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A TRACER INVESTIGATION OF A LABORATORY VENTILATION SYSTEM

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SUMMARY

Several SF_6 tracers tests were conducted within a laboratory-office building in order to investigate the building ventilation system. This work serves as a demonstration of how tracer techniques can be used to characterize building ventilation systems. The results show that ventilation efficiencies can vary widely among different parts of the building. Tracer released into the laboratory side of the building rapidly appeared on the office side of the building. The tracer data suggest that, in some cases, existing air flow rates may be greater than those specified in the ventilation design data.

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1 INTRODUCTION

The possibility of accidental releases of toxic materials within commercial or educational laboratory buildings makes knowledge of the ventilation efficiences in such facilities extremely valuable. As Drivas et.al. (1972) first demonstrated, SF_6 tracer methods offer a unique and simple means of characterizing the air flow within buildings. In this work, a tracer study of the ventilation system at the Norwegian Institute for Air Research (NILU) was conducted. The purpose of this work was to study the ventilation characteristics of the laboratory-office building and to demonstrate the application of tracer techiques to the investigation of building ventilation systems.

2 THE NILU VENTILATION SYSTEM

The NILU building is a semi-rectangular structure, measuring approximately 60m x 27m x 10m, which houses a chemistry laboratory, an instrument laboratory, and offices for research and administrative personnel. As shown in Figure 1, the laboratories are on 2 floors on the north side of the building, and the offices are on 3 floors on the south side of the building. The chemistry laboratory and a portion of the instrument laboratory are ventilated by a forced air system with no recirculation. Fresh air is drawn from an intake vent on the side of the center penthouse on the roof, while exhaust air from the rooms and fume hoods is emitted from a vent on top of the same penthouse. The offices on the south side of the building are serviced only by an exhaust system which draws air from the offices and emits it through a vent on top of a second penthouse located on the west end of the roof. When in normal operation, both systems are on continuously.

Data from the ventilation specifications provided by A/S Norsk Viftefabrikk indicate that the maximum laboratory exhaust flow rate equals 11845 m^3/kr and the maximum office exhaust flow rate equals 2450 m^3/kr. An air compressor located in room 105 has an exhaust capacity equal to 1200 m^3/kr. Air flow rate data and estimated volumes for a number of locations within the building are listed in Table 1. These data were used to calculate the air residence time, τ, which is given by:

$$\tau = \frac{V}{Q}$$

where V is the volume and Q is the flow rate. In the case of a perfectly well-mixed room, the value of τ equals the time in which the concentration of an instantaneously spilled gas decreases by 1/e. For the purposes of the tracer experiment, a characteristic concentration decay constant, τ_e, is also defined as the time in which the concentration of a spilled

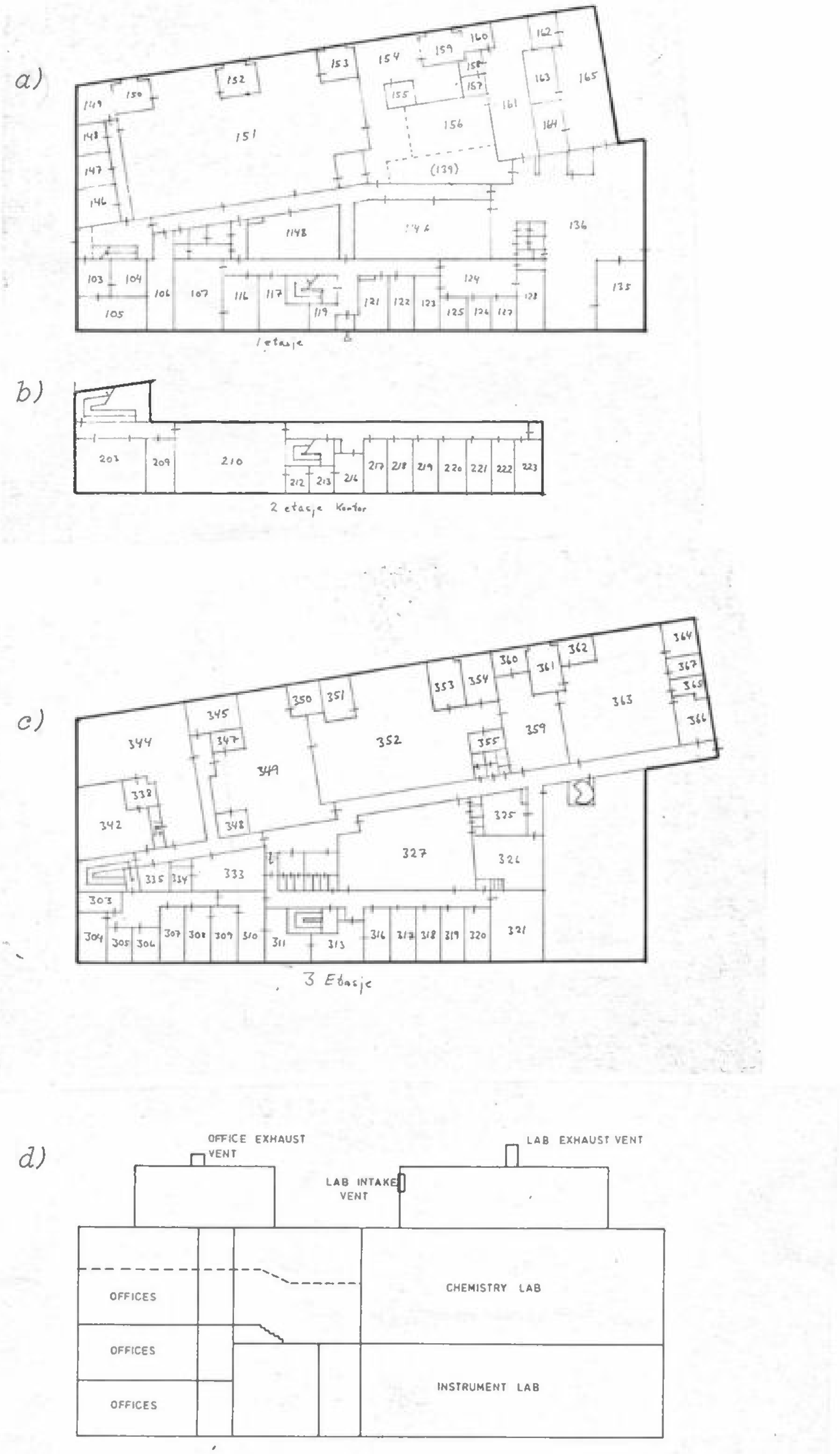

*Figure 1: Floor plan of the NILU building:
a) 1st floor, b) 2nd floor, c) 3rd floor and
d) vertical cross-section.*

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Table 1: NILU ventilation parameters

Location	Volume V (m^3)	Flow rate Q (m^3/hr)	τ=V/Q (hr)
Room 151	1166	-	-
Room 154	379	610	0.6
Room 222	29	50	0.6
Room 309	34	65	0.5
Room 363	506	1310	0.4
Lab.exhaust system	11068	11895	0.9
Office exhaust system	3065	2450	1.3

gas decreases by 1/e. For a well-mixed room, $\tau_e = \tau$. However, since rooms are seldom perfectly well-mixed, τ_e is usually greater than τ.

3 ROOM VENTILATION STUDIES

Ventilation patterns were investigated and values of τ_e were determined individually in rooms 151, 154 and 222. In each case, a small volume of SF_6 was released instantaneously near the center of the room. A small fan was run for approximately 2 minutes after the release to help disperse the tracer throughout the room. Instantaneous air samples were periodically collected in 20 cm^3 plastic syringes. All samples were analyzed within a few hours of each test using 2 electron capture gas chromatographs located in room 363. These instruments are capable of detecting SF_6 in concentrations ranging from 10^{-6} parts SF_6/part air (10^6 parts per trillion, ppt) to 10^{-12} parts SF_6/part air (1 ppt). Further details concerning the operation and calibration of the instruments are available elsewhere (Lamb, 1978).

The results of these experiments are shown in Figure 2. These data indicate that concentrations within a room do, in fact, decrease exponentially. The values of the characeristic concentration decay constants for rooms 151, 154, and 222 were 4.2 hours, 1.6 hours and 0.25 hours, respectively. Room 151, which is a working area for approximately 9 people, undergoes only 2 air changes in an 8-hour period; this low ventilation rate results because room 151 has no forced ventilation system. All ventilation takes place through open doors and windows. Room 154 has a greater ventilation rate than room 151 because room 154 is serviced by a single fresh air inlet and a fume hood exhaust. However, since the fresh air inlet is positioned directly in front of the fume hood, fresh air is not directly supplied to most of the working area in the room. Room 222, which is a small one-person office, appears to be effectively ventilated.

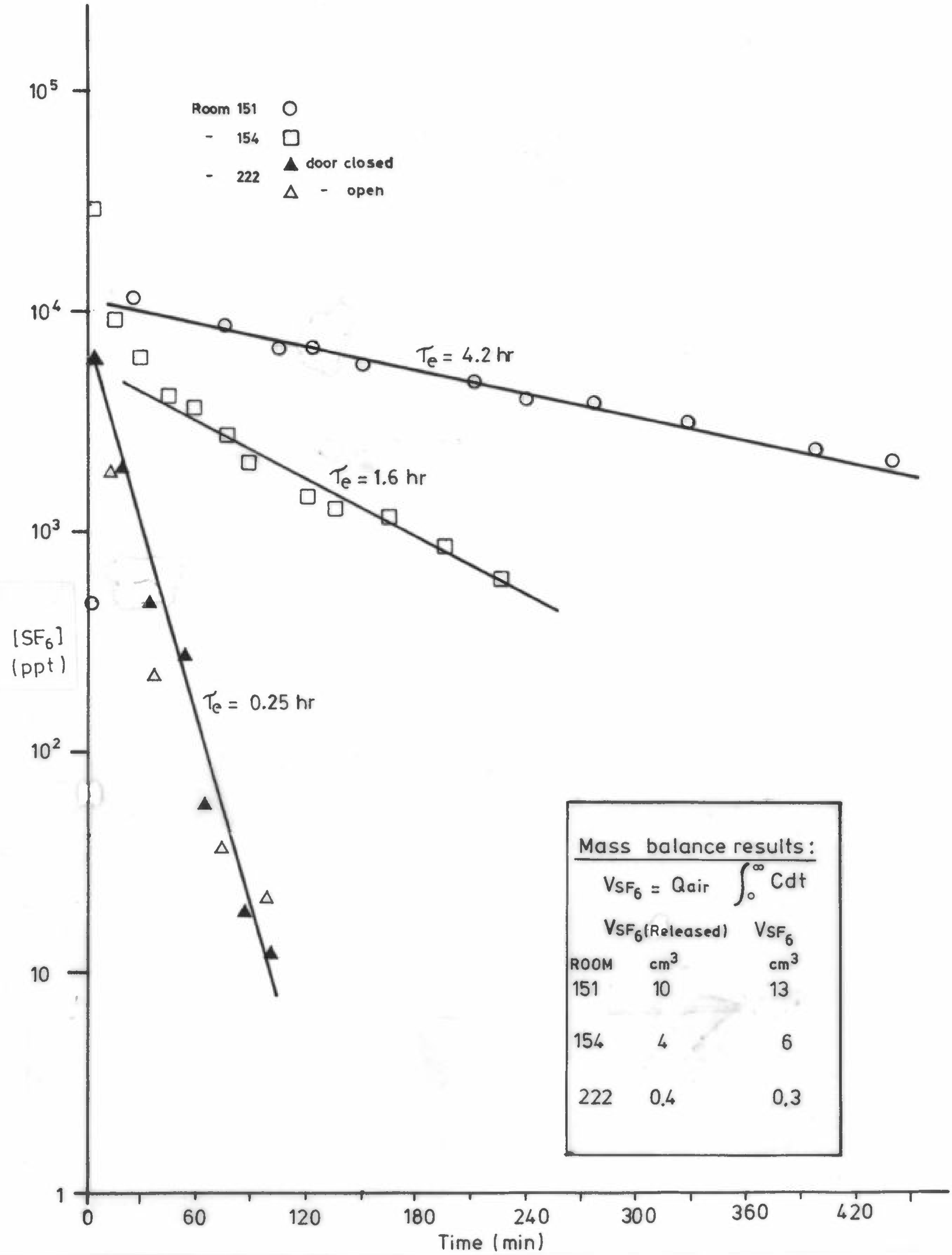

Figure 2: Results of individual room ventilation tests.

This room experiences 4 air changes each hour. Data collected during 2 different tests in room 222 indicate that the ventilation rate is not effected by the position of the door.

A mass balance can be performed on the tracer data since the initial volume released in a room (V_{SF_6}) should be equal to the air flow rate (Q) multiplied by the integral of the concentration (C(t)) as a function of time:

$$V_{SF_6} = Q \int C(t)dt$$

The results of this calculation and the actual volume of SF_6 released are listed in the table shown with Figure 2. The value of Q for room 151 was calculated from $Q = V/\tau_e$; values of Q for the remaining rooms were taken from the ventilation design specifications. Generally, the mass balances show relatively good agreement. The accuracy could be improved by direct measurement of the air flow rate.

4 BUILDING VENTILATION STUDY

A tracer test of the entire NILU building was performed by instantaneously releasing 100 cm^3 of SF_6 into the laboratory inlet vent on the side of the center penthouse. Instantaneous air samples were periodically collected in the laboratory and office exhaust vents, in rooms 151, 154, 122, 222, 309 and at two locations in room 363. The results are shown in Figures 3-6. The SF_6 appeared immediately after the release in both exhaust vents, and in rooms 154, 309 and 363. It appeared in room 222 after approximately 15 minutes and in room 151 after 90 minutes. No SF_6 was observed in room 122.

The concentrations in the laboratory exhaust vent decreased expontentially (τ_e= 0.65 hours) to a steady state concentration equal to approximately 1100 ppt. This steady level was apparently caused by a small leak in an SF_6 bottle stored in a fume hood.

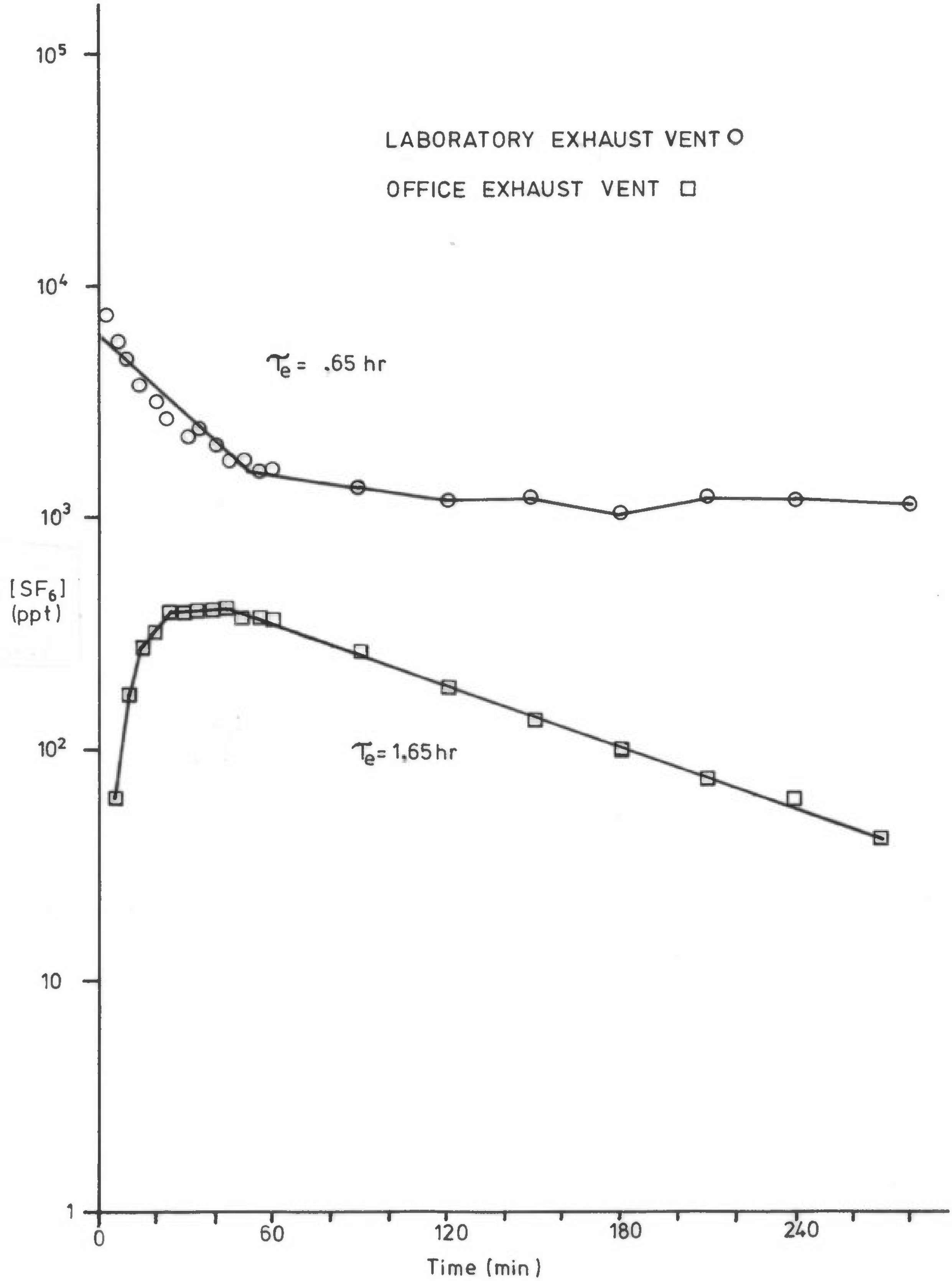

Figure 3: Instantaneous SF_6 concentrations observed in the laboratory and office exhaust vents during the NILU building ventilation test.

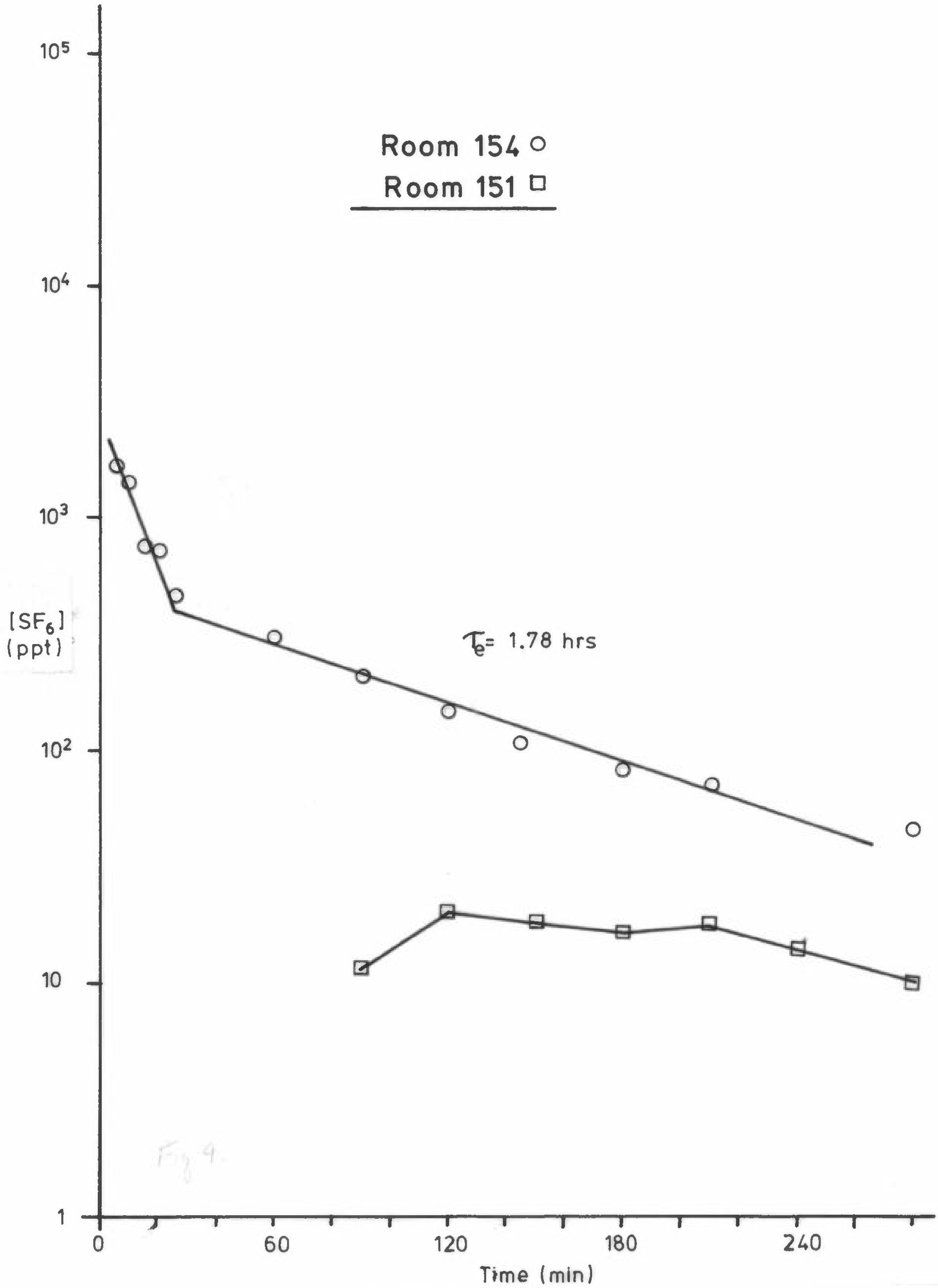

Figure 4: *Instantaneous SF_6 concentrations observed in Rooms 151 and 154 during the NILU building ventilation test.*

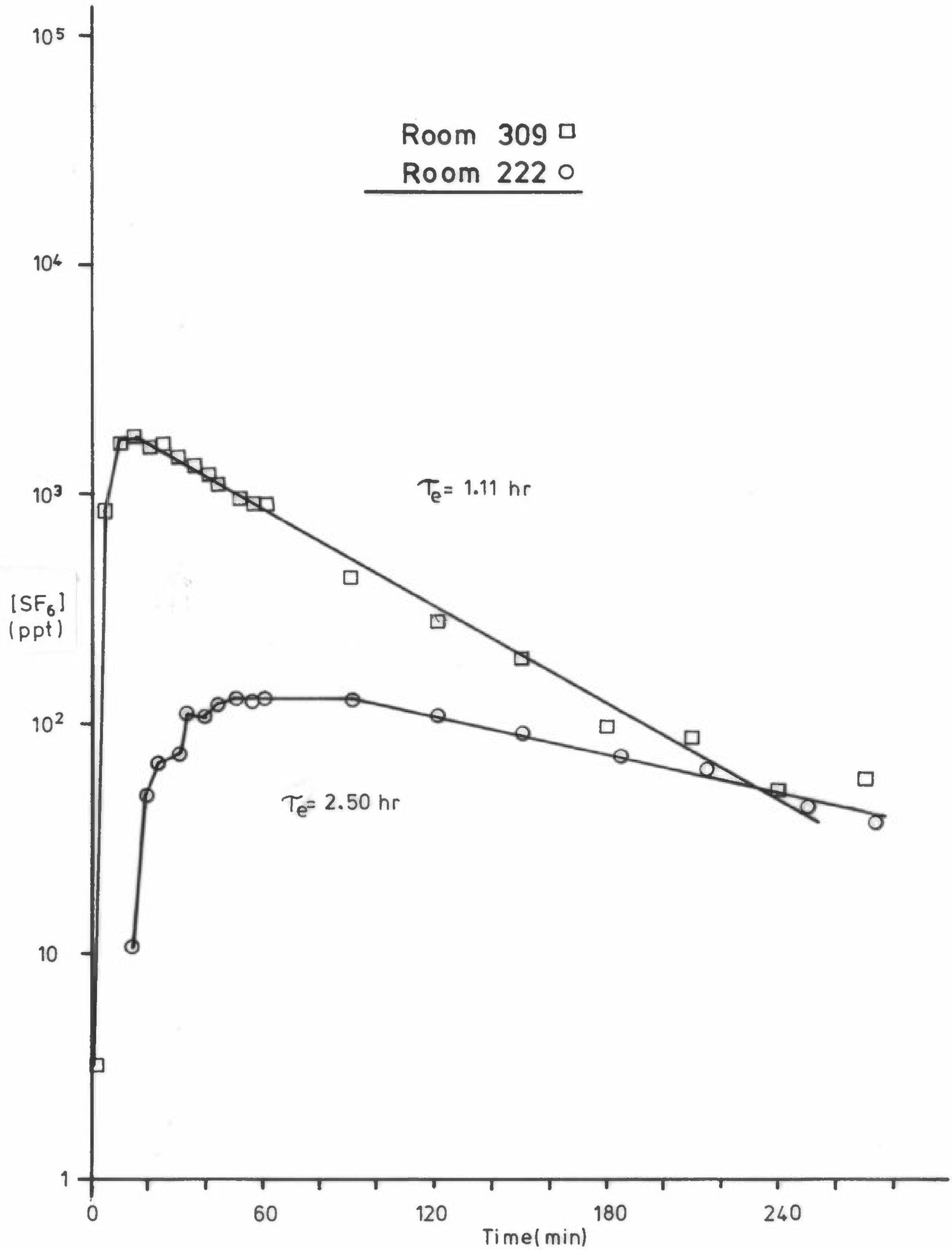

Figure 5: Instantaneous SF_6 concentrations observed in Rooms 222 and 309 during the NILU building ventilation test.

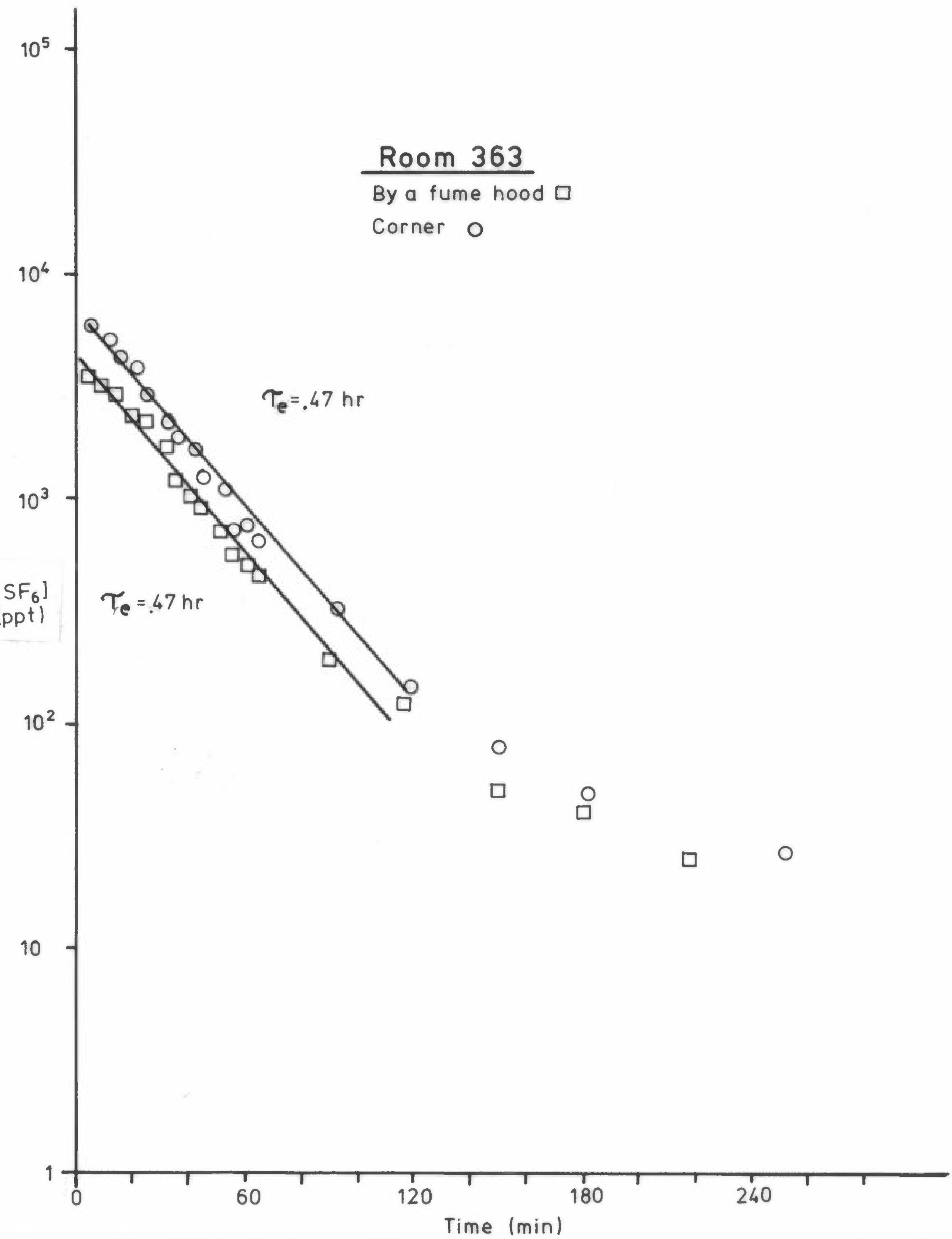

Figure 6: Instantaneous SF_6 concentrations observed at two locations in Room 363 during the NILU building ventilation test.

This leak did not appear to influence concentrations observed elsewhere in the building. The leak rate of SF_6 (Q_{SF_6}) can easily be calculated with the steady state concentration ($\bar{C}_{SF_6}$) and the total air flow rate (Q_{air}):

$$Q_{SF_6} = \bar{C}_{SF_6} \cdot Q_{air} = 13 \text{ cm}^3/\text{hr}$$

Note that if the SF_6 release rate had been accurately measured, the concentration data could be used to calculate the total air flow rate according to this relationship. This method may be of use in other ventilation studies.

Concentrations observed in the other locations all decreased exponentially, but with a large difference in the characteristic concentration decay times. In room 154, τ_e was 1.8 hours which is approximately equal to the value of τ_e measured during the previous individual room studies. In contrast, τ_e for room 222 equaled 2.5 hours in the building test and only 0.25 hours in the individual room tests. Apparently, SF_6 from the laboratory side slowly diffused to the second floor acting as a continuous source to room 222. Similarly, it appears that SF_6 introduced into the ventilated portion of the first floor slowly diffused into room 151. The data collected in front of a fume hood and in a corner of room 363 show that the room is relatively well-mixed with a relatively high ventilation rate. The value of τ_e for both sample locations equaled 0.47 hours. Room 363 is a chemistry laboratory with a large number of fume hoods.

A mass balance can be performed on the data collected at the exhaust vents. If all of the SF_6 released into the building was exhausted through the ventilation system, the calculated volume of SF_6 observed at the exhaust ducts should equal the volume initially released. However, this calculation indicates that only 57% of the SF_6 was emitted through the laboratory exhaust duct, while 2% of the SF_6 was observed in the office exhaust.

The discrepency between the volume released and that observed suggests that the SF_6 escaped by another means or that the specified air flow rate was lower than the actual value. Because the building is new, and during the test, windows were closed, it does not appear that a significant amount of SF_6 could escape by exfiltration from the building. Accurate measurement of the air flow rate might yield a result higher than that currently specified.

Significantly, the mass balance results indicate that only 2% of the gas released into the laboratory ventilation system is transported into the office exhaust system. In contrast, the office exhaust flow rate accounts for 21% of the laboratory fresh air supply. It appears that most of the office fresh air supply is drawn from outside the building through windows and doors.

A summary of the experimental and calculated characteristic decay constants is given in Table 2. The ratio of these constants, $k = \tau/\tau_e$, is also listed for each case. Generally, values of k will be less than 1 for rooms which are not well-mixed, such as room 154. The value of k will approach 1 for rooms which are relatively well-mixed; room 363 and the office exhaust system appear to belong in this category. The value of k will only be larger than 1 if there is an error in the value of τ or τ_e. Since the volume of a system can be easily determined generally, a high value of k suggests that the actual air flow rate is larger than the value used in the calculation. It appears that the specified values of Q for room 222 and for the laboratory system are smaller than the actual flow rates. These apparent errors in the values of Q may explain why the mass balance results for room 222 and for the laboratory exhaust system were lower than expected.

Table 2: Comparison of calculated and experimental air residence times.

Location	τ (hr)	τ_e (hr)	$k = \tau/\tau_e$
Room 151	-	4.2	-
Room 154	0.6	1.6	0.4
Room 222	0.6	.25	2.4
Room 363	0.4	.47	0.9
Laboratory exhaust system	0.9	.65	1.4
Office exhaust system	1.3	1.65	0.8

5 CONCLUSIONS

The individual room experiments and the building experiment show that large differences in the ventilation efficiencies of different rooms occur in the NILU building.
The chemistry laboratory and the offices for research and administrative personnel have relatively high ventilation rates. In contrast, both the forced-ventilated and naturally-ventilated portions of the instrument lab have low ventilation rates. Significant levels of SF_6 appeared on both sides of the building almost immediately after the release. However, mass balance calculations indicate that only 2% of the gas released into the laboratories on the north side was exhausted through the offices on the south side. The tracer data also suggest that in some cases, existing air flow rates may be greater than those specified in the ventilation design data.

During these tests, a total of 223 samples was collected and analysed. The total amount of SF_6 used in these studies was less than 115 cm^3 (0.7 g). The number of person-hours for sampling and analysis was approximately 20 hours. The cost of the equipment (excluding the gas chromatographs) and the labor was less than 3500 N.kr. These facts and the results presented herein demonstrate that tracer techniques offer a simple, relatively inexpensive method for characterizing building ventilation systems.

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