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ESTIMATION OF ZONE EFFECTIVE-VOLUME USING TRACER-GAS TECHNIQUES

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ABSTRACT

The concentration-decay and pulse-injection tracer-gas techniques were used to evaluate the effective volume of a zone, Measurement of airflow rates were carried out in an environmental chamber using SF_6 as the tracer gas. Results showed the flow rate estimated from the concentration-decay technique is about 4.5 to 14.3% higher than actual flow rate if the effective volume of the chamber is assumed equal to the physical volume. The effective volume estimated from tracer-gas measurements was found to be about 1.5 to 2.7% higher than the physical volume of the chamber.

NOTATION

$C_{d(0)}$	Concentration of tracer gas at t = 0, tracer-decay technique (ppm)
$C_{d(t)}$	Concentration of tracer gas at t > 0, tracer-decay technique (ppm)
$C_{p(t)}$	Concentration of tracer gas at t > 0, pulse-injection technique (ppm)
F_d	Airflow rate based on tracer-decay technique (m^3/s)
F_p	Airflow rate based on tracer-gas pulse-injection technique (m^3/s)
F_w	Airflow rate based on Wilson-flowgrid measurements (m^3/s)
$G_{(t)}$	Pulse-injection rate (m^3/s)

t Time (s)

V_{et} Effective volume of the chamber, based on tracer-gas measurements (m^3)

V_{ew} Effective volume of the chamber, based on Wilson-flowgrid measurements (m^3)

V_{ph} Physical volume of the chamber (m^3)

INTRODUCTION

Accurate prediction of airflow in buildings is important as it affects energy efficiency, thermal comfort and air quality. Tracer-gas techniques such as concentration-decay, pulse-injection and constant-injection, can be used to determine airflow in buildings although it is the concentration-decay technique which is most widely used as it requires relatively simple equipment. The decay technique involves the injection of a tracer gas into a zone followed by a period of mixing to establish a uniform tracer-gas concentration. The decay of tracer-gas concentration is then measured and airflow rate can be estimated using equation (1). It is seen from equation (1) that the volume used to estimate airflow rate is the effective volume. This is the volume in which mixing occurs and is not necessarily equal to the physical volume of the zone. Furniture can make the effective volume smaller than the physical volume (see Figure 1) whereas "dead" volumes such as a false ceiling and connected zones can make the effective volume larger than the physical volume. In most tracer gas measurements, the effective volume of a building is assumed to be equal to the physical volume and the presence of furniture and other "dead" volumes is ignored. This can lead to considerable errors in estimating airflow rates. A preliminary study on estimation of the effective volume in a multizone situation has been carried out by Afonso and Maldonado[2]. The study did not examine the effect on airflow rate of varying the amount of furniture in the room.

The present paper examines the errors which arise if the airflow rate is estimated with the assumption that the effective volume of a zone is equal to the physical volume. Measurements of airflow rates were carried out in a single-zone chamber using SF_6

tracer gas. The concentration-decay and pulse-injection techniques were employed to estimate the effective volume of the chamber.

THEORY

The effect volume of a zone can be estimated using the concentration-decay and pulse-injection techniques. The concentration-decay technique was used to estimate the air-change rate in chamber. The decay method involves the initial injection of a tracer gas, eg, SF_6, into the chamber followed by a period of mixing to establish a uniform tracer-gas concentration. The decay of tracer gas is then measured. Assuming that the concentration of tracer gas in the outdoor air is negligible, and that there is no source of tracer gas within the chamber, the air-flow rate can be given by the following equation:

$$F_d = (1/t)\, V_{et}\, \mathrm{In}\, (C_{d(0)}/C_{d(t)}) \qquad (1)$$

The pulse-injection technique was used to estimate airflow rate supplied via a duct to the chamber. This technique is based on the injection into the duct inlet of a short-duration pulse of tracer gas, at a rate $G_{(t)}$. The variation of concentration with time is measured at the duct exit. The amount of injected tracer gas is small, so it does not contribute significantly to the volume flow rate of air in the duct.

If we assume that the tracer gas is well mixed across the section of the duct, then the volume flow rate of tracer gas leaving the duct is equal to the product of the flow rate and the exit concentration (ie, $F_{(t)} \times C_{(t)}$). If the tracer gas is assumed to be purged from the duct after a time interval (t_1 t_o t_2) then the volume of tracer gas leaving the duct must equal the amount injected. Applying the integral volume balance of tracer gas, we have[3]:

$$F_P = [\int_{t_1}^{t_2} C_{P(t)}\, dt]^{-1} \int_{t_1}^{t_2} G_{(t)}\, dt \tag{2}$$

Substituting equation (2) into (1) we have:

$$V_{et} = \frac{[\int_{t_1}^{t_2} C_{p(t)}\, dt\,]^{-1} \int_{t_1}^{t_2} G_{(t)}\, dt}{(1/t)\ \ln (C_{d(0)}/C_{d(t)})} \tag{3}$$

EXPERIMENTAL

Experiments were carried out using a single-zone chamber shown in Figure 2. The chamber was 7.2m x 1.42m x 1.71m and was constructed from plywood sheet with a cavity wall insulated using glass wool. The front panel of the chamber was made of perspex in order to allow smoke visualisation tests to be carried out. Air was supplied to chamber via a variable speed centrifugal fan, made by Fischback Ltd, Germany. The capacity of the fan was controlled using a speed controller. The fan was attached to a 310mm diameter galvanised-steel duct.

The pulse-injection technique was used to measure airflow in duct. This involved the injection of 1.5L of SF_6 at the inlet of the fan and monitoring the downstream concentration using a sample bag. The pump attached to the sample bag was switched on 10 seconds before injection was begun and switched off after the tracer gas had been completely purged. A Wilson pitot-tube grid, made by Airflow Development Ltd, High Wycombe, UK, was used to cross-check the results. A honeycombe disperser was placed in the duct close to the fan in order to improve the accuracy of velocity pressure readings taken from the flowgrid. The Wilson flowgrid was connected to an electrical manometer to enable velocity readings to be made,

The tracer-decay technique involved injection of 10.5L of SF_6 into the chamber. Five small axial fans placed at different locations in the chamber were employed to improve the mixing of tracer gas with air. The tracer gas was allowed to mix for about 1 hour before samples were taken from the chamber. A multi-point sampling unit was used to collect tracer gas samples from the chamber for subsequent injection into a gas analyser.

The concentration of tracer gas was measured using an infra-red gas analyser, type BINOS 1000, made by Rosemount Ltd, Hanau, Germany. The accuracy of the measurements was estimated to be within ± 5%.

Boxes of 1, 1.5, 2, 2.5 m^3 were used to compare the physical volume with the measured effective volume. The boxes were placed in the chamber during the tests in order to determine their effect on the flow rate estimated using tracer-gas techniques.

RESULTS AND DISCUSSION

Experiments were performed to compare the physical volume of the chamber with the effective volume estimated from tracer-gas measurements. The first experiment was carried to determine the airtightness of the chamber. In this case, the inlet and outlet of the chamber were sealed and the tracer-gas decay technique was used to estimate the air-change rate. The air-change rate was found to be $0.042h^{-1}$.

Tests were then carried out to determine the effective volume of the chamber when it was completely empty and when boxes of 1 - 2.5 m^3 were placed in the chamber. The pulse-injection technique and Wilson grid were used to estimate the air flow rate supplied to the chamber and the tracer-decay technique was used to determine the air-change rate. Air was supplied to the chamber at a constant rate of 0.1111 m^3/s as measured using the pulse-injection technique (or flow rate = 0.1117 m^3/s using Wilson flowgrid). Each experiment was repeated twice to cross-check the results. Figure 3 shows the variation of tracer-gas concentration with time for various tests. The estimated effective volume and airflow rate are given in Table 1.

It is clear from Table 1 that the effective volume estimated from tracer-gas techniques is about 1.5 to 2.7% higher than the physical volume. For measurements based on the Wilson flowgrid, the estimated effective volume was about 2 to 3.2% higher than the physical volume of the chamber.

If the effective volume was not estimated accurately (ie, volume of the boxes placed in the chamber were not accounted for) the flow rate estimated from the tracer-gas decay technique was about 4.5 to 14.3% higher than the actual flow rate supplied to the chamber. Similar results were obtained when the Wilson flowgrid was used to estimate the airflow rate supplied to the chamber.

CONCLUSIONS

This study showed that is is necessary to estimate the effective volume accurately if the tracer gas decay-technique is used to estimate the airflow rate in a building. The volume of furniture and other "dead" volumes in the room must be accounted for and a minimum time of about 1 hour is necessary to achieve adequate tracer mixing for accurate measurement of airflow rate.

REFERENCES

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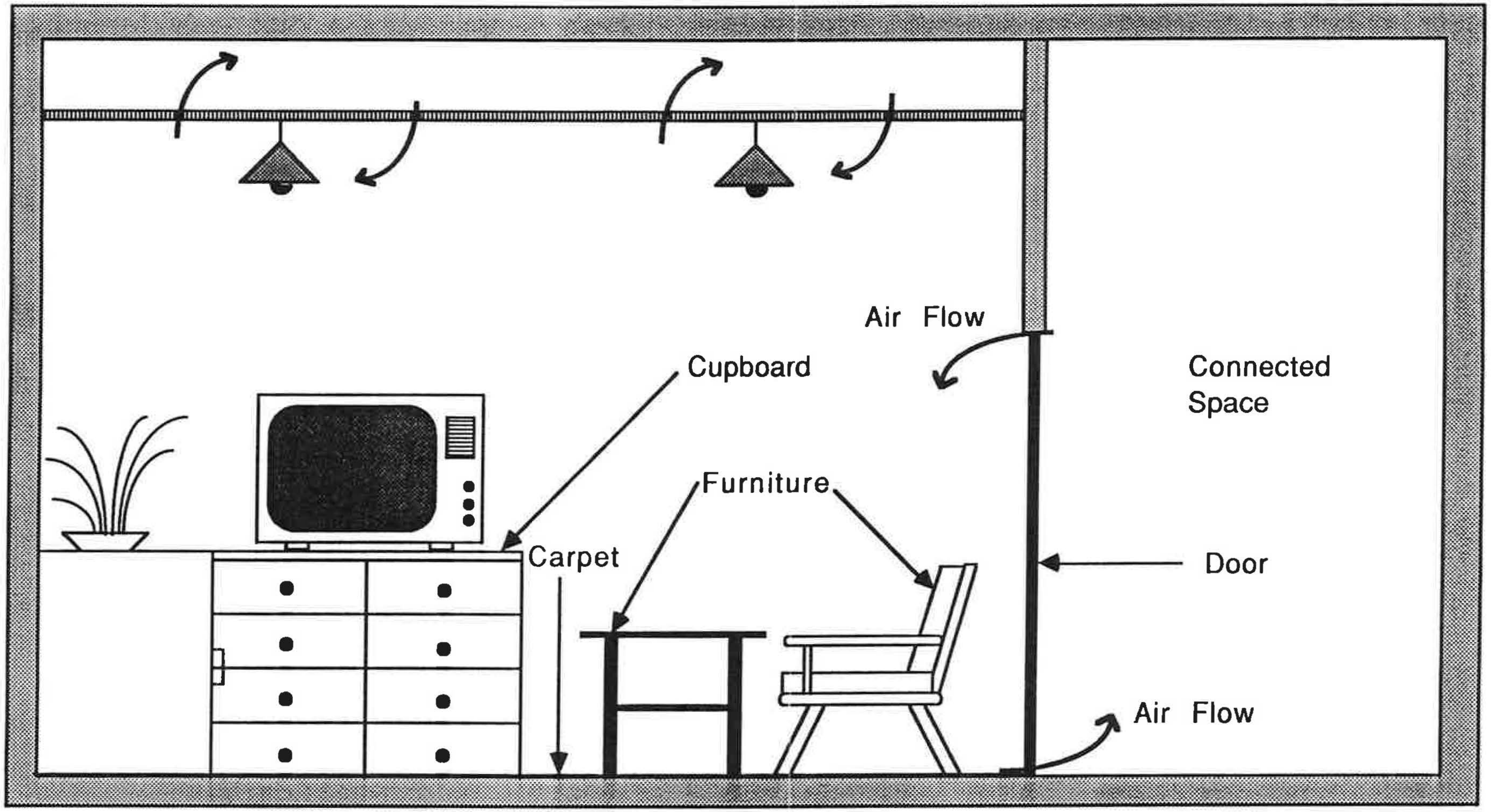
Figures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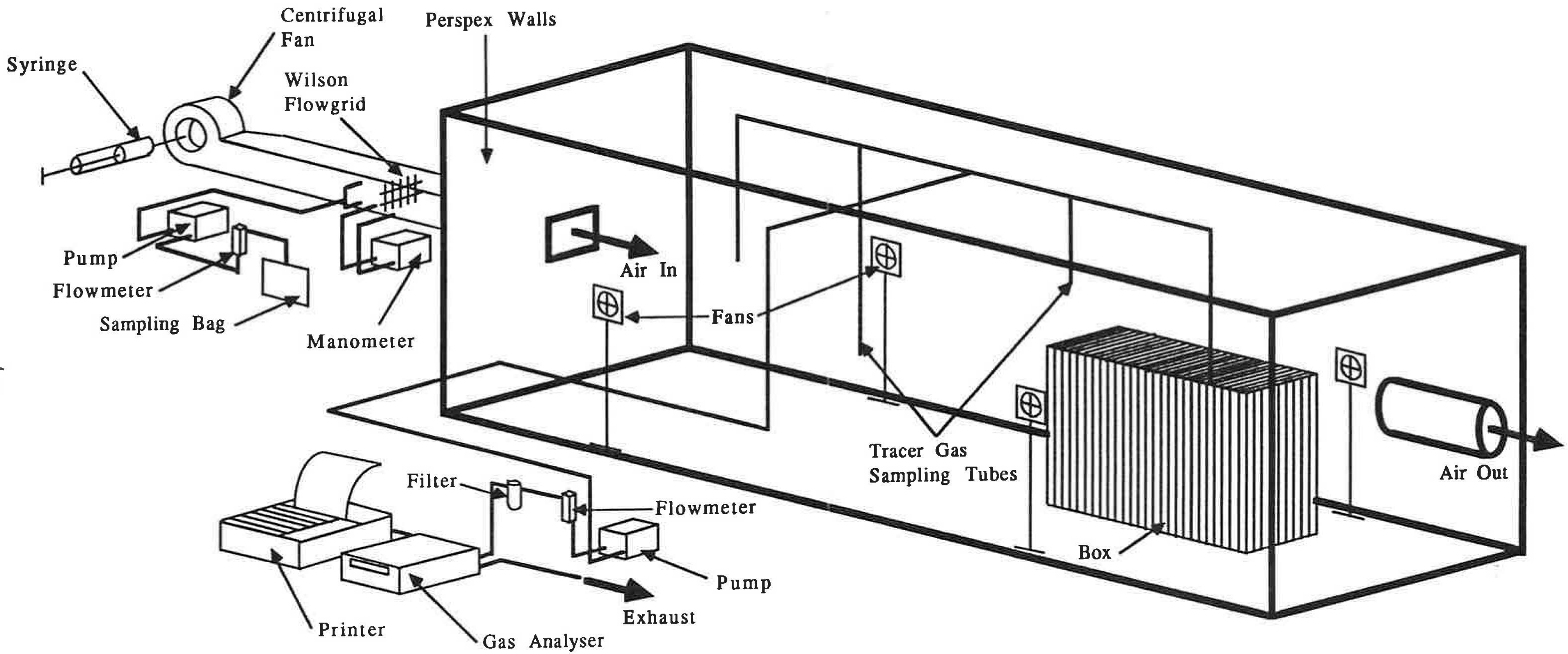
Furniture
Carpet
Door
Air Flow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Wilson Flowgrid
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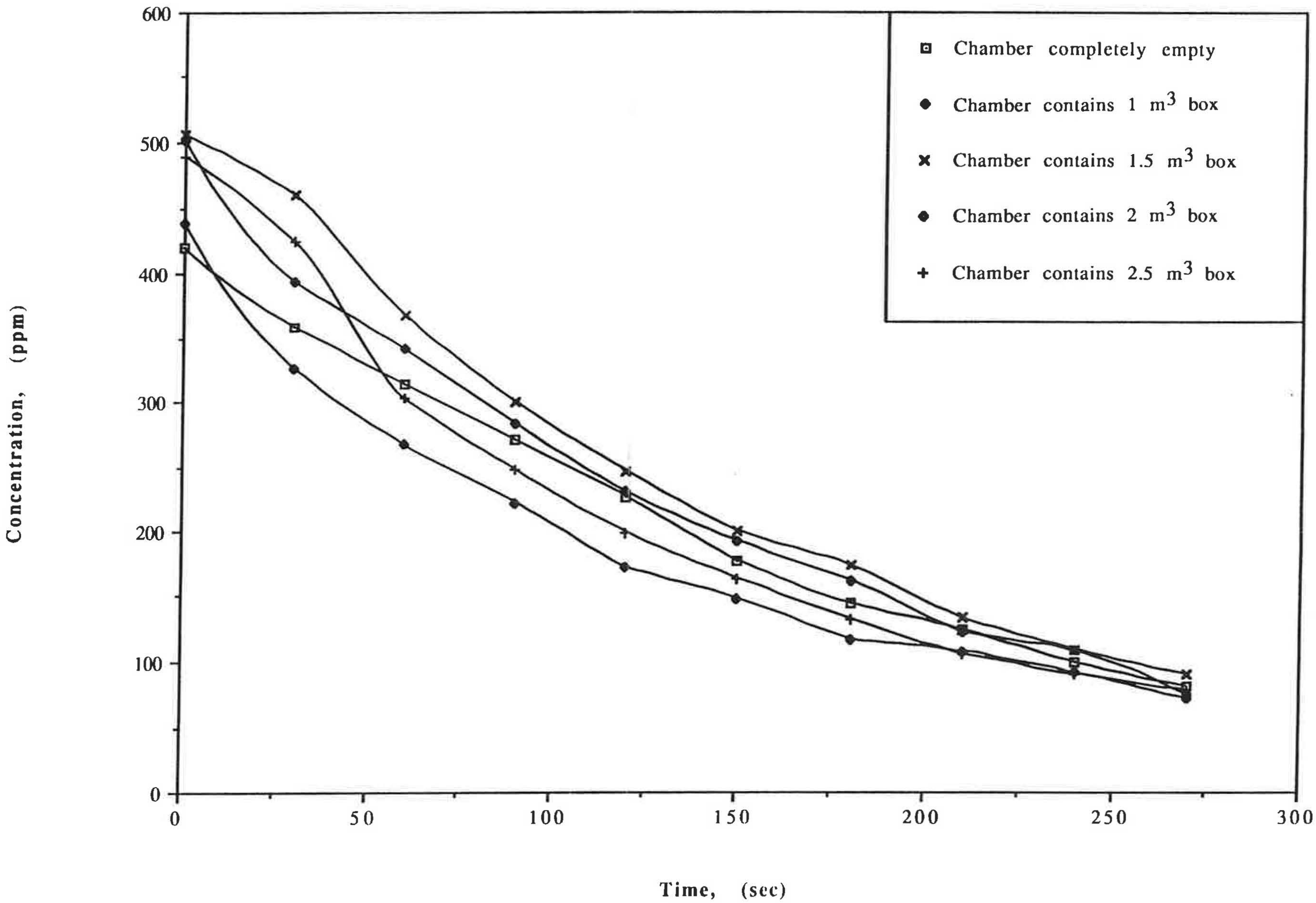
Exhaust
Printer
Gas Analyser



Chamber completely empty
Chamber contains 1 m3 box
Chamber contains 1.5 m3 box
Chamber contains 2 m3 box
Chamber contains 2.5 m3 box
Concentration, (ppm)
Time, (sec)
0
100
200
300
400
500
600
50
150
250

TABLE 1 Experimental Results

CONDITION	AIR CHANGE RATE (s-1)	Vet (m3)	Vew (m3)	Vph (m3)	(Vet -Vph)/Vph (%)	(Vew - Vph)/Vph (%)	(Fd - Fp)/Fp (%)	(Fd - Fw)/Fw (%)
Chamber completely empty	0.00596	18.64	18.74	18.16	2.64	3.19	-2.58	-3.10
Chamber contains 1 m3 box	0.00639	17.39	17.49	17.16	1.34	1.92	4.45	3.89
Chamber contains 1.5 m3 box	0.0065	17.08	17.17	16.66	2.52	3.06	6.25	5.68
Chamber contains 2 m3 box	0.00674	16.48	16.56	16.16	1.98	2.48	10.17	9.58
Chamber contains 2.5 m3 box	0.00699	15.9	15.99	15.66	1.53	2.11	14.26	13.64