is located in the basement mechanical room, it was likely that the tracer gas migrated into the corridors of the upper floors through the building's heating and ventilating system.

The effects of wind and stack action on the tracer gas (contaminant) concentrations in individual apartments for this case are more visible than for the previous case because of the wind direction and lower outdoor air temperature. For example, the tracer gas concentration was almost zero in Apt.202 where the wind and stack action worked together to prevent the corridor air from entering. On the other hand, the tracer gas concentration in the apartment directly downstream of Apt.202 (i.e., Apt.205, across the hall) was considerably higher, because being on the leeward side the wind and stack action worked against each other. The resultant air pressure in Apt.205 was not strong enough to prevent the corridor air from entering.

5.3 Outdoor air distribution by the ventilation system

Figures 13 and 14, show the outdoor air distribution test results. The tracer gas was injected into the supply air duct of the heating and ventilating system. During the test the wind blew from the west at 24 km/h and the outdoor air temperature was -16°C. As shown, the tracer gas migrated rapidly into the corridors first and then into individual apartments. The results also show that there was a large difference in tracer gas concentration between Apt.202 (2nd floor) and Apt.502 (5th floor, directly above Apt.202). Both apartments are located on the west side of the building. At the second floor, the west wind and stack effect acted together to pressurize the apartment. The air pressure inside the apartment was, therefore, strong enough to prevent the corridor air from entering this apartment. On the other hand, at the fifth floor, the wind and stack effect worked against each other, resulting in the pressure inside the apartment being inadequate to prevent the corridor air from entering, and causing an increase in the tracer gas concentration inside the apartment.

The results suggest that the building's heating and ventilating system is effective at distributing the outdoor air into the corridor of every floor. However, the capacity may not be adequate to overcome the effect of wind and stack action to force the corridor air into individual apartments as designed. Therefore, under certain weather conditions, the air and hence odour or contaminants in the apartments can leak into the corridor and move to other apartments via stairwells or other vertical shafts. On windy days, the air or contaminants can also move from an apartment on the windward side horizontally across the corridor to the apartments on the leeward side.

6. SUMMARY

Tracer gas tests were conducted in a five-storey apartment building to determine the air and contaminant flow patterns within the building. The results are summarized as follows:

Contaminants generated in the garbage room would migrate into the corridors via the garbage chute and its connections to the corridors. Once in the corridor, the contaminants would be carried by the corridor air to other apartments. Any means to lower the pressure in the garbage chute relative to the corridors would be helpful in preventing the contaminants migrating into individual apartments, such as a dedicated exhaust fan for the garbage room, vented directly outdoors.

The wind and stack effect could force contaminants generated in the party room or individual apartments into the corridor of the same floor. Once in the corridor, those contaminants can then be carried by the corridor air to other apartments.

The building's heating and ventilating system was effective at distributing the outdoor air into the corridor of every floor, but the capacity was inadequate to overcome the effect of wind and stack action and force the corridor air into all apartments. As a result, any contaminant generated in the apartments or utility rooms could get into the corridors. The amount would depend on wind speed and direction, stack action and the use of exhaust fans in the apartments.

7. REFERENCES

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2. Said, M.N. 1990, "Air and smoke movement model for tall buildings", Internal Report, Institute for Research in Construction, NRC.

3. Shaw, C.Y., Gasparetto, S. and Reardon, J.T. 1990, "Method for Measuring Air Leakage in High-Rise Apartments", in STP 1067 Air Change Rate and Airtightness in Buildings, ed. M.H. Sherman, American Society for Testing and Materials, pp.222-230.

4. Reardon, J.T., Kim, A.K. and Shaw, C.Y. 1987, "Balanced Fan Depressurization Method for Measuring Component and Overall Air Leakage in Single- and Multifamily Dwellings", ASHRAE Transactions, Vol.93, Part 2, pp.137-152.

8. ACKNOWLEDGEMENTS

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TABLE 1

Description of Test Building

Year Constructed:	1981
Year Tested:	1989
Height (storeys):	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
	13 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

TABLE 2

Airtightness Values

	C $L/s \cdot m^2 \cdot Pa^n$	n
Whole Building		
Building Envelope (Overall)	0.264	0.66
Individual Storeys		
Exterior Wall		
Second Storey	0.277	0.73
Third Storey	0.486	0.61
Fourth Storey	0.506	0.60
Floor/Ceiling Separation		
First/Second Floor	0.036	0.64
Second/Third Floor	0.035	0.54
Third/Fourth Floor	0.013	0.76
Fourth/Fifth Floor	0.02	0.69
Individual Apartments		
Internal Partitions		
Minimum	0.052	0.65
Average	0.147	0.65
Maximum	0.286	0.65
Floor/Ceiling Separation		
Minimum	0.015	0.65
Average	0.032	0.65
Maximum	0.045	0.65
Stairwells		
North	0.492	0.5
South	0.755	0.53

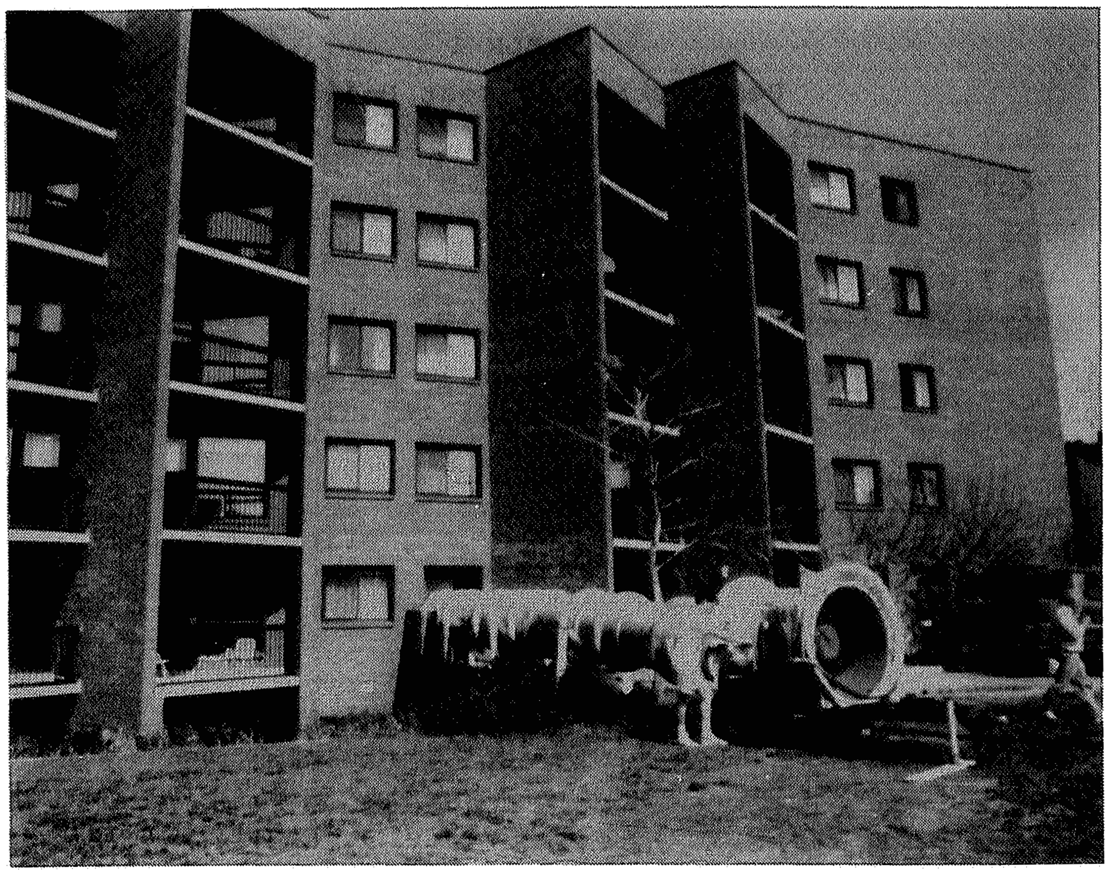

Figure 1 Test Building

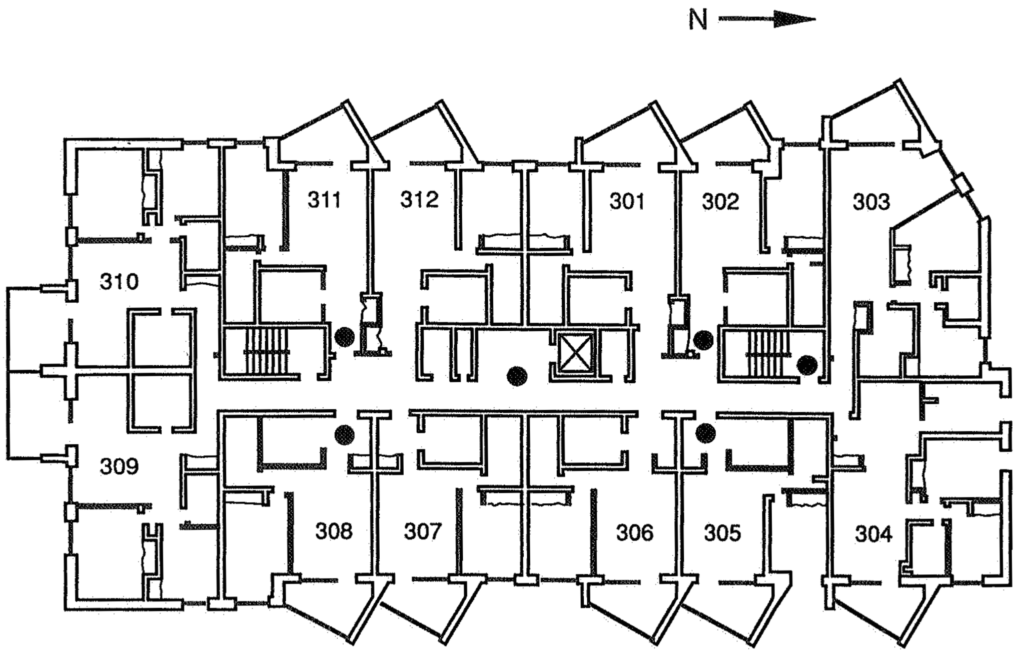

Figure 2

Floor plan of a typical floor showing tracer gas sampling locations.

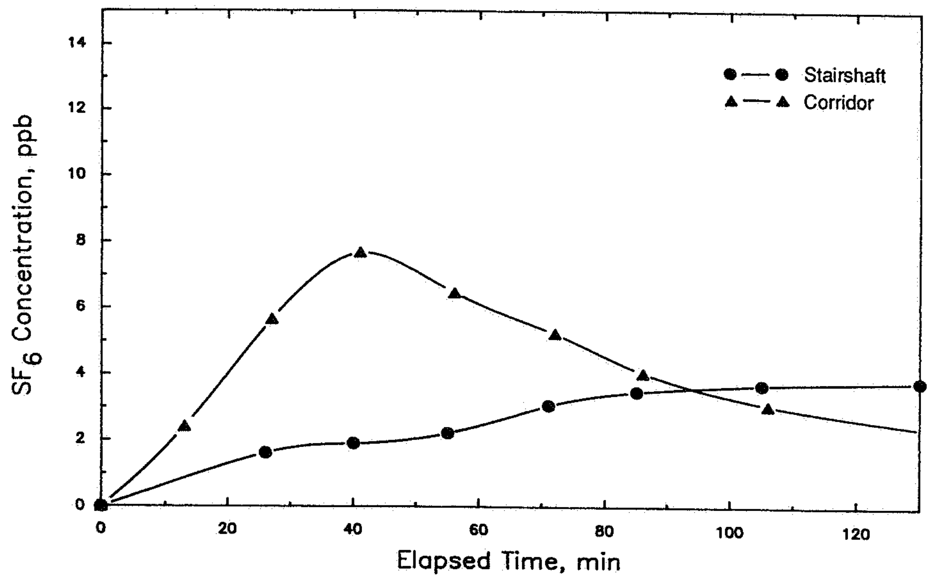

Figure 3

Contaminant dispersion patterns for the basement with the ground floor garbage room as the source location; winter conditions.

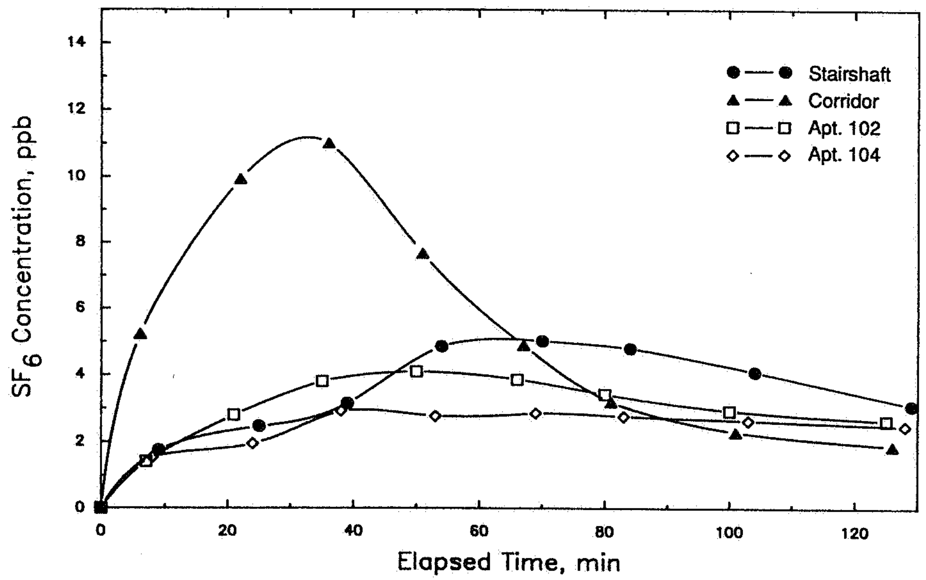

Figure 4

Contaminant dispersion patterns for the first floor with the ground floor garbage room as the source location; winter conditions.

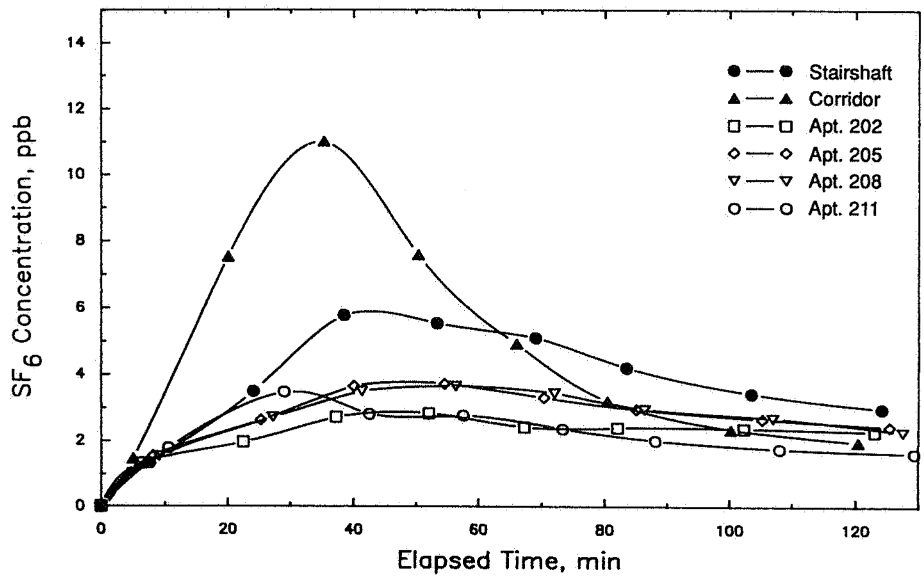

Figure 5

Contaminant dispersion patterns for the second floor with the ground floor garbage room as the source location; winter conditions.

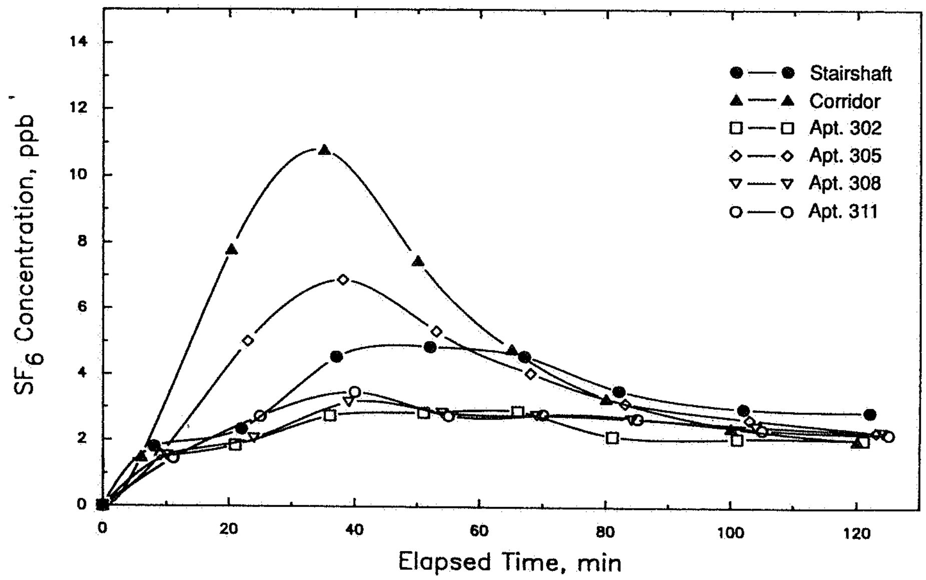

Figure 6

Contaminant dispersion patterns for the third floor with the ground floor garbage room as the source location; winter conditions.

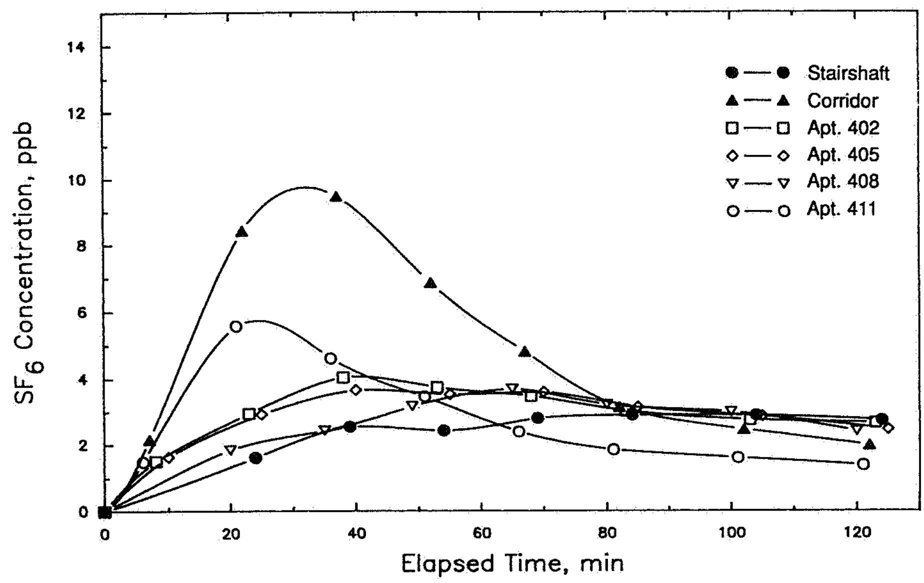

Figure 7

Contaminant dispersion patterns for the fourth floor with the ground floor garbage room as the source location; winter conditions.

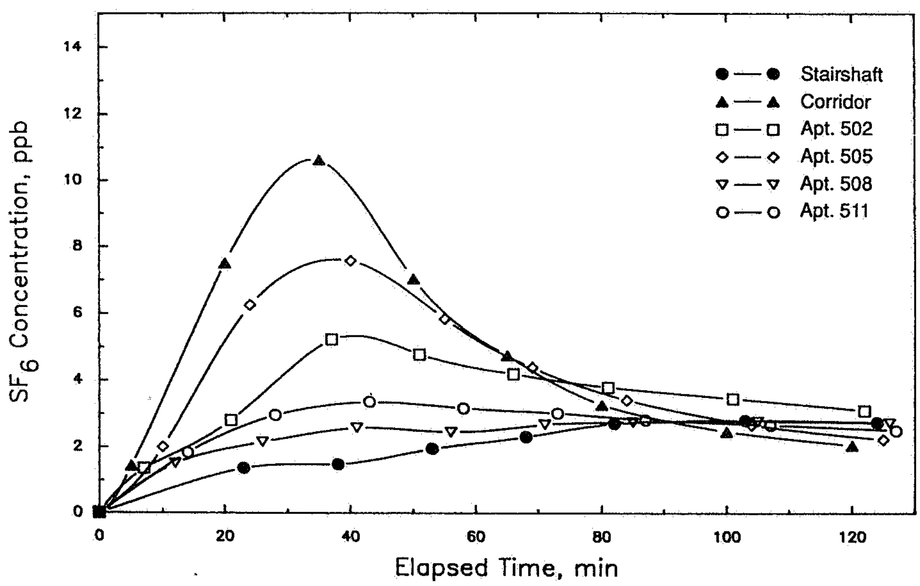

Figure 8

Contaminant dispersion patterns for the fifth floor with the ground floor garbage room as the source location; winter conditions.

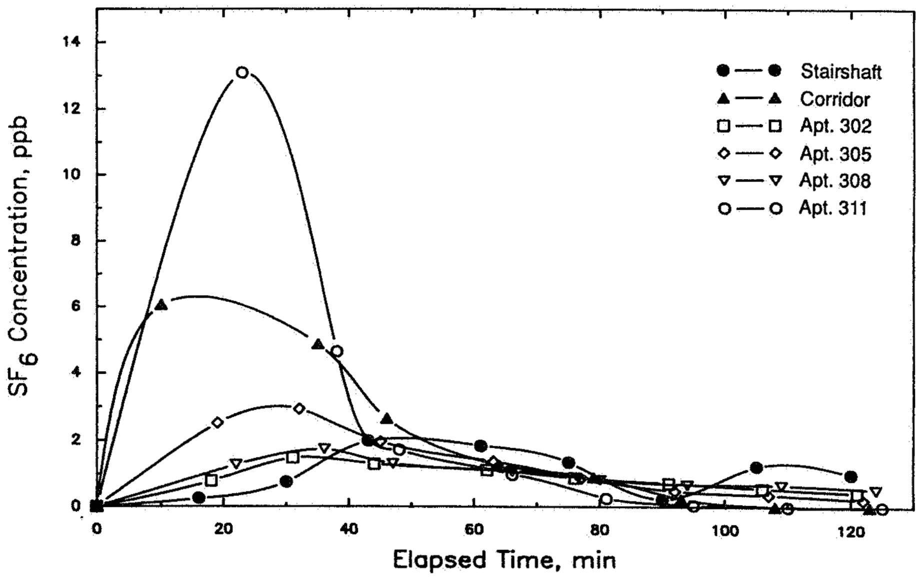

Figure 9

Contaminant dispersion patterns for the third floor with the ground floor garbage room as the source location; summer conditions.

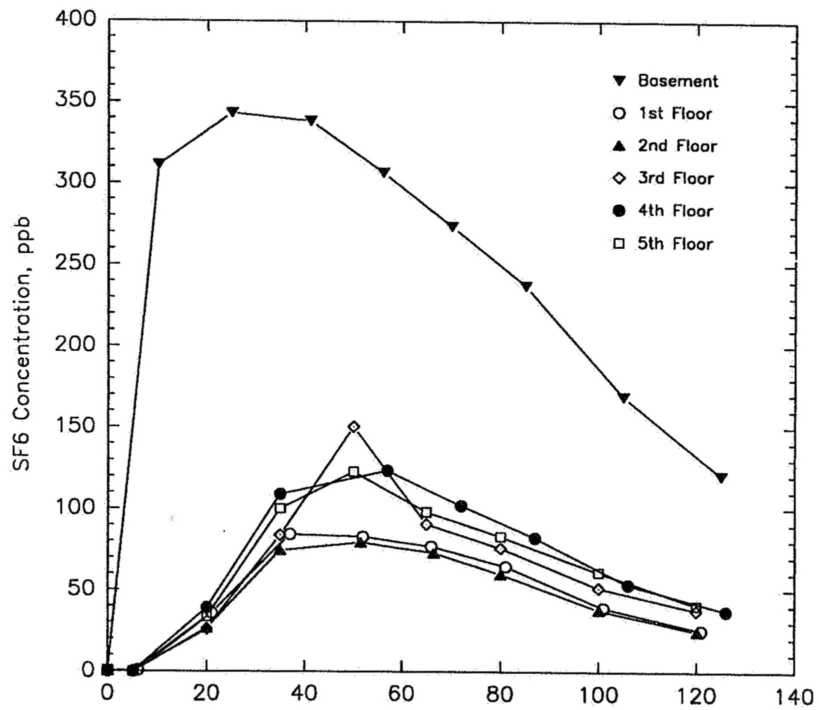

Figure 10

Contaminant dispersion patterns for the corridors with the basement party room as the source location; winter conditions

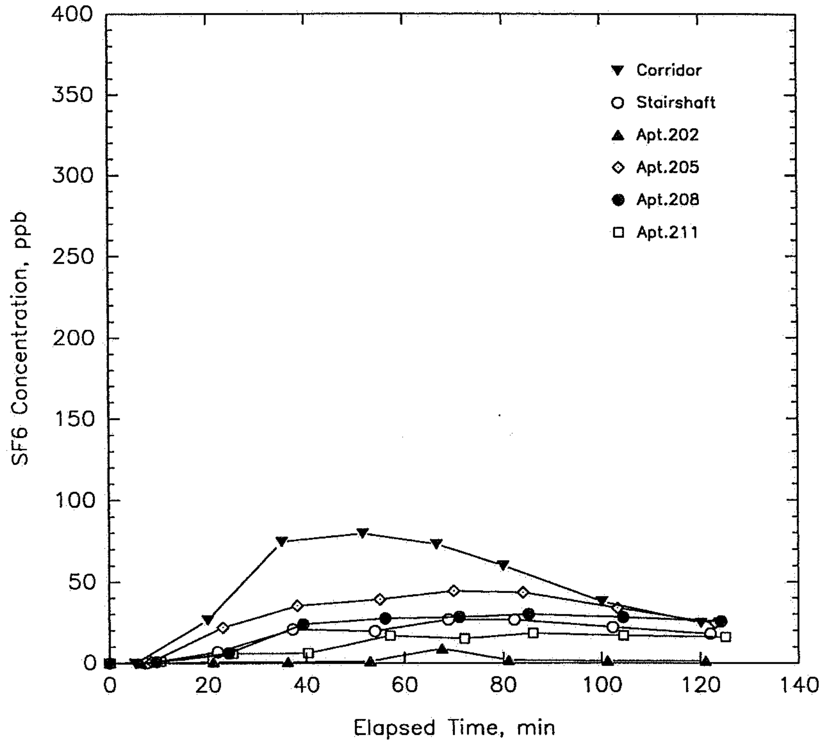

Figure 11

Contaminant dispersion patterns for the second floor with the basement party room as the source location; winter conditions

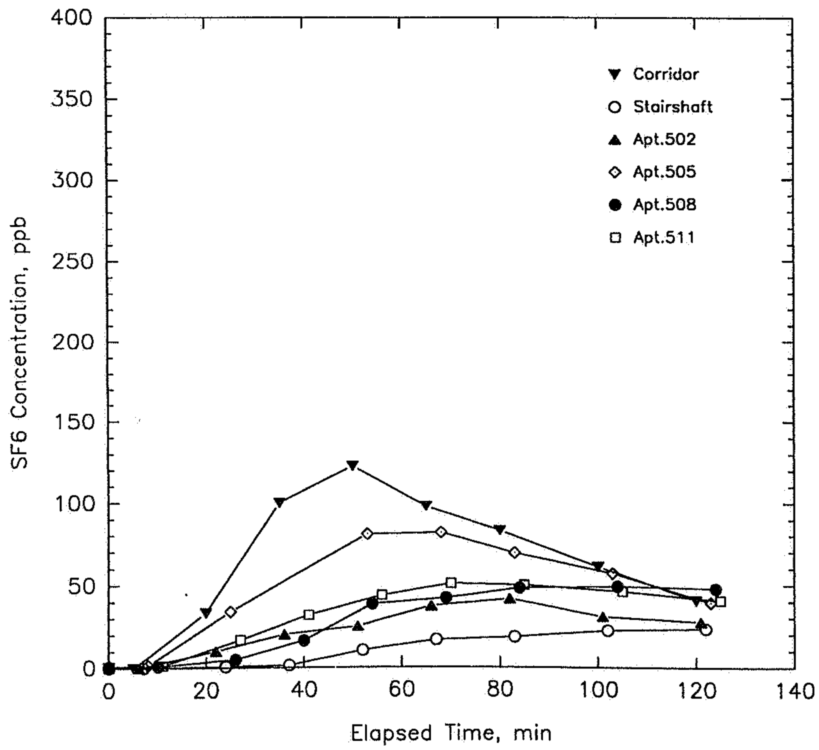

Figure 12

Contaminant dispersion patterns for the fifth floor with the basement party room as the source location; winter conditions

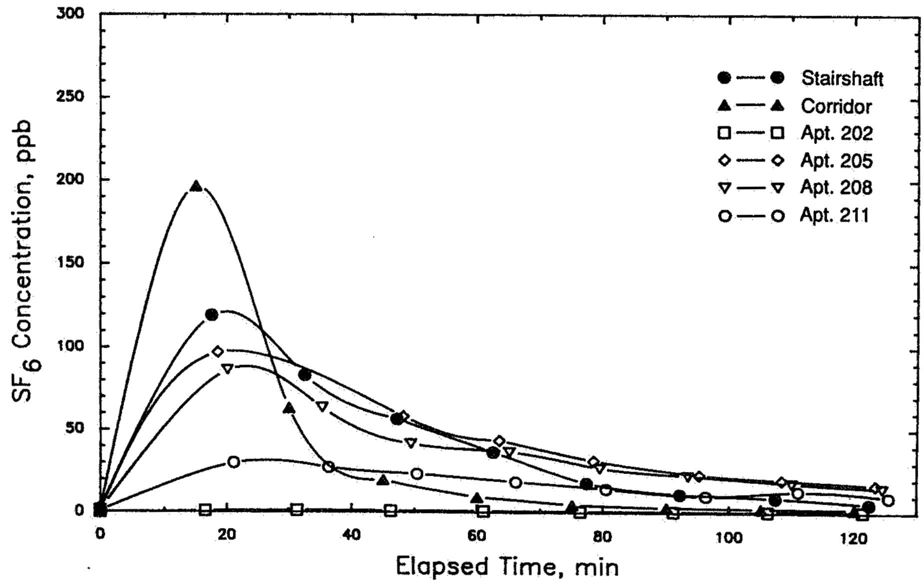

Figure 13

Outdoor air distribution patterns for the second floor; winter conditions.

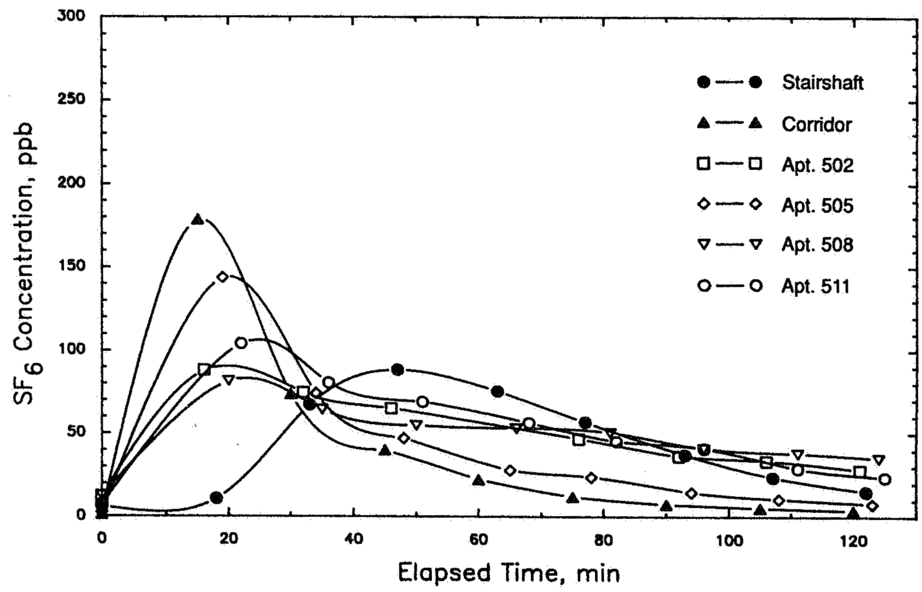

Figure 14

Outdoor air distribution patterns for the fifth floor; winter conditions.