Smoke movement studies in a 15-storey hotel
Tamura, G. T.; Manley, P. J.

Publisher's version / Version de l'éditeur:

ASHRAE Transactions, 91, 2B, pp. 1237-1253, 1985

National Research Council Canada
Conseil national de recherches Canada

Institute for Research in Construction
Institut de recherche en construction

Smoke Movement Studies in a 15-Story Hotel

by G.T. Tamura and P.J. Manley

Reprinted from
ASHRAE Transactions
Vol. 91,Part 2B, 1985
p. 1237 - 1253
(IRC Paper No. 1402)

Price $2.00

NRCC 26359

Canada

RÉSUMÉ

On a mesuré la pression et le taux de gaz traceur dans un hôtel de 15 étages, en hiver (lorsque l'effet de tirage se manifestait dans le bâtiment), afin d'évaluer les dangers de la fumée associés au feu. Du gaz traceur a été émis continuellement pour simuler la production de fumée froide dans la pièce d'essai au feu. Lorsque l'essai a été effectué au rez-de-chaussée, la fumée s'est répandue très rapidement dans les cages d'escalier, les gaines d'ascenceur et aux étages supérieurs. Lorsqu'il a été effectué dans une chambre du deuxième étage, la fumée ne s'est pratiquement pas propagée dans le bâtiment tant que le mur extérieur de la pièce d'essai est demeuré intact et que la porte de la pièce est restée fermée. Cependant, le degré de propagation de fumée s'est accru considérablement quand on a pratiqué une ouverture dans le mur extérieur pour simuler une fenêtre brisée. Il n'a cessé d'augmenter lorsqu'on a aussi ouvert la porte d'entrée de la pièce d'essai, puis la porte de l'escalier de l'étage en cause.

On a mesuré les différences de pression et la direction de l'écoulement de l'air lors du fonctionnement des systèmes de pressurisation des cages d'escalier et des gaines d'ascenceur. Étant donné que les corridors se trouvent indirectement pressurisés par ces systèmes, il est peu probable que la fumée provenant de la pièce en feu se propage dans le reste du bâtiment.

HI-85-25 No. 2

Smoke Movement Studies in a 15-Story Hotel

G.T. Tamura, P.E. **P.J. Manley, P.E.**
ASHRAE Member

ABSTRACT

Pressure and tracer gas measurements for a 15-story hotel in winter (when the building was under the influence of stack action) are used to assess the smoke hazard associated with fire. Tracer gas was released continuously to simulate generation of cold smoke in the fire room. With fire on the ground floor, the stair and elevator shafts and the upper floors became smoke filled in a very short time. With fire in a room on the second floor, the hotel remained relatively uncontaminated provided that the exterior wall of the fire room remained intact and the room entrance door remained closed. The extent of contamination increased significantly, however, when an opening in the exterior wall was created to simulate a broken window. Contamination increased further when the room entrance door was also opened and increased still more when the stair door on the fire floor was open.

Measurements of pressure differences and airflow direction were made with the stair and elevator shaft pressurization systems in operation. Because of the indirect pressurization of the corridors by these systems, smoke from the fire room will probably be prevented from contaminating the remainder of the building.

INTRODUCTION

The smoke hazard in apartment buildings and hotels is potentially less than that in open-floor buildings because compartmentation resists flow of smoke within a building. Significant numbers of fatalities in recent hotel fires, however, indicate that smoke can spread during fire to endanger the lives of occupants remaining in rooms or attempting to escape through corridors and stairways.

To gain a better understanding of how smoke moves in a compartmented building, studies have been conducted under various simulated fire conditions in a 15-story hotel (MacLaren Engineers Inc. 1984). Pressures and airflow patterns were obtained by measuring the pressure differences across the closed doors of room entrances, outside balconies, elevators, and stairs on a number of floors. A tracer gas, SF_6 (sulfur hexafluoride) (Klote and Fothergill 1983), was released continuously to simulate smoke from fires on the ground floor and in a second floor room. Gas samples collected throughout the hotel provided a measure of the SF_6 concentration build-up with time.

The hotel is equipped with pressurization fans to protect the two stairshafts and the service elevator, which is designated to serve firefighters in the event of fire. These systems were assessed by measuring and comparing pressure differences and airflow directions with and without fans in operation.

G.T. Tamura is a senior research officer, Division of Building Research, National Research Council of Canada, Ottawa, Canada, K1A 0R6; P.J. Manley is a senior project manager, MacLaren Engineers Inc., Toronto, Canada.

DESCRIPTION OF TEST BUILDING

The hotel is a 15-story tower, with meeting rooms and an elevator lobby on the first floor and guest rooms on the next 13 floors. Two half-floors at the top contain the mechanical and elevator machine rooms. On the first floor the tower is connected by a wide corridor to a large single-story building housing the registration and lobby areas, lounge rooms, restaurant, and recreational facilities. Figures 1 and 2 show plans of the ground floor and a typical guest floor. Built in 1980, the hotel has the following features:

1. Approximate area per guest floor, 710 m^2 (7650 ft^2),
2. Central service area, including two stairwells, three passenger elevators, and one service elevator,
3. Separate air supply and exhaust system for meeting rooms on the first floor,
4. Corridor air supply on guest floors from a single roof-mounted fan,
5. Central bathroom exhaust from each guest unit by means of a single roof-mounted fan,
6. Fan coil units in each guest room,
7. Outside balcony for each guest room,
8. Automatic smoke control systems comprising
   -- pressurization fans at the top of each stairwell, to be activated together with automatic openers for the exit doors at the bottom of the stair shafts (exit door of the north stair shaft leads to the lobby on the ground floor, and that of the south stair shaft to a basement corridor),
   -- a pressurization fan located at the top of the service elevator shaft,
   -- automatic closures for the fire doors in the corridor of each floor (Figure 2), including that on the ground floor separating the tower from the single-story structure (Figure 1).

TEST PROCEDURES

Eight tests were carried out during December 1983 and January 1984. The first two used one of the first floor meeting rooms as the fire room, and the remaining six tests involved one of the guest rooms on the north side of the second floor as the fire room. The test configurations (Table 1) were structured to investigate how the building air supply and exhaust system, an open balcony door simulating a broken window in the fire room, an open entrance door to the fire room, and an open stair door on the fire floor would affect smoke movement. The smoke control systems were not operated for these tests.

Measurements were conducted on the 1st, 2nd, 3rd, 6th, 11th, and either the 13th or 14th floors. Locations where pressure difference measurements and collection of tracer gas samples were taken on the ground floor are shown in Figure 1 and those for the guest floors in Figure 2. The test rooms were all served by the same vertical exhaust duct. This permitted study of possible transfer through the exhaust duct of tracer gas from the fire room to the upper rooms. With a guest room on the north side of the second floor as the fire room, measurements of pressure difference and gas samples were taken in the rooms adjacent to it to investigate the transfer of tracer gas through party walls.

Pressure difference and flow direction measurements for each test provided the pressure differences and airflow pattern in the building. Those across the entrance and balcony doors of guest rooms, across doors of service elevator and lobbies, stairwells, and guest elevators for the test floors were measured with a piezo-resistive pressure transducer sensitive to 1.2 Pa (0.005 in of water). Airflow testers generating white smoke were used to show the direction of airflow at the washroom exhaust in the guest rooms and in the corridor supply-air grilles. During one test with ventilation systems on, airflow rates were measured with a hot wire anemometer inside a test duct placed against the bathroom exhaust-air grille. Corridor supply air rates were measured with a velocity pressure-averaging (pitot-static) tube inside a prefabricated wooden duct sealed to the perimeter of the supply-air grille.

Tracer gas concentrations were measured following determination of pressure differences and airflow directions in the building. The gas release system consisted of a cylinder of either 1.01 or 10.5% SF_6 in nitrogen, a two-stage regulator, and two calibrated variable-area flow meters in parallel capable of delivering up to 250 mL/min. Fans were used to create a homogeneous mixture of tracer gas and air in the fire room. Air samples were taken in the hotel prior to the start of tracer gas release to record any residual SF_6 from the previous day's test.

The concentration of SF_6 in the fire compartment was monitored continuously by means of a nondispersive, infrared gas analyzer connected to a strip chart recorder. The concentration of SF_6 was brought to approximately 200 ppb in the fire compartment within about 5 minutes; then the gas flow rate was reduced so as to maintain that concentration within ±25 ppb. The steady-state concentration in the fire compartment was increased to approximately 500 ppb for the last two tests in order to increase the SF_6 concentrations throughout the building and thereby increase the accuracy of the test results.

Gas samples to be analyzed for SF_6 concentration were collected in the guest rooms, corridors, service lobbies, stairwells, and passenger elevator shaft (see Figures 1 and 2 for sampling locations) at 15-minute intervals during a 2-hour period. Samples from the guest rooms, stairwells, and elevator shaft were collected in the corridor, using a small pump to draw air at a rate of 1 L/min. A clean 50-mL hypodermic syringe (22-gauge needle) was flushed at each location with the air to be sampled, and 45 mL of it was then injected into a 20-mL evacuated glass tube (Tamura and Evans 1983). The samples were sent to the laboratory for analysis with an ion-capture detector chromatograph (sensitivity of 0.5 ppb). The detection limit for this method of sampling and analysis was determined to be ±1.6 ppb at the 90% confidence interval. Inside and outside temperatures, and wind speed and direction were recorded during each test.

TESTS ON SMOKE CONTROL SYSTEMS

The effect of shaft pressurization on the pressure difference and airflow patterns in the building were assessed. Pressurization fans for the south stair shaft, which exits to outside at the basement level, and for the service elevator shaft were operating. The car in the service elevator shaft was located at the fourth floor, and all elevator doors were closed for the duration of the tests. The fan for the north stair shaft, which exits to the lobby on the ground floor, was not operated because it would interfere with hotel operation (possible excessive cooling of the ground floor when the exit door was open). Neither were the automatic closures for the fire doors in the corridors activated. Measurements did include airflow readings in the supply air duct for the service elevator shaft, a complete set of pressure and flow direction readings on all test floors, air temperatures within the south stair shaft, and flow velocities at the bottom exit door of the south stair shaft. The flow rates of fans feeding outside air directly into the top of each stair shaft were not measured; those from the specification drawings of the mechanical systems were used.

With the pressurization systems for the south stair shaft and the service elevator shaft operating, various doors of the second floor were opened in sequence as follows: (1) balcony door of the north fire room open, (2) as for (1) plus stair door of the south stair shaft on the second floor open, and (3) as for (2) plus entrance door of the north fire room open. Pressure differences across the various doors of the second floor and flow directions through open doors were recorded.

RESULTS AND DISCUSSIONS

Airflow direction, pressure difference, and tracer gas concentration patterns resulted mainly from air movement caused by building stack action and the ventilation systems. No heat was generated in the fire room to simulate thermal expansion and increased stack action due to elevated temperatures. Stack action is often the dominant motive force for upward movement of smoke in high-rise buildings. Tests conducted in winter without a fire would give a good indication of the smoke movement to be expected in the event of a smoky, low-temperature fire.

In presenting the results from the tracer gas tests, the concentrations of tracer gas in the various spaces are expressed as a percentage of that in the test fire room. In considering loss of visibility from smoke density and toxicity by CO, an acceptable atmosphere was considered to be less than 1% of the polluted atmosphere in the fire area (ASHRAE Handbook

1980); concentrations above this level are considered hazardous. As an indication of risk to life, the percentage concentration of tracer gas at 30 minutes was chosen for escape routes such as corridors, stairs, and elevator shafts; that at 60 minutes was chosen for rooms where occupants may remain for the duration of a fire. In this context the percentage concentrations at the specified times were calculated and are presented for discussion.

Measurements at Supply and Exhaust Grilles

Exhaust flow rates measured in one bathroom on each of the 2nd, 3rd, 6th, 11th, and 13th floors varied from 7 to 24 L/s (15 to 52 cfm), for an average of 15 L/s (31 cfm). Similarly, supply air rates in the corridors varied from 200 to 540 L/s (430 to 1140 cfm), for an average of 350 L/s (750 cfm) per floor. From these values, the overall supply air rate was estimated to be about twice that of the exhaust air rate. With the ventilation system off, air flowed into both the exhaust grille in the bathrooms and the supply air grille in the corridors on all test floors.

Test 1 - Ground Floor Fire

Tables 2a and 2b give the results of pressure and tracer gas concentration measurements for Test 1a, a ground floor fire in the south meeting room; the door of the fire room was open to the corridor and the mechanical ventilation systems were operating. Measured pressure differences across closed doors indicate that the direction of airflow on the ground floor would be from the corridor into the north stairwell, guest elevator, and service lobby and elevator. Similar results were obtained for the second and third floors. Flow patterns on the 6th and 11th floors were indeterminate; pressure differences were in the order of 0 to 1 Pa (0 to 0.004 in of water). The direction of flow on the 13th floor was in the opposite direction to that of the lower floors except for the service lobby door. The neutral pressure plane appeared to be somewhere between the 6th and 11th floors.

The results of tracer gas measurements (Table 2b) indicate that concentrations in the test spaces were above the 1% level except for the south stair shaft, which extends to the basement floor and has no access door on the ground floor. Concentrations in the north stair shaft, which terminates on the ground floor, were well above the 1% level, however, indicating that leakage flow through cracks round the exit door [average crack width 4.2 mm (0.17 in)] contributed substantially to contamination of this stair shaft.

The gas concentration in the south room on the second floor (directly above the fire room) was 37% and in the north room, 8%; it was 4 and 3% in the corresponding rooms on the third floor, and still lower on the floors above. It appeared that contamination of the upper floors occurred largely by transfer of tracer gas from the ground floor through the stair and elevator shafts, whereas contamination of the second floor occurred directly through the floor construction. Identification of possible passageways between the fire room and the room above was attempted. Tests with smoke pencils indicated a definite movement of air into the bathroom through openings round the plumbing, and gradual movement of air out of the room through the heating and cooling service plenum located under the ceiling of the entrance hall of the room. When tracer gas was released in the ground floor room, the buildup of tracer gas concentration was confined mainly to the closed bathroom belonging to the room above, a further indication that the plumbing chase provided the main connection.

Comparison of the results of Test 1b (ventilation systems off), shown in Table 3a, with those of Test 1a (ventilation systems on), as in Table 2a, indicates slight pressurization of the corridor by the ventilation systems. The tracer gas concentration pattern of Test 1b was similar to that of Test 1a, except for the north rooms on the third and sixth floors where concentrations were less than 1%.

Test 2 - Second Floor Fire Room

Pressure difference and smoke concentration patterns for a simulated fire in the north room on the second floor are given in Tables 4a and 4b for ventilation systems on (Test 2a), and in Tables 5a and 5b for ventilation systems off (Test 2b). The test conditions were the same as those for Test 1, except that the balcony door of the room on the 13th floor directly above the fire room was open to simulate an open window. For Test 2a, all measured spaces had SF_6 concentrations below 1% except rooms adjacent to the fire room and the north room on the

13th floor; these had a concentration of 2%. Although prior to the test the direction of flow measured in the bathroom of the latter room was into the exhaust grille, it might have reversed during the test to allow tracer gas from the fire room to enter it through the bathroom exhaust duct. Such ducts are a potential passage for smoke migration to upper rooms.

The pressurization of the corridors, with and without mechanical ventilation (Tests 2a and b), was similar to that of Tests 1a and b. With the ventilation system operating (Test 2a), the pressure difference across the door of the fire room was negligible; with ventilation systems off (Test 2b), the pressure difference was 4 Pa (0.016 in of water) with air flowing from the fire room into the corridor. This resulted in tracer gas concentrations of 1 and 2% in the corridor and service lobby of the second floor and in the lower half of the north stair shaft. Thus, pressurization of the corridor with ventilation systems on inhibited movement of tracer gas from the fire room into the corridor. For Test 2b, the tracer gas concentration in the north room of the 14th floor with balcony door open was negligible, indicating that there was no transfer of tracer gas to this room through the bathroom exhaust duct. It is possible, of course, that dilution occurred from the open window.

Test 3 - Second Floor Fire (Balcony Door of Fire Room Open)

The conditions for Test 3a, conducted with the ventilation systems on, were similar to those of Test 2a except that the balcony door of the fire room was open to simulate a window either open or broken as a result of fire and the balcony door of the north room on the 14th floor closed (Tables 6a and b). The pressure difference across the entrance door of the fire room was 5 Pa (0.02 in of water), as compared to 0 Pa for Test 2a; it resulted in heavy contamination of adjacent rooms (21% and 58%), of the room directly above (12%), and of the second floor corridor (1 to 6%). There was much less contamination (about 1%) in the elevator shaft, stairs, and upper floors. The results of Test 3b, ventilation systems off, are given in Table 7a and b; they were similar to those of Test 3a except that the levels of contamination were lower, the concentrations in the rooms and corridors on the 11th and 13th floors being less than 1%. The pressure difference across the entrance door of the fire room was 2 Pa (0.01 in of water).

With the balcony door open, the pressures in the fire room increased, approaching those of the exterior, as might be expected in winter for a room located below the neutral pressure level of a building. This resulted in an increase in the amount of contamination beyond the fire room.

Test 4 - Second Floor Fire (Balcony and Entrance Doors of Fire Room Open)

Test 4a was conducted with the balcony door of the fire room open and the ventilation system on, as for Test 3a except that the entrance door of the fire room was also open. The results of measurements are given in Tables 8a and b. The pressure differences across the stair and elevator doors in the center core of the second floor were greater for Test 4a (room entrance door open) than for Test 3a (room entrance door closed). Tracer gas concentrations in the corridor of the second floor increased to about 40% and in the south room of the second floor to above 20%. The stairs, elevators, and corridors in the floors above the fire floor were heavily contaminated. The concentrations of tracer gas in the rooms in the upper floors varied from 1 to 4%, except for the south rooms on the third and sixth floors where concentrations were less than 1%. On the ground floor, concentrations of tracer gas above 1% were confined to the meeting rooms and stairwells. This test demonstrated the importance of automatic closures for room entrance doors.

When, in addition, the fire floor door of the north stair shaft was open (Test 4b, Tables 9a and b), the level of contamination increased dramatically in all test spaces except the corridor and service lobby of the ground floor. The concentrations of the tracer gas in the rooms on the floors above the second varied from 2 to 8%; in the south room of the second floor it was 37%.

Results of Smoke Control System Tests

The supply air rate for pressurization of the north and south stair shafts, according to "as built" drawings, is 8.8 m^3/s (18 600 cfm) for each fan. The supply air rate for pressurization of the service elevator shaft was measured at 6.5 m^3/s (15 500 cfm).

Pressure measurements taken in the south stairwell with the bottom exit door open and the service elevator shaft pressurized (Table 10) show that the pressure differences varied from 19 to 41 Pa (0.07 to 0.16 in of water) and the airflow rate at the exit door was 4.3 m^3/s (9100 cfm). As well, the service elevator shaft was pressurized from 14 to 23 Pa (0.05 to 0.09 in of water) and the service elevator lobbies, in turn, were pressurized from 39 to 46 Pa (0.15 to 0.18 in of water). Pressurizing the south stair shaft and service elevator shaft resulted in indirectly pressurizing the corridors, causing air to flow into the rooms and from there to the exterior for the entire height of the building. The amount of corridor pressurization would have been greater if the pressurization fan of the north stair shaft had also been activated.

The air temperatures in the south stairwell 20 minutes after starting the pressurization fan were as follows:

Floor	Temperature, °C
Outside	-16
15	- 3
13	2
11	7
6	14
3	17
Basement	19

The air temperature was above freezing below the 14th floor level, with intake of outside air at -16°C. The air felt warmer in the upper levels than the temperatures indicated, possibly because of radiant heat transfer from the walls.

With the smoke control pressurization systems operating, the pressure differences on the second floor were unaffected by the opening of the balcony door of the fire room on the north side of the same floor; pressure measurements on other floors were not made. When, in addition, the door of the south stair shaft on the second floor was opened, the corridor was pressurized, causing increased pressure in the corridor relative to that of the north room, i.e., from 7 Pa (0.03 in of water) to 25 Pa (0.10 in of water). When the entrance door of the north fire room was also opened, there was a strong current of air from the south stairwell through the corridor into the north fire room and from there to the exterior. In the event of fire, smoke generated in the fire room would probably be inhibited from entering the corridor. Under the same condition, but without the smoke control systems in operation (Test 4b), the results of the tracer gas test indicated that the entire building would be heavily contaminated with smoke.

Table 10 also shows that on the ground floor the direction of flow is from the floor space into the north stairs and passenger elevator shaft, both of which were not pressurized during the test. In the event of fire on the ground floor some smoke contamination would be expected in these shafts.

SUMMARY

1. During tests simulating fire on the ground floor of a 15-story building, with and without ventilation systems operating, tracer gas (under the influence of stack action) moved rapidly up the elevator and north stair shafts. The critical level of concentration of 1% of that of the fire room was generally exceeded in the corridors and rooms of upper floors. The south stairwell, with no access to the main floor, remained uncontaminated. The tests revealed that the tracer gas migrated from the fire room on the ground floor through the plumbing raceway, causing rapid build-up of tracer gas concentration in the room above.
2. For tests simulating fire on the second floor, with balcony and entrance doors of the fire room closed and the ventilation system off, the only significant tracer gas concentrations noted were in the corridor and service lobby of the second floor. With the ventilation system on, the extent of tracer gas contamination in the building was minimal, indicating that pressurization of the corridors by mechanical ventilation assists in preventing smoke

from spreading beyond the fire room. Presumably the tracer gas in the fire room migrated to the exterior through the bathroom exhaust duct.

3. During the second-floor room-fire test, with the balcony door open to simulate a broken window, the adjacent rooms (that directly above, the second-floor corridor, elevator and stair shafts, and the corridors of the upper floors) were all considered to be contaminated. When, in addition, the fire room entrance door was opened, the entire building (except for part of the ground floor) was contaminated by smoke. This worsened when the stair door on the second floor was also opened.
4. Operating the stair and elevator shaft pressurization systems indirectly pressurized the corridors, causing air to flow into the guest rooms and out through the exterior walls; thus, the corridors and rooms as well as the stair and elevator shafts were protected from smoke contamination. With a fire on the ground floor, however, some smoke contamination would be expected in unpressurized shafts.

It may be concluded that in compartmented buildings without smoke control, severe smoke contamination of escape routes and rooms can be expected if there is fire on the (open type) ground floor. Similarly, severe contamination can be expected if there is fire in a lower-floor room that has a large opening in the exterior wall and the entrance door is open. The severity of smoke contamination would be much less if the entrance door of the fire room were closed.

Because some smoke contamination of compartmented buildings can be expected in the event of fire, measures to protect occupants are necessary. Automatic door closures for room entrance doors would greatly reduce the extent of smoke contamination. Balconies attached to all guest rooms, as for the test building, could serve as refuge areas. Mechanical pressurization of the stair and elevator shafts with outside air would provide smoke-free escape or firefighters' access routes. A sprinkler system might also be considered, particularly on the ground floor where a lobby often serves as part of an exit route. All such measures are recognized and included in the National Building Code of Canada (1980).

ACKNOWLEDGMENT

The authors gratefully acknowledge the cooperation and assistance of the staff of the Delta Meadowvale Inn in preparing and conducting the tests, and of Markborough Properties for granting permission to conduct tests and publish this paper. They also acknowledge the assistance of R. Helmeste, J. de Jong, and R.G. Evans in planning and conducting the tests and processing the results. The authors are also grateful to members of the staff of MacLaren Engineers Inc. who participated in the tests.

This paper is a contribution from the Division of Building Research, National Research Council of Canada.

REFERENCES

ASHRAE. 1980. ASHRAE Handbook -- 1980 Systems, "Fire and Smoke Control." Atlanta: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., p. 41.5-41.6.

Klote, J.H., and J.W. Fothergill Jr. 1983. Design of Smoke Control Systems for Buildings. (Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.), p. 45.

McLaren Engineers Inc. 1984. Smoke Movement Studies in a Compartmented Building. Report to the National Research Council of Canada, Contract No. 35452-8000-000.

National Building Code of Canada. 1980. National Research Council of Canada, Associate Committee on the National Building Code, Ottawa, Canada.

Tamura, G.T., and R.G. Evans. 1983. "Evaluation of Evacuated Glass Tubes for Sampling of SF_6/Air Mixture for Air Exchange Measurement," ASHRAE Journal, October 1983, p. 40-43.

TABLE 1
Test Conditions

Simulated Fire	Test No.	Fire Room Window	Fire Room Door	13th Floor Window	2nd Floor Stair Door	Corridor Air Supply	Room Exhaust	Outside Temp, °C	Outside Wind, km/h
Ground floor room	1a	closed	open	closed	closed	on	on		
	b	closed	open	closed	closed	off	off	-10	28 N
Second floor room	2a	closed	closed	open	closed	on	on	-12	2 E
	b	closed	closed	open	closed	off	off	-12	9 N
	3a	open	closed	closed	closed	on	on	-2	13 WSW
	b	open	closed	closed	closed	off	off	1	17 SW
	4a	open	open	closed	closed	on	on	-8	15 SE
	b	open	open	closed	open	on	on	2	15 WNW

TABLE 2a
Pressure Difference across Doors, Pa, Test 1a.
Ground floor fire, ventilation systems operating,
-16°C, 22 km/h, W

Sampling Location	North Room	South Room	Service Lobby	North Stairs	South Stairs	Pass. Elev.	Service Elevator	Outside	
Floor \ Ref	Corridor						Service Lobby	North Room	South Room
13	-7	-5	-1	2	1	1	0	-37	-27
11	-6	-6	0	0	0	0	-1	-17	-16
6	-1	0	-2	-1	1	0	1	-11	2
3	0	0	-3	-3	0	-1	0	12	12
2	0	0	-8	-7	-3	-4	0	10	10
1	-10	fire room	-33	-37	no door	-35	-5	10	7
B					-34				

TABLE 2b
SF_6 Tracer Gas Concentration, % of Concentration in Fire Region, Test 1a.
Ground floor fire, ventilation systems operating,
-16°C, 22 km/h, W

Floor	Room North	Room South	Corridor West	Corridor East	Service Lobby	Stairwell North	Stairwell South	Passenger Elevator
13	2	3	4	3	3	6	1	7
11	1	2	3	2	2	8	<1	6
6	1	2	4	2	3	12	<1	7
3	3	4	3	2	3	17	<1	4
2	8	37	6	6	10	18	<1	7
1	20	100	18	17	20	18	-	9
B							<1	

Tracer gas concentrations in guest rooms at 60 min and remaining areas at 30 min

TABLE 3a
Pressure Difference across Doors, Pa, Test 1b.
Ground floor fire, ventilation systems not operating,
-10°C, 28 km/h, N

Sampling Location	North Room	South Room	Service Lobby	North Stairs	South Stairs	Pass. Elev.	Service Elevator	Outside	
Floor \ Ref	Corridor						Service Lobby	North Room	South Room
14	-5	-1	0	2	2	2	0	9	-27
11	1	-1	0	1	1	1	0	15	-15
6	3	0	-2	-1	1	0	0	1	-
3	3	0	-1	-2	1	0	-2	26	10
2	7	1	-4	-4	0	-1	-1	32	10
1	-1	fire room	-2	-31	no door	-4	-6	31	-4
B					-34				

TABLE 3b
SF_6 Tracer Gas Concentration, % of Concentration in Fire Region, Test 1b.
Ground floor fire, ventilation systems not operating,
-10°C, 28 km/h, N

Floor	Room		Corridor		Service Lobby	Stairwell		Passenger Elevator
	North	South	West	East		North	South	
14	4	3	7	7	5	1	<1	11
11	3	4	9	3	4	3	<1	10
6	<1	1	2	<1	1	7	<1	8
3	<1	10	2	1	1	14	<1	8
2	1	50	7	1	3	17	<1	19
1	1	100	24	21	18	21	-	-
B							<1	

Tracer gas concentrations in guest rooms at 60 min and remaining areas at 30 min

TABLE 4a

Pressure Difference across Doors, Pa, Test 2a.

Second floor fire, ventilation systems operating, fire room balcony door open, -12°C, 2 km/h, E

Sampling Location	North (X)Room(X)	South Room	Service Lobby	North Stairs	South Stairs	Pass. Elev.	Service Elevator	Outside	
Floor \ Ref	Corridor						Service Lobby	North (X)Room(X)	South Room
13	-24	-9	0	1	0	1	0	open window	-17
11	-6	-4	-1	1	1	1	0	-8	-8
6	-2	0	-1	0	0	0	0	-	5
3	-2	0	-2	-2	0	0	0	13	16
2	(0)0(-1)	0	-6	-5	-2	-2	0	(16)16(12)	14
1	0	-	-18	-29	no door	-20	-4	3	4
B					-30				

(X) Rooms immediately west and east of fire room

TABLE 4b

SF_6 Tracer Gas Concentration, % of Concentration in Fire Region, Test 2a.

Second floor room fire, ventilation systems operating, fire room balcony door open, -12°C, 2 km/h, E

Floor	Room		Corridor		Service Lobby	Stairwell		Passenger Elevator
	(X)North(X)	South	West	East		North	South	
13	2	<1	<1	<1	<1	<1	<1	<1
11	<1	<1	<1	<1	<1	<1	<1	<1
6	-	<1	<1	<1	<1	<1	<1	<1
3	<1	<1	<1	<1	<1	<1	<1	<1
2	(6)100(1)	<1	<1	<1	<1	<1	<1	<1
1	<1	-	<1	<1	<1	<1	-	<1
B							<1	

(X) Rooms immediately west and east of fire room. Tracer gas concentrations in guest rooms at 60 min and in remaining areas at 30 min

TABLE 5a
Pressure Difference across Doors, Pa, Test 2b.
Second floor fire, ventilation systems not operating
-12°C, 9 km/h, N

Sampling Location	North (X)Room(X)	South Room	Service Lobby	North Stairs	South Stairs	Pass. Elev.	Service Elevator	Outside	
Floor \ Ref	Corridor						Service Lobby	North (X)Room(X)	South Room
14	-32	-5	2	4	5	6	1	open window	-12
11	-2	-2	1	0	3	1	0	3	0
6	1	0	-1	-1	2	0	0	21	15
3	2	1	-2	-2	2	0	0	16	19
2	(0)4(-1)	1	-22	-5	-2	-4	-15	(32)35(34)	45
1	-5	1	-25	-41	no door	-4	-6	15	-2
B					-47				

(X) Rooms immediately west and east of the fire room

TABLE 5b
SF_6 Tracer Gas Concentrations, % of Concentration in Fire Region, Test 2b.
Second floor room fire, ventilation systems not operating
-12°C, 9 km/h, N

Floor	Room		Corridor		Service Lobby	Stairwell		Passenger Elevator
	(X)North(X)	South	West	East		North	South	
14	<1	<1	<1	<1	<1	<1	<1	<1
11	<1	<1	<1	<1	<1	<1	<1	<1
6	<1	<1	<1	<1	<1	1	<1	<1
3	<1	<1	<1	<1	<1	1	<1	<1
2	(<1)100(<1)	<1	-	1	1	2	<1	<1
1	<1	<1	<1	<1	<1	<1	<1	<1
B							<1	

(X) Rooms immediately west and east of the fire room. Tracer gas concentrations in guest rooms at 60 min and in remaining areas at 30 min

TABLE 6a

Pressure Difference across Doors, Pa, Test 3a.

Second floor fire, ventilation systems operating, fire room balcony door open, -2°C, 13 km/h, WSW

Sampling Location	North (X)Room(X)	South Room	Service Lobby	North Stairs	South Stairs	Pass. Elev.	Service Elevator	Outside	
Floor \ Ref	Corridor						Service Lobby	North (X)Room(X)	South Room
14	-13	-10	0	2	1	1	0	-19	-14
11	1	-5	0	3	2	1	0	2	-2
6	-2	-1	-2	-1	0	0	0	-3	-1
3	-2	-1	-3	-2	0	-1	0	5	2
2	(-1)5(0)	-1	-5	-6	-2	-3	0	(6)open(10) window	6
1	-4	-3	-12	-27	no door	-22	-6	7	2
B					-23				

(X) Rooms immediately west and east of the fire room

TABLE 6b

SF_6 Tracer Gas Concentrations, % Concentration in Fire Region, Test 3a.

Second floor fire, ventilation systems operating, fire room balcony door open -2°C, 13 km/h, WSW

Floor	Room		Corridor		Service Lobby	Stairwell		Passenger Elevator
	(X)North(X)	South	West	East		North	South	
14	1	<1	1	<1	1	<1	<1	2
11	1	1	1	<1	<1	<1	1	1
6	<1	1	<1	<1	<1	<1	<1	1
3	12	<1	<1	2	<1	2	<1	2
2	(58)100(21)	2	6	6	4	6	2	3
1	<1	-	<1	<1	<1	<1	-	<1
B							<1	

(X) Rooms immediately west and east of the fire room. Tracer gas concentrations in guest rooms at 60 min and in remaining areas at 30 min

TABLE 7a
Pressure Difference across Doors, Pa, Test 3b.
Second floor fire, ventilation systems not operating
-1°C, 17 km/h, SW

Sampling Location	North (X)Room(X)	South Room	Service Lobby	North Stairs	South Stairs	Pass. Elev.	Service Elevator	Outside	
Floor \ Ref	Corridor						Service Lobby	North (X)Room(X)	South Room
13	-7	-6	0	1	1	-1	0	-14	-12
11	-6	-4	0	0	1	1	0	-7	-7
6	-2	-1	0	0	0	0	0	2	-2
3	-1	-1	-3	-2	0	0	0	4	1
2	(0)-2(0)	-1	-4	-3	-1	-6	0	(1)open(4) window	8
1	-1	-	-25	-25	no door	-20	-6	-5	11
B					-30				

(X) Rooms immediately west and east of the fire room

TABLE 7b
SF_6 Tracer Gas Concentrations, % Concentration in Fire Region, Test 3b.
Second floor fire, ventilation systems not operating
-1°C, 17 km/h, SW

Floor	Room (X)North(X)	Room South	Corridor West	Corridor East	Service Lobby	Stairwell North	Stairwell South	Passenger Elevator
13	<1	<1	<1	<1	<1	1	<1	<1
11	<1	<1	<1	<1	<1	<1	<1	<1
6	1	1	<1	1	<1	2	1	<1
3	2	1	1	1	1	2	2	1
2	(21)100(24)	<1	2	4	1	1	<1	2
1	1	-	<1	<1	<1	<1	<1	<1
B							<1	

(X) Rooms immediately west and east of the fire room. Tracer gas concentrations in guest rooms at 60 min and in remaining areas at 30 min

TABLE 8a
Pressure Difference across Doors, Pa, Test 4a.
Ventilation systems on, fire room balcony and entrance doors open,
-8°C, 15 km/h, SE

Sampling Location	North (X)Room(X)	South Room	Service Lobby	North Stairs	South Stairs	Pass. Elev.	Service Elevator	Outside	
Floor \ Ref	Corridor						Service Lobby	North (X)Room(X)	South Room
14	-11	-6	1	3	2	3	0	-15	-4
11	-6	-4	-1	0	-1	0	0	-15	-4
6	-2	0	-2	-1	0	0	0	10	10
3	-1	0	-2	-2	0	0	0	7	20
2	(0)open(-1) door	0	-2	-10	-5	-4	0	(5)open(7) window	19
1	-2	5	-12	-21	no door	-17	-1	6	21
B					-19				

(X) Rooms immediately west and east of the fire room

TABLE 8b
SF_6 Tracer Gas Concentrations, % Concentration in Fire Region, Test 4a.
Ventilation systems on, fire room balcony and entrance doors open,
-8°C, 15 km/h, SE

Floor	Room		Corridor		Service Lobby	Stairwell		Passenger Elevator
	(X)North(X)	South	West	East		North	South	
14	2	4	4	3	1	11	3	10
11	1	1	7	4	2	14	5	7
6	1	<1	5	3	2	17	5	8
3	5	<1	<1	1	2	24	6	7
2	(23)100(25)	22	38	40	29	40	12	35
1	2	2	<1	<1	<1	1	-	<1
B							<1	

(X) Rooms immediately west and east of the fire room. Tracer gas concentrations in guest rooms at 60 min and in remaining areas at 30 min

TABLE 9a
Pressure Differences across Doors, Pa, Test 4b.
Second floor fire, ventilation systems operating
2°C, 15 km/h, WNW

Sampling Location	North (X)Room(X)	South Room	Service Lobby	North Stairs	South Stairs	Pass. Elev.	Service Elevator	Outside	
Floor \ Ref	Corridor						Service Lobby	North (X)Room(X)	South Room
13	2	-8	-2	1	5	1	0	8	-15
11	-1	-5	-1	1	5	1	0	5	-7
6	0	-3	-2	0	7	0	0	11	-5
3	2	-1	-4	-1	7	-1	0	13	5
2	(0)open(-3) door	-1	-9	-10	open door	-7	0	(14)open(14) window	3
1	-5	0	-11	-17	no door	-11	1	14	-4
B					-9				

(X) Rooms immediately west and east of the fire room

TABLE 9b
SF_6 Tracer Gas Concentrations, % Concentration in Fire Region, Test 4b.
Second floor fire, ventilation systems operating,
2°C, 15 km/h, WNW

Floor	Room		Corridor		Service Lobby	Stairwell		Passenger Elevator
	(X)North(X)	South	West	East		North	South	
13	2	6	8	12	7	28	19	12
11	6	7	12	15	7	29	27	12
6	2	8	12	16	11	24	31	9
3	4	4	6	10	8	28	31	4
2	(37)100(42)	37	37	45	43	36	-	36
1	4	4	<1	<1	<1	6	<1	6
B							<1	

(X) Rooms immediately west and east of the fire room. Tracer gas concentrations in guest rooms at 60 min and in remaining areas at 30 min

TABLE 10
Smoke Control System Test.
Pressure difference across doors, Pa

Sampling Location	North Room	South Room	Service Lobby	North Stairs	South Stairs	Pass. Elev.	Service Elevator	Outside	
Floor \ Ref	Corridor						Service Lobby	North Room	South Room
13	-10	-10	+39	0	+41	0	+14	-47	-61
11	-9	-9	+39	-1	+37	0	+14	-52	-42
6	-6	-8	+41	0	+33	0	+23	-20	-22
3	-5	-5	+46	-3	+22	-1	+23	-11	-13
2	-7	-9	+42	-5	+19	-4	+21	-6	-7
1	0	+3	+40	-14	no door	-11	+23	-7	-10
B									

Test Conditions
1. South stairwell and service elevator pressurization fans operating
2. Service elevator locked at fourth floor
3. Corridor air supply and room exhaust fans operating in normal mode
4. Outside: -16°C, 22 km/h W

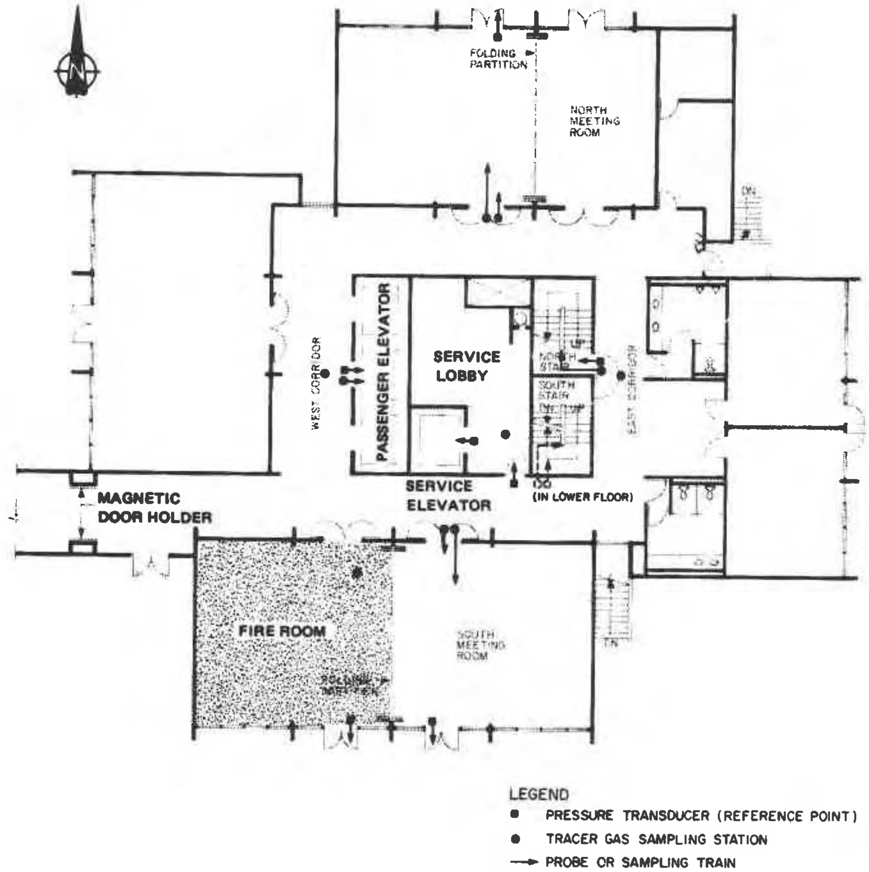

Figure 1. Main floor plan - pressure difference and tracer gas sampling locations

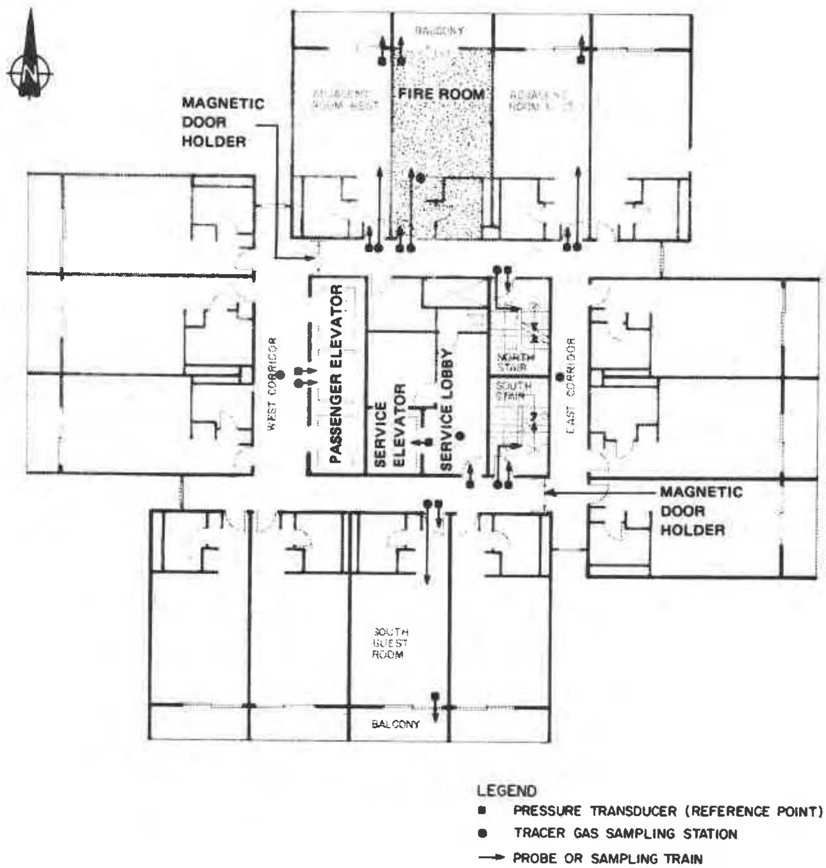

Figure 2. Second and typical floor plan - pressure difference and tracer gas sampling locations

This paper is being distributed in reprint form by the Institute for Research in Construction. A list of building practice and research publications available from the Institute may be obtained by writing to the Publications Section, Institute for Research in Construction, National Research Council of Canada, Ottawa, Ontario, K1A 0R6.

Ce document est distribué sous forme de tiré-à-part par l'Institut de recherche en construction. On peut obtenir une liste des publications de l'Institut portant sur les techniques ou les recherches en matière de bâtiment en écrivant à la Section des publications, Institut de recherche en construction, Conseil national de recherches du Canada, Ottawa (Ontario), K1A 0R6.