Energy Impact of Ventilation and Air Infiltration
14th AIVC Conference, Copenhagen, Denmark
21-23 September 1993

Computer Modelling & Measurement of Airflow in an Environmental Chamber

J S Kohal, S B Riffat

Building Technology Group, School of Architecture,
University of Nottingham, University Park Nottingham,
NG7 2RD, UK

SYNOPSIS

The use of sulphur hexafluoride (SF_6), nitrous oxide (N_2O) or carbon dioxide (CO_2) as tracer-gases have been examined for the measurement of airflow in a two-zone environmental chamber. A series of measurements were carried out to examine airflows through a doorway under natural convection, forced convection and combined natural and forced convection. Results were compared with those predicted using the MULTIC computer program.

LIST OF SYMBOLS

$C(t)$	Concentration of tracer gas at $t > 0$ (ppm)
$C(_0)$	Concentration of tracer gas at $t = 0$ (ppm)
H	Opening height (m)
W	Opening width (m)
T_1	Air temperature in zone 1 (^0C)
T_2	Air temperature in zone 2 (^0C)
ΔT	Temperature difference (^0C)
t	Time (s)
V	Volume of zone (m^3)
F	Volumetric flow rate (m^3/s)
ACH	Air change rate (h^{-1})

1. INTRODUCTION

Accurate prediction of air movement in buildings is an important factor influencing the design of HVAC systems, energy efficiency, thermal comfort and indoor air quality. Considerable effort has been invested in the development of airflow computer programs, eg., MULTIC (1), BREEZE (2), COMIS (3). However, further work to validate these models using experimental data is required before they can be used with confidence in ventilation studies.

Measurement of airflow in buildings can be accomplished using tracer-gas techniques (4) such as concentration-decay, constant-concentration and pulse-injection. The concentration-decay technique is widely used for measurement of airflows as it requires relatively simple equipment. The decay technique involves the injection of a known amount of tracer-gas into a building followed by a period of mixing to establish a uniform tracer-gas concentration. The decay of gas concentration is then measured. Various tracer-gases have been used but their relative accuracies for estimating airflows are uncertain.

The first objective of this paper is to evaluate errors in airflow measurements using different tracer-gases such as SF_6, N_2O and CO_2. The second objective is to compare measured values of interzonal airflow with those predicted by the MULTIC computer program.

A series of measurements of airflow through a doorway in a two-zone environmental chamber have been carried out. Airflows under natural convection, forced convection and combined natural and forced convection were examined.

2. EXPERIMENTAL

Experiments were carried out using an environmental chamber, Figure 1. The chamber consisted of two tightly sealed zones, each with dimensions of 2.5m x 3.0m x 2.4m. The chamber was constructed of plywood sheet with a cavity insulated using polystyrene.

Air was supplied to the chamber via a variable speed axial fan. The fan type, 315-D63SG/5/12/Bb was made by ELTA Fan Ltd. UK. The capacity of the fan was adjusted using a speed controller. A similar fan was used to extract the air from the chamber. The fans were connected to the chamber using ducts made of galvanised sheet of 0.3m diameter. Each zone was provided with three grilles (size = 2.0 m x 0.5 m) which were located on the side wall and ceiling of the chamber. The grilles with spiliters were used to supply and extract air from the chamber. The two zones were separated by a sliding doorway. The height (H) of the doorway could be adjusted but the width (W) was fixed at 0.7 m.

A multi-point sampling unit was used to collect tracer-gas samples from each zone for subsequent injection into a gas analyser, see Figure 2. The concentrations of SF_6 and N_2O tracer gas were measured using a BINOS 1000 analyser made by Rosemount Ltd., Germany. The concentration of CO_2 was measured using MIRAN IB2 analyser made by Quantitech Ltd., UK.

The experimental procedure involved the initial injection of a tracer gas into the chamber. Following a mixing period of about 30 min, using fans, the decay of tracer gas was measured. Assuming that the concentration of tracer gas in the outdoor air is negligible and that there is no further generation of tracer gas in the zone after time zero, the following equation can be used to estimate the airflow rate.

$$F = (1/t)\, V\, \ln [C(0) / C(t)] \tag{1}$$

3. RESULTS AND DISCUSSION

3.1 Accuracy of Tracer-Gases for Measuring Airflows

A series of tests were conducted in the chamber using SF_6, CO_2 and N_2O tracer gases. Table 1 shows the experimental results.

The first tests were conducted using SF_6 tracer-gas. Figure 3 shows typical variations of tracer-gas concentration with time for an air exchange rate of 42.6 h^{-1}. The rate of change of tracer-gas concentration in the chamber was small at low airflow rates but increased at higher flow rates. Well-conditioned data was obtained during these measurements, as shown by the concentration/time curve. This indicated that uniform tracer-gas concentration had been achieved in the chamber after a mixing period of 30 min. Figure 4 shows the variation of air change rate measured using a pitot tube and hot wire anemometer with air change rate measured using SF_6 tracer-gas. The differences between air change rates measured using the SF_6 tracer gas and measurements made using the pitot tube and hot wire anemometer are given by:

$$D_{TP} = \frac{ACH_{tracer} - ACH_{pitot}}{ACH_{pitot}} \times 100 \qquad (2)$$

$$D_{TH} = \frac{ACH_{tracer} - ACH_{hot\text{-}wire}}{ACH_{hot\text{-}wire}} \times 100 \qquad (3)$$

Table 1 shows comparison of air change rate measurements made using SF_6, CO_2 and N_2O tracer gas with observations made using pitot tube and hot-wire methods.

The minimum and maximum values of D_{TP} and D_{TH} were in the ranges - 34 to 25% and -32 to 14% respectively. The average values of D_{TP} and D_{TH} were - 11 and 7% respectively.

The second tests were carried out using CO2 as the tracer-gas. Figure 5 shows the concentration versus time curves for an air exchange rate of 28.5 h^{-1}. The variation of air exchange rate measured using the pitot tube and hot-wire anemometer with air change rate measured using N_2O is given in Figure 6. The minimum and maximum values of D_{TP} and D_{TH} were in the ranges - 14 to 18% and -4 to 10% respectively. The average values of D_{TP} and D_{TH} were -1 and 4%, respectively. On this basis air change rate measured using SF_6 and N_2O were in closer agreement with pitot tube and hot-wire measurement than values obtained with CO_2.

The final set of measurements were carried out using N_2O. Figure 7 shows the concentration versus time curves for an air exchange rate of 41.2 h^{-1}. The variation of air change rate measured using the pitot tube and hot-wire anemometer with air change rate measured using N_2O is given in Figure 8. The minimum and maximum values of D_{TP} and D_{TH} were in the ranges - 14 to 18% and -4 to 10% respectively. The average values of D_{TP} and D_{TH} were -1 and 4%, respectively. On this basis air change rate measured using SF_6 and N_2O were in closer agreement with pitot tube and hot-wire measurement than values obtained with CO_2.

3.2 Airflow Measurements Between Two Zones

Measurements of airflow rate were carried out using the two-zone chamber. The concentration-decay technique using SF_6 tracer gas was used in these tests. The experimental procedure involved the injection of tracer gas in zone 1 while the connecting doorway was closed. Following a mixing period of about 30 min, the sliding door between the two zones was opened to a certain height (eg, 10 cm) and the concentration of SF_6 in each zone was measured simultaneously. SF_6/air samples were taken from various locations in each zone using sampling tubes connected to a manifold.

Experimental work involved investigation of interzonal airflow under the following conditions:

i) Natural convection
ii) Forced convection
iii) Combined natural and forced convection

The first tests (i) were carried out to study the effect of interzonal temperature difference on airflows through openings having dimensions (HxW) of 0.1m x 0.7m, 0.2m x 0.7m and 0.3m x 0.7m. Zone 1 was heated to various temperatures using a thermostatically controlled heater. Zone 2 was unheated. Air temperatures were measured at the centre of each zone and the outside temperature during the measurement periods was also recorded. The accuracy of the temperature sensors was $\pm$ 0.1 ^{0}C.

Figure 9 shows the variation of tracer-gas concentration with time for an interzonal temperature difference of 12.8 ^{0}C and opening size of 0.1m x 0.7m. The decay curve in zone 1 was found to be a simple exponential function of time. This indicates that the tracer gas in the zone was fully dispersed. The flow rate through the opening was found to increase as the size of the opening became larger. For example, the interzonal airflow was 4.05 L/s for an opening of 0.1 m x 0.7 m compared with 11.7 L/s for an opening of 0.3m x 0.7 m. Comparison of experimental results with airflow rates predicted by the MULTIC program were generally in good agreement. The flow rate predicted by the MULTIC program through an opening of 0.3m x 0.7 m was 16.2 L/s compared with a measured value of 11.7 L/s.

The second series of airflow measurements was carried out under forced convection. Figure 10 shows the variation of tracer-gas concentration with time for forced convection. In this case the heater in zone 1 was switched off and air was supplied to the chamber via the axial fan. Airflow rates were found to be 31 and 45 L/s for openings of 0.2 m x 0.7 m and 0.3 m x 0.7 m, respectively.

The final set of tests were conducted under combined natural and forced convection. In this case the heater and axial fan were switched on. Figure 11 shows the variation of tracer-gas concentration with time for combined natural and forced convection. The combined flow rate through the openings was significantly higher than values obtained under natural convection. For example, the combined air flow through an opening of 0.1 m x 0.7 m was 43.7 L/s compared with 4.05 L/s for natural convection. The difference in airflow measurements under combined natural and forced convection and those obtained using forced convection was less pronounced. For example, the combined air flow rate through an opening of 0.3 m x 0.7 m was 64.35 L/s compared with 45.45 L/s for forced convection.

4. CONCLUSIONS

i) The use of SF_6, N_2O and CO_2 tracer gas has been examined using the concentration-decay technique. Tracer-gas measurements made using SF_6 and N_2O were found to be in closer agreement with pitot tube and hot-wire measurements than those made using CO_2.

ii) Measurements of interzonal airflow rates through openings of different sizes indicated that combined natural and forced convection gives readings about 40% higher than airflow rates obtained under forced convection alone.

iii) Airflow measurements made using the concentration-decay technique were

ACKNOWLEDGEMENT

We wish to express our thanks to Professor K.E. Siren, Helsinki University of Technology, for providing a copy of the MULTIC program.

REFERENCES

1. Siren, K., "A procedure for calculating concentration histories in dwellings" Building and Environment, 23(2), 103-114, 1988

2. BREEZE, "A multizone infiltration model", Air Infiltration Review, 9(1), 1-3, 1987

3. International Workshop COMIS, Conjunction of multizone infiltration specialist at Lawrence Berkeley Laboratory, Berkeley, CA, 1988/1989.

4. Lagus, P. and Persily, A.K., "A review of tracer-gas techniques for measuring airflow in buildings", ASHRAE Trans. 92(2), 1075-1087, 1985.

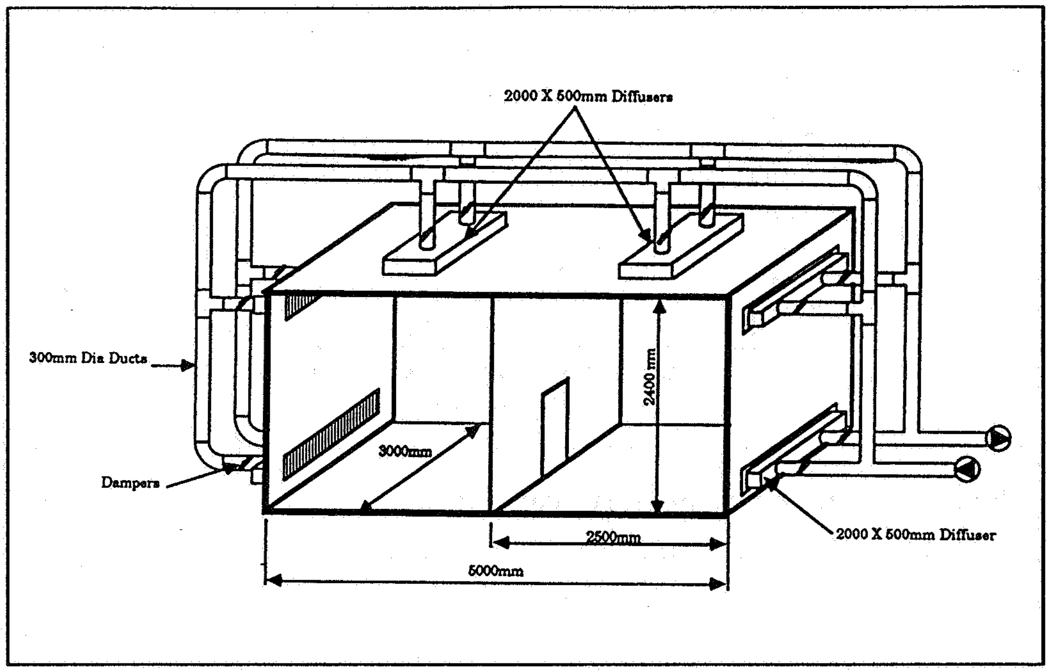

Figure 1 - A Two-zone chamber for tracer-gases technique.

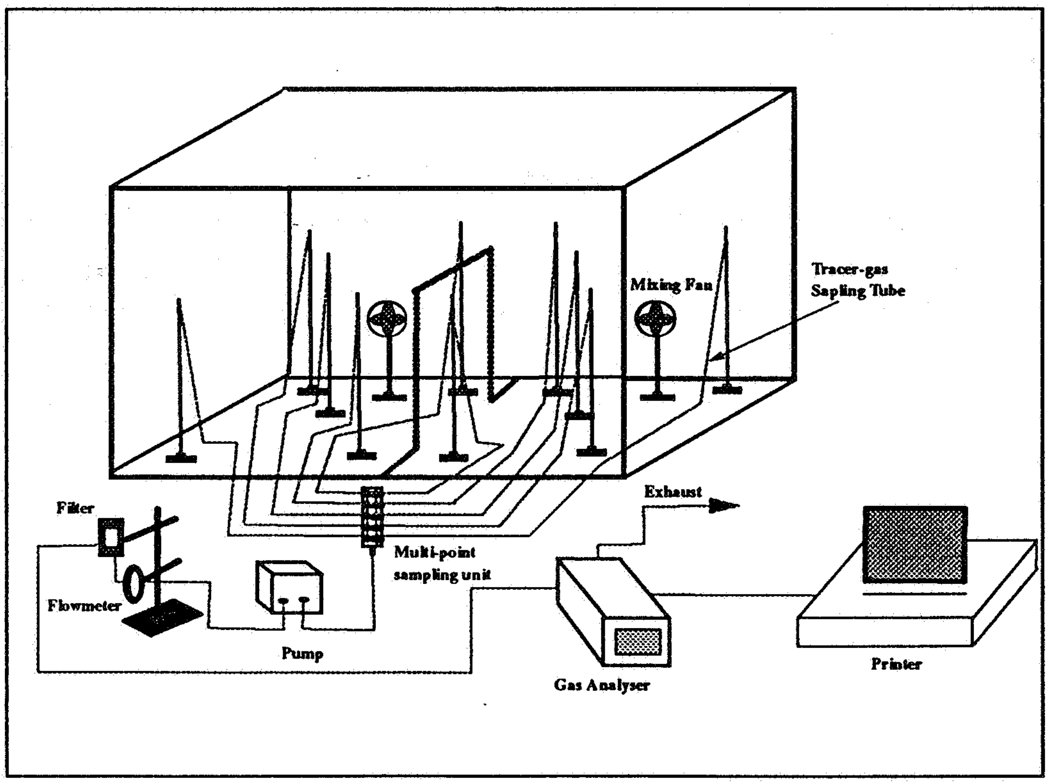

Figure 2- Schematic of the two-zone chamber instrumation for measuring airflows .

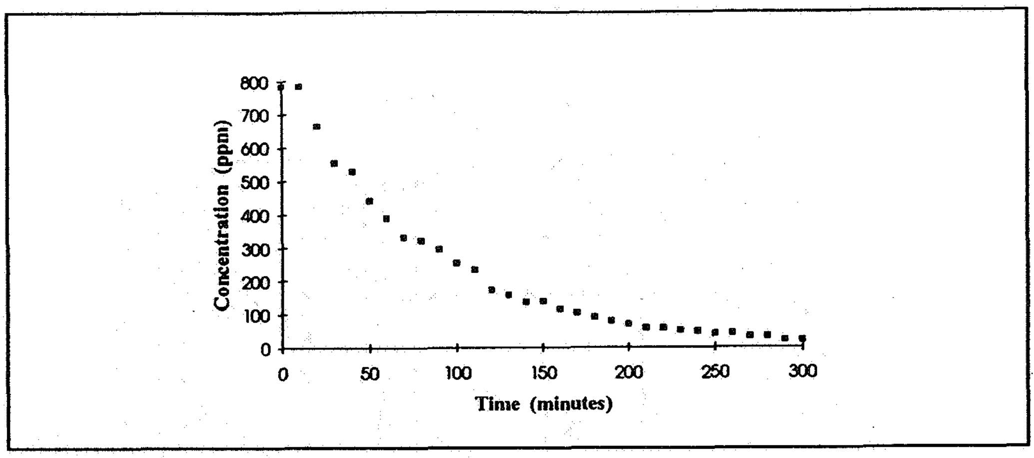

Figure 3 - The variation of SF_6 concentration with time, ACH = 42.6

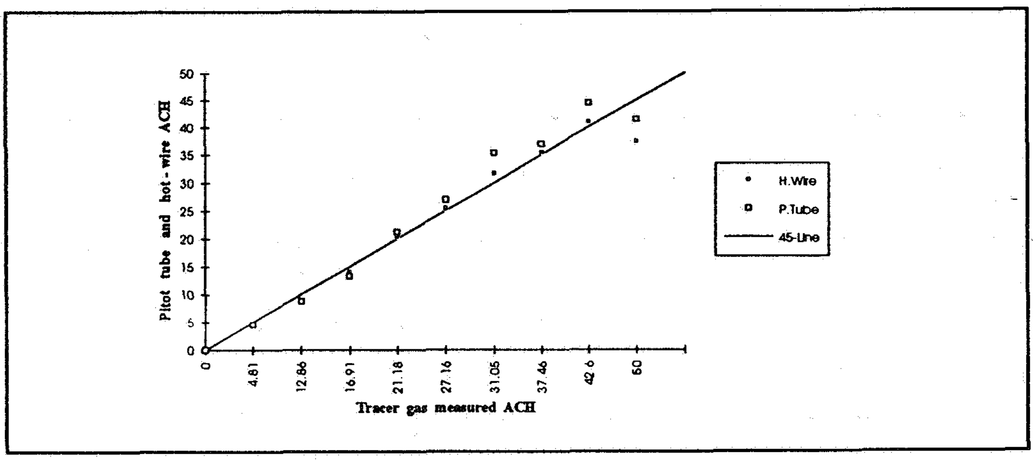

Figure 4 - Comparison of air change rate measurements made using SF_6 tracer gas with observations made using pitot tube and hot-wire methods.

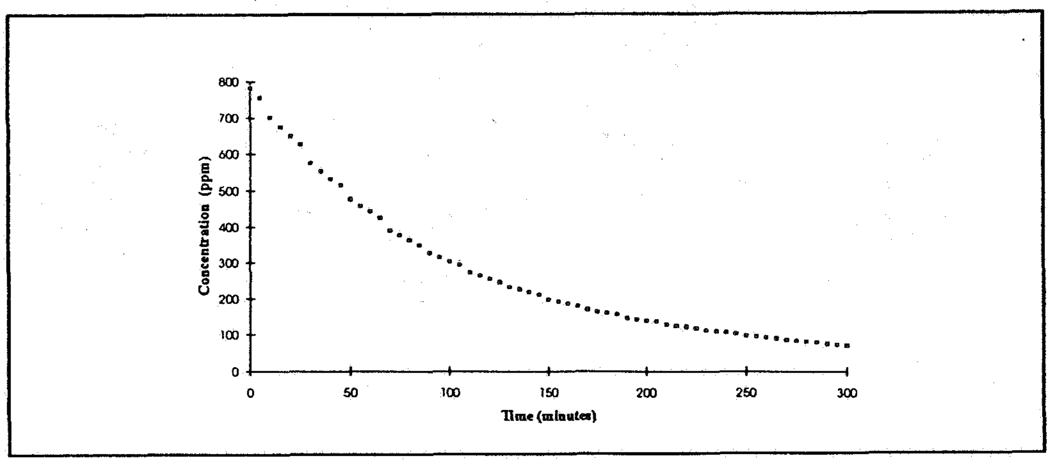

Figure 5 - The variation of CO_2 concentration with time, ACH = 28.5

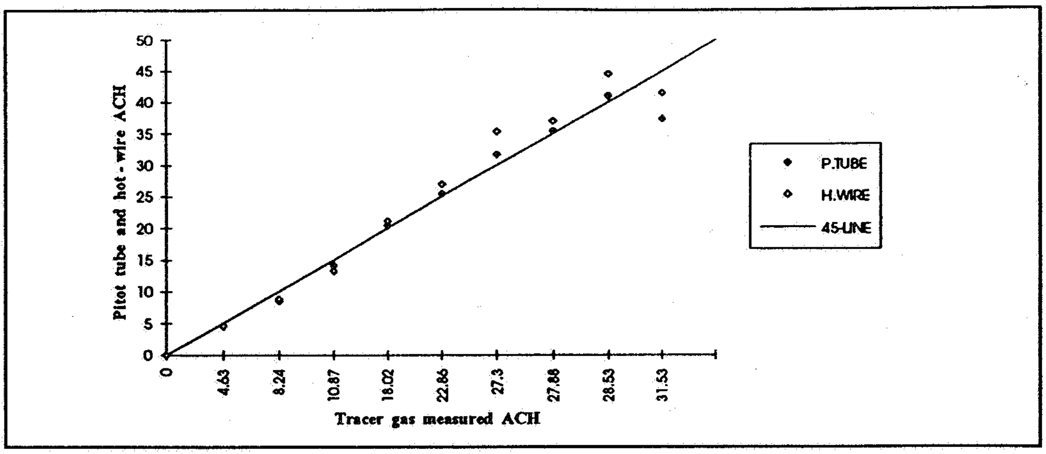

Figure 6 - Comparison of air change rate measurements made using CO_2 tracer gas with observations made using pitot tube and hot-wire methods.

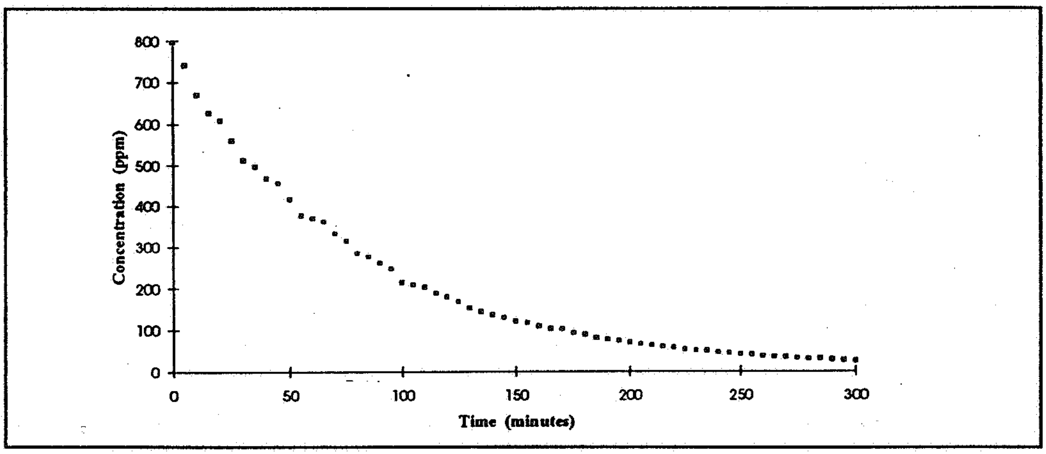

Figure 7 - The variation of N_2O concentration with time, ACH = 41.2

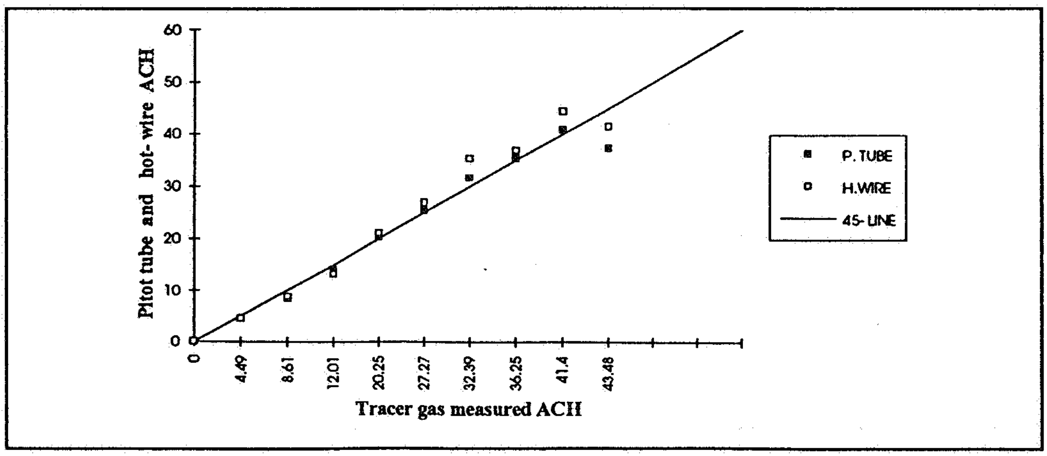

Figure 8 - Comparison of air change rate measurements made using N_2O tracer gas with observations made using pitot tube and hot-wire methods.

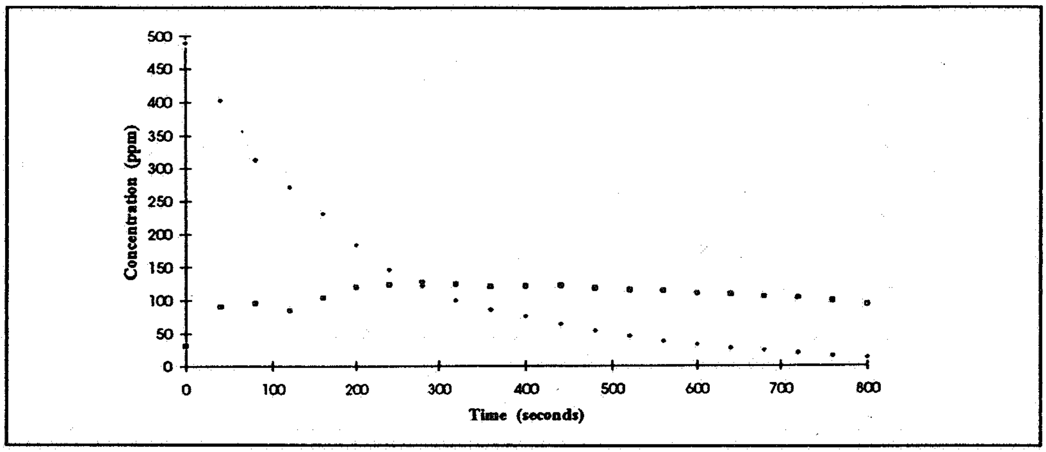

Figure 9 - The variation of SF_6 concentration with time in zones 1 and 2; natural flow.

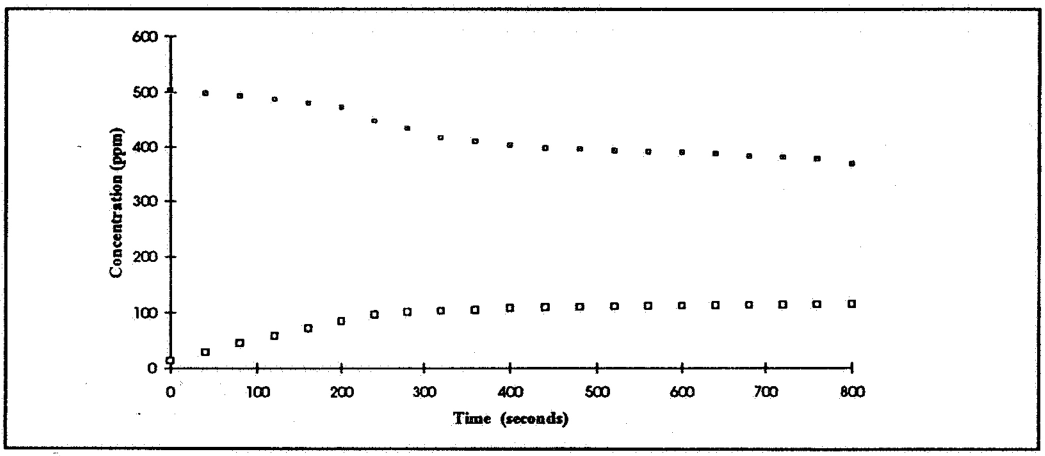

Figure 10- The variation of SF_6 concentration with time in zones 1 and 2; forced flow.

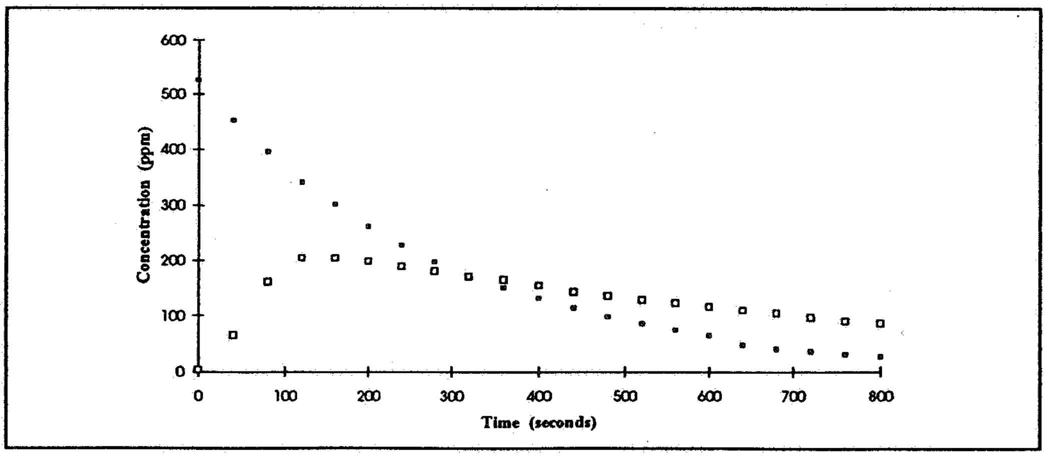

Figure 11- The variation of SF_6 concentration with time in zones 1 and 2; combined natural and forced flow.

Exp No: Fan Speed (HZ)	1 5	2 10	3 15	4 20	5 25	6 30	7 30	8 40	9 45
SF_6 (ACH)	4.8	12.9	16.9	21.2	27.2	31.1	37.5	42.6	50.0
CO_2 (ACH)	4.6	8.3	9.2	18	22.9	27.3	27.9	28.5	31.5
N_2O (ACH)	4.5	8.6	12.0	20.3	27.3	32.4	36.3	41.4	43.5
Pitot tube (ACH)	4.6	8.5	14.1	20.4	25.5	31.7	35.4	41.0	37.4
Hot-wire (ACH)	4.8	8.8	13.3	21.1	26.9	35.3	36.9	44.5	41.4

Table1 - Comparison of air change rate measurements made using SF_6 , CO_2 , and N_2O tracer gas with observations made using pitot tube and hot-wire methods.