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MEASUREMENT OF AIR FLOWS BETWEEN THE UPPER AND LOWER FLOORS OF A TWO STOREY HOUSE

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MEASUREMENT OF AIR FLOWS BETWEEN THE UPPER AND LOWER FLOORS OF A TWO STOREY HOUSE

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SUMMARY

Two portable tracer gas decay systems have been used to assess air flow between the floors of a two storey house. The method has been validated in the laboratory by measuring air flows between two small chambers using both the tracer systems and an independent flow device.

1. INTRODUCTION

The study of infiltration and interzonal air movement in houses is important for both energy conservation and indoor air quality control [1].

The air tightness of buildings can be examined by pressurization using blower doors. Unfortunately, this technique is unable to provide information on air infiltration and interzonal air movement in a building under natural climatic conditions. As an alternative, tracer gas techniques may be used for measuring air change rates in buildings. Gases used in previous studies include carbon dioxide, nitrous oxide, hydrogen, methane, ethane, perfluorocarbons and sulphur hexafluoride. The later has been used in our work as it has desirable tracer gas characteristics in terms of detectability, safety, and çost and has been used successfully in previous air infiltration studies [2,3,4].

In the past, measurement of air movement in buildings has been accomplished using a single tracer gas technique [4] but recently multiple tracer gas techniques have found increased application [5,6,7,8]. Although measurements can be made more quickly and accurately using a multiple tracer gas method, the cost of the tracer gases and equipment is high.

The purpose of this work is to demonstrate measurement of air flow between floors of a house using a single tracer gas method and to assess the accuracy of the technique. Two portable SF_6 systems were used in these experiments. The design, construction and calibration of the SF_6 system are described in this report along with an analysis of the experimental results obtained and an appraisal of the measurement technique.

2. TWO-ZONE MASS-BALANCE EQUATIONS

Fig. 1 is a schematic diagram of a house in which the downstairs and upstairs are designated zone 1 and zone 2, respectively. Air can infiltrate from outside the house into each zone (Q_{01} and Q_{02}) and exfiltrate from each zone to the outside (Q_{10} and Q_{20}). In addition, air can exchange between the two zones in both directions (Q_{12} and Q_{21}).

In a test example the tracer gas may be released in zone 1 while all its doors and windows are closed. Following tracer gas mixing the communication doors between the two zones are opened. Some tracer gas will be carried into zone 2 where it will mix with air and some will return to zone 1. If one applies the tracer material balances in each zone, assuming that a steady state exists and that the concentration of tracer gas in the outside air is negligible, then:

The rate of decrease of tracer concentration in zone 1 at time t is given by:

$$V_1 \ (dC_1/dt) = -(C_1)\ Q_{10} - (C_1)\ Q_{12} + (C_2)\ Q_{21} \qquad (1)$$

where:

V_1 is the interior volume of zone 1.

C_1 and C_2 are the concentrations of the tracer at time t in zone 1 & 2 respectively.

Similarly, the rate of decrease of tracer concentration in zone 2 at time t is given by:

$$V_2 \ (dC_2/dt) = (C_1)\ Q_{12} - (C_2)\ Q_{21} - (C_2)\ Q_{20} \qquad (2)$$

where: V_2 is the interior volume of zone 2.

The other two flow rates can be then determined using the continuity equations as follows:

$$Q_{01} = Q_{12} + Q_{10} - Q_{21} \qquad (3)$$

$$Q_{02} = Q_{20} + Q_{21} - Q_{12} \qquad (4)$$

Mass-balance equations may be solved using the theoretical technique described in ref.[9].

An alternative method to estimate air flows between internal spaces was used by Sinden [10]. The method assumes a multi-zone system may be represented by a series of cells of known and constant volumes which are all connected to a cell of infinitely large volume, i.e., the outside space. The mass balance for each zone can be expressed by a series of equations which can be then solved using matrices. A similar method was used in our work. The estimated air flow rates for specific moments in time are usually incorrect and in some cases are negative values. However, it is important to realize that we are not concerned with air flow rates at specific times, but rather with mean flow rates over finite time intervals usually greater than one hour.

In order to improve the accuracy of measuring interzonal air flows, a refined experimental method was developed for use in our work. This involved releasing tracer gas first in zone 1 and monitoring the concentrations in the two zones. The experiment was then repeated, this time releasing the tracer gas released in zone 2 instead of zone 1. This method provides an alternative to use of the two-tracer gas technique providing the weather conditions are stable during the measurements.

3. MEASUREMENT SYSTEM

The microcomputer-measuring system is shown in Fig. 2. The system was made up from the following major components:

(a) Sampling and Injection Unit.

(b) Column

(c) Chromatographic Oven

(d) Electron Capture Detector

(e) Microcomputer and Interface

The operation of the system is described, with reference to Fig. 3. Argon, used as the carrier gas, normally flows at a constant rate through the column via the sampling valve. The carrier gas then passes through the detection cell before being vented to the atmosphere. The sampling unit consists of a two-position, 6-port valve, connected to a 0.5 cm^3 sampling loop. The valve can be easily rotated to position 1 or 2 using a small motor.

The column was made by packing a 1.5 m x 4.3 mm i.d. nylon tube with 60-80 mesh aluminium oxide.The tube was coiled three times and placed horizontally inside an electrically heated oven. The oven was maintained at a constant temperature using a temperature controller. The electron capture detector, which uses Ni-63 radioactive cell, was made by Pye Unicom Ltd. This was also placed inside the oven as shown in Figure 5. A pump was used to draw air from the test space to create a flow through the sample loop. By rotating the sample valve to position 2, air in the sample loop was injected into the argon flow which carried it into the column and finally to the detector for analysis. The amplified reversed response from the detector cell is then displayed as peaks on the computer monitor as shown in Fig. 4. The first peak represents the O_2 concentration in the sample and the second peak represents the SF_6 concentration.

The system incorporates a BBC micro-computer with two 5¼ inch dual-sided floppy disc drives ,a parallel printer and interfaces for both analogue and digital data. The interfacing of the gas chromatograph and the sampling and injection units was accomplished by specially designed interface cards. The system is very flexible and can be used for unattended operation.

4. SYSTEM CALIBRATION

Calibration of the two SF_6 systems was carried out using the test rig shown in Fig. 5. The rig consisted of 215 litres capacity metal chamber in which a small fan was used for mixing air and tracer gas. Air from a cylinder was line fed to an opening in the chamber and its flow rate could be regulated between 10-150 and 100-1250 l/h using Brooks Ltd. flowmeters. Provision was made for the injection of SF_6 tracer gas into the chamber and also for allowing the homogeneous SF_6/air mixture to leak out through a tube. Samples of SF_6/air mixture were drawn into tubes located at different levels in the chamber. These samples were then passed through the ECD gas chromatograph for analysis.

Experiments were conducted for infiltration rates in the range 0.1 to 2 air change/hour (ach). Fig. 6 shows the variation of measured air change rate versus calculated values for system 1. For system 1, the coefficient of correlation was found to be 0.9947 and the slope was 0.941 with an average error of 1.1%. The corresponding data for system 2 were 0.9873, 0.986 and 1.5% respectively.

5. MEASUREMENT AND RESULTS

The tracer decay method has been used to measure interzonal air flows in a three bedroomed, semi-detached house, Fig. 7.

Measurements of air flows up and down the stairwells of this house were performed. The downstairs floor, zone 1, had a volume of 67 m^3 and contained the living room, dining room and the kitchen. The upstairs, zone 2, had a volume of 95 m^3 and contained the bathroom, three bedrooms, stairway and hall. Two SF_6 systems were used in these experiments. The two systems which were identical in construction were calibrated against each other over a range of gas concentrations. A linear relationship was established to allow comparison of results between the two systems. The first system was used to collect samples from zone 1 while the second was used to collect samples from zone 2. At the beginning of each test the communication doors between the two zones were closed and gaps were effectively sealed. Tracer gas was released downstairs where it was mixed with air using an oscillating desk fan. To ensure that a uniform concentration had been achieved in zone 1, samples were taken at four sampling points. After a mixing period of about 30 minutes the communication doors were opened and samples were taken every 3 minutes for a total experimental time of about 90 minutes. The SF_6 systems analysed the samples in-situ so providing instantaneous readings of gas concentration in each zone.

Fig. 8 shows a plot of tracer gas concentration with time for both the upstairs and downstairs when SF_6 gas was released downstairs and Fig. 9 shows the same when the gas released upstairs. Fig. 10 displays a schematic of interzonal air flows. This figure shows that Q_{12} and Q_{21} are almost equivalent as there was a small temperature difference (about 0.2 °C) between the two floors. However, the situation is quite different in winter when the floors are heated to different temperatures, e.g. the living/dining room heated to 21 °C while the bedrooms are heated to 18 °C. During this period the air flows between the two floors and to the outside cause significant energy losses.

The house infiltration rate was estimated to be about 0.6 ach. The experiment showed the tracer decay curve (concentration/time variations) in zone 1 was a simple exponential curve.

6. VALIDATION OF THE TWO-ZONE AIR FLOW MEASUREMENTS

To validate the tracer gas technique used in this work some experiments were carried out under controlled conditions. For this purpose a small-scale test rig was built, Fig. 11. This simply consisted of two chambers (215 litres each) connected in a closed loop by a small pump and a flow meter.

At the beginning of each experiment SF_6 tracer gas was injected into chamber 1 which contained a small fan. Following the initial mixing, the pump was turned on. SF_6/air samples were drawn from the two chambers using nylon tubing and analysed in the two SF_6 units.

Experiments were carried out for two different values of air flow rates. The calculated and measured (using the flowmeter) flow rates for experiment 1 were 124 and 114 l/h while those for experiment 2 were 232 and 244. Figure 12 shows a plot of tracer gas concentration with time for experiment 1. The errors between calculated and measured air flow rates were +9% and -5%, respectively. The accuracy of our measurements is similar to that obtained by Afonso et. al.[11] using N_2O tracer gas and a two-compartment laboratory model.

6. CONCLUSIONS AND RECOMMENDATIONS

(1) The use of the compact micro-computer SF_6 system has proved to be a reliable and practical approach for measuring air movement in houses.
(2) We have found that the use of the portable SF_6 system is an inexpensive and simple way of estimating the two-zone air flows in houses. However, for multi-zone measurement in large buildings, the use of multiple tracer gases is preferable as it reduces the time required to make these measurements.
(3) To study the inter-zone convection heat transfer, further experiments are needed to estimate the air movement between ,for example the conservatory and living room, where a higher temperature difference usually occurs.
(4) More tests are also required to evaluate the the air flows between the house and its roof-space as well as between the kitchen and bedrooms. These experiments would be useful in determining the extent of condensation which might ocuur in the roof-space or in the bedrooms as a result of the transfer of warm humid air from the bathroom and kitchen.
(5) We are currently planning to modify our SF_6 system so that a single system can be used instead of the two portable systems.

ACKNOWLEDGEMENTS

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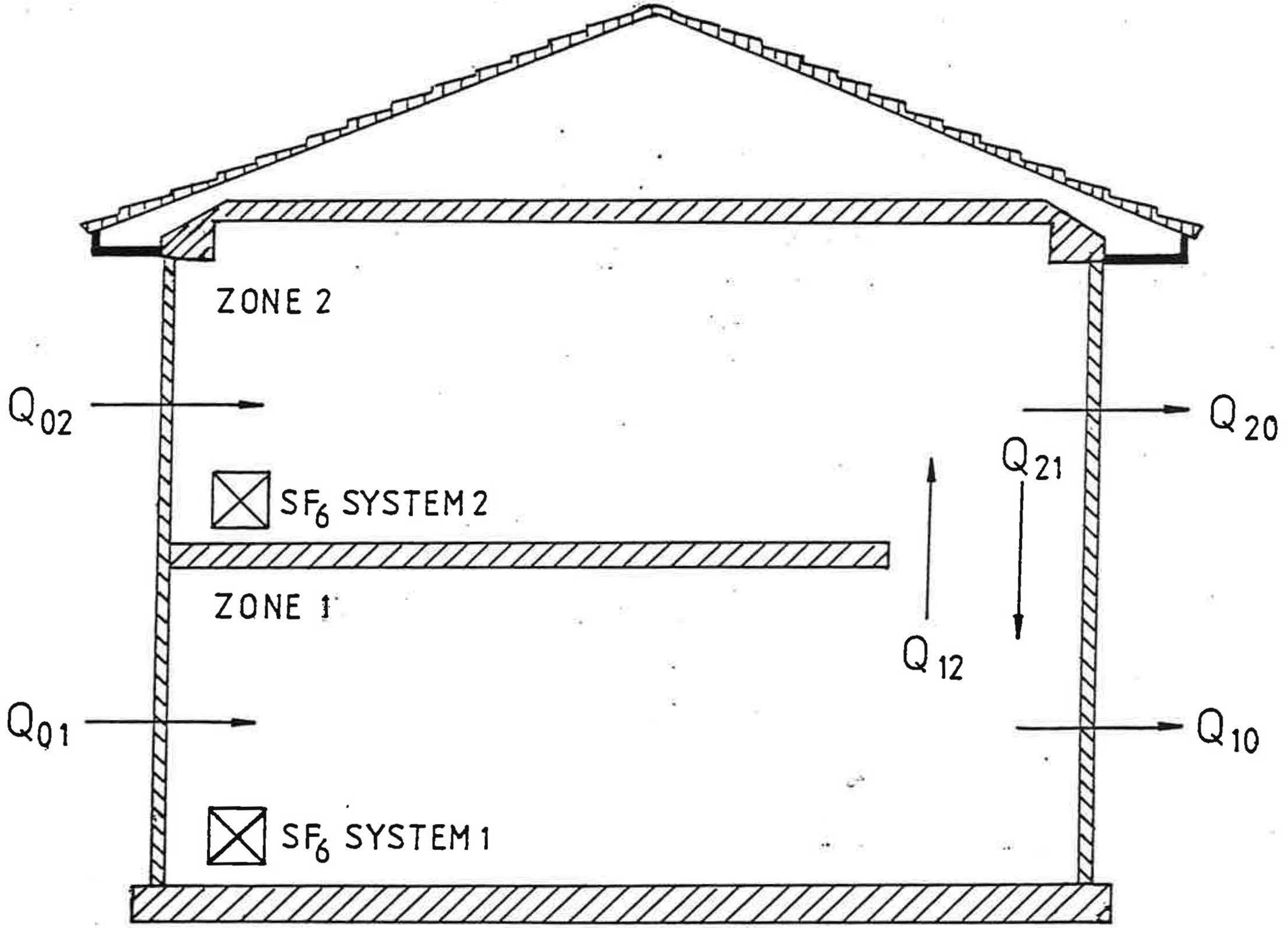
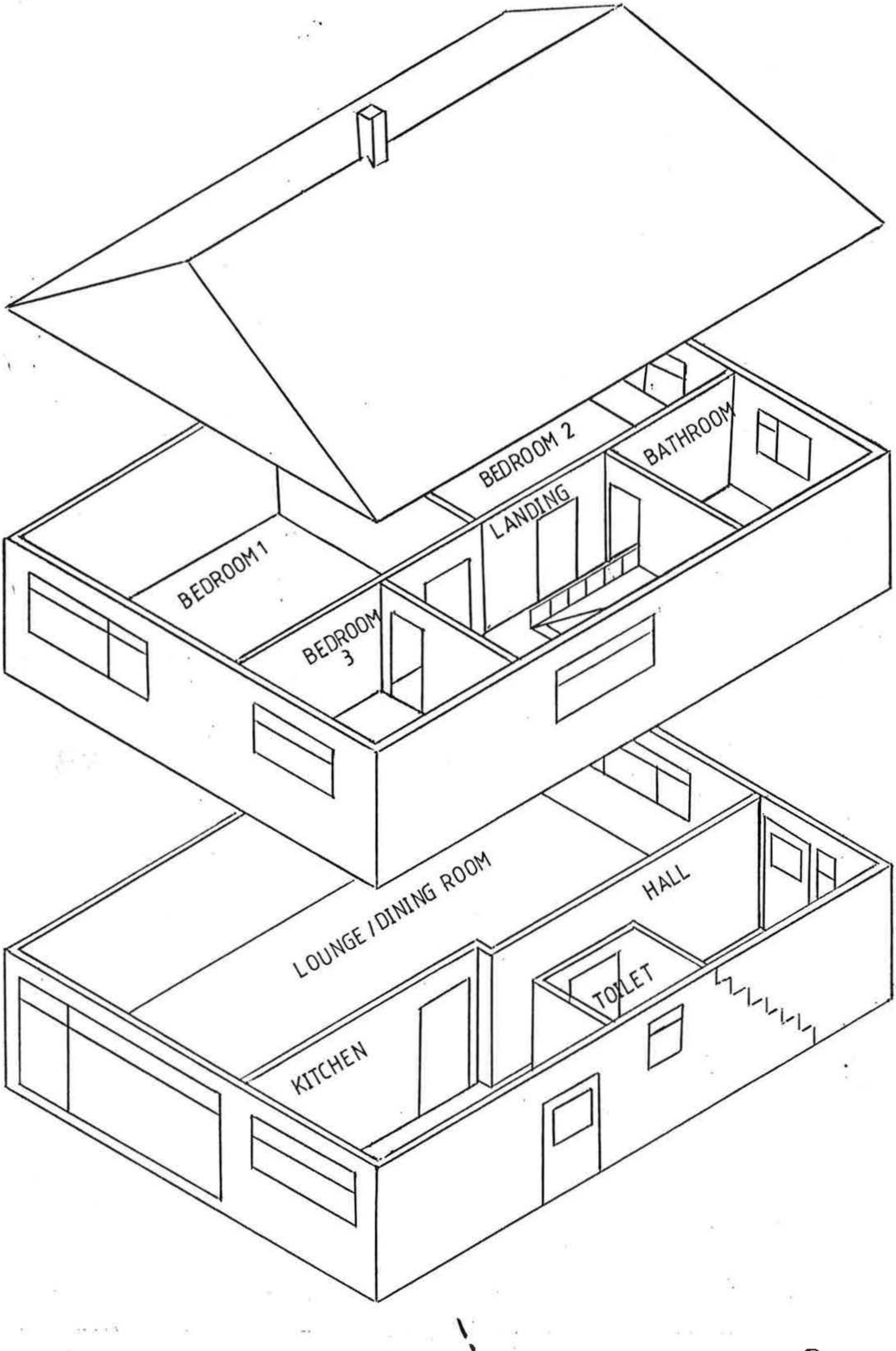
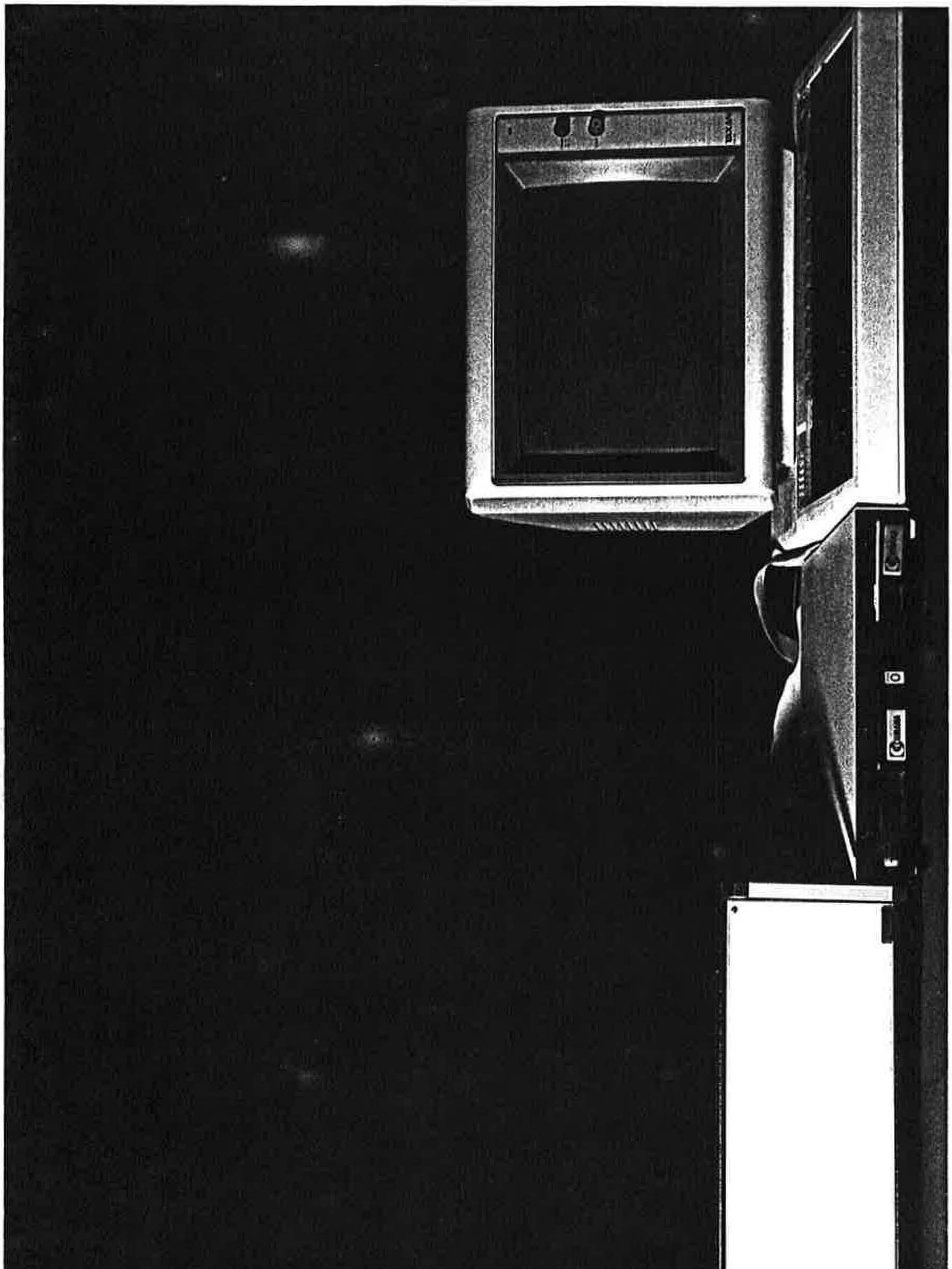
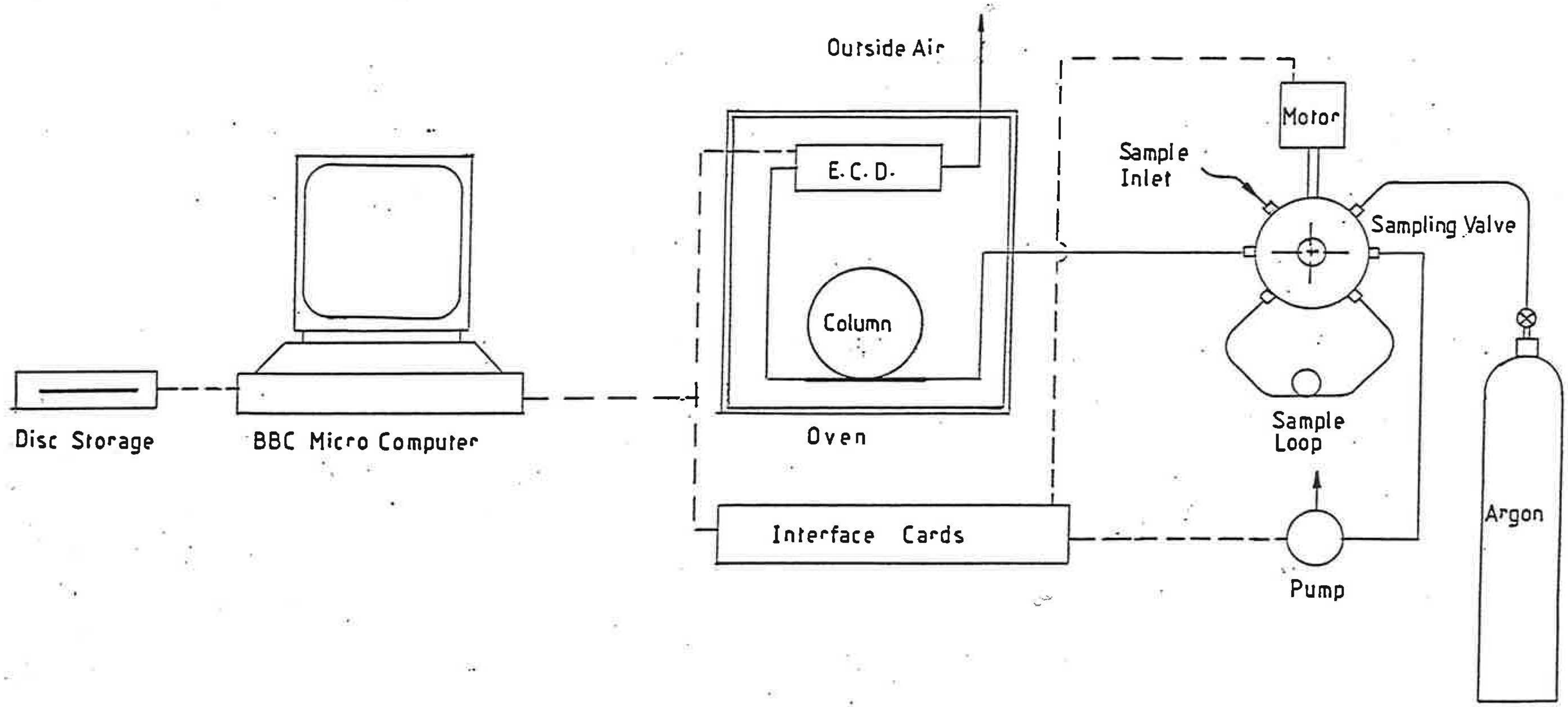
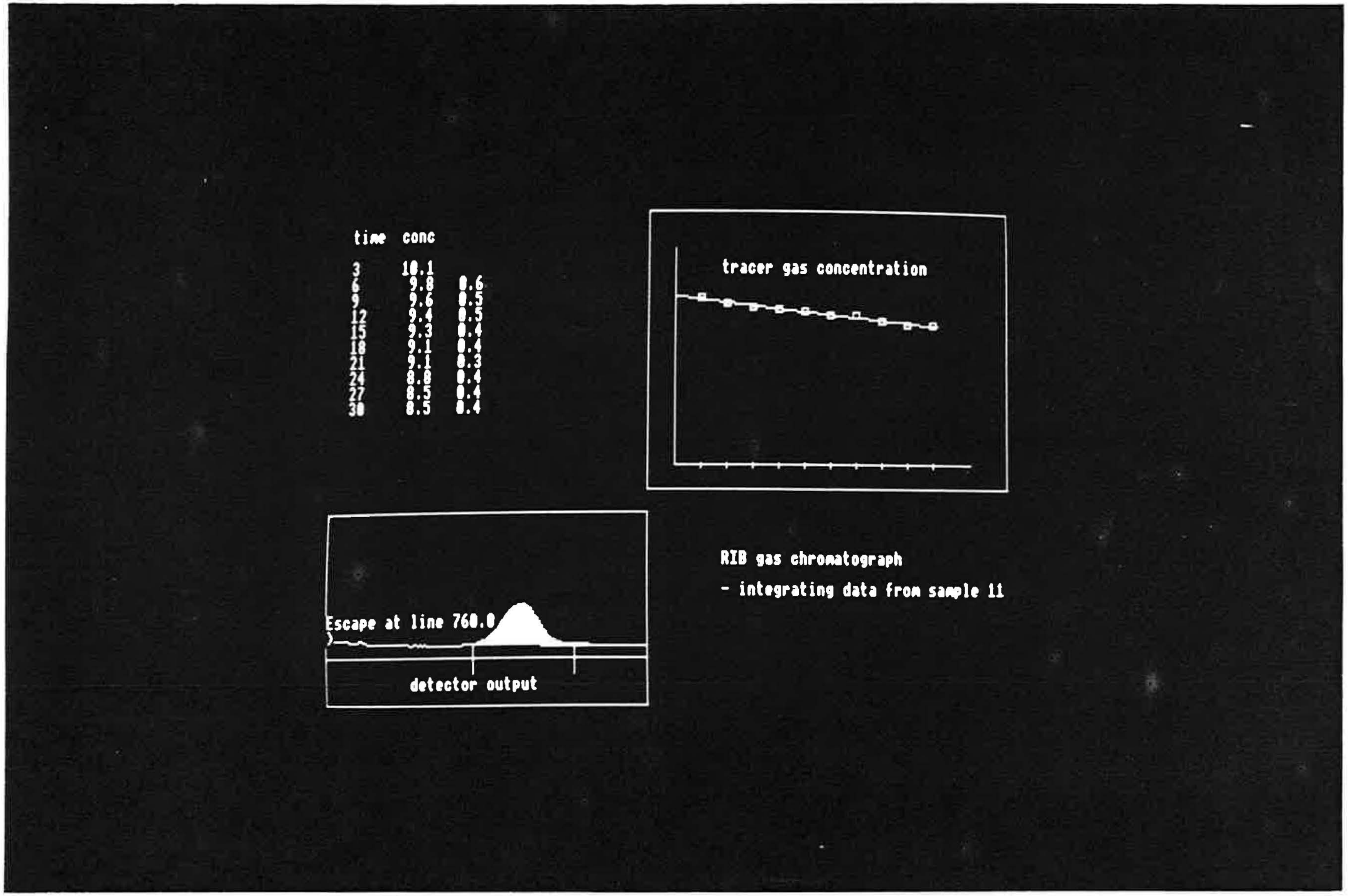

ZONE 2
Q_{02}
Q_{20}
Q_{21}
SF_6 SYSTEM 2
ZONE 1
Q_{12}
Q_{01}
Q_{10}
SF_6 SYSTEM 1


BEDROOM 2
BATHROOM
LANDING
BEDROOM 1
BEDROOM 3
LOUNGE / DINING ROOM
HALL
TOILET
KITCHEN

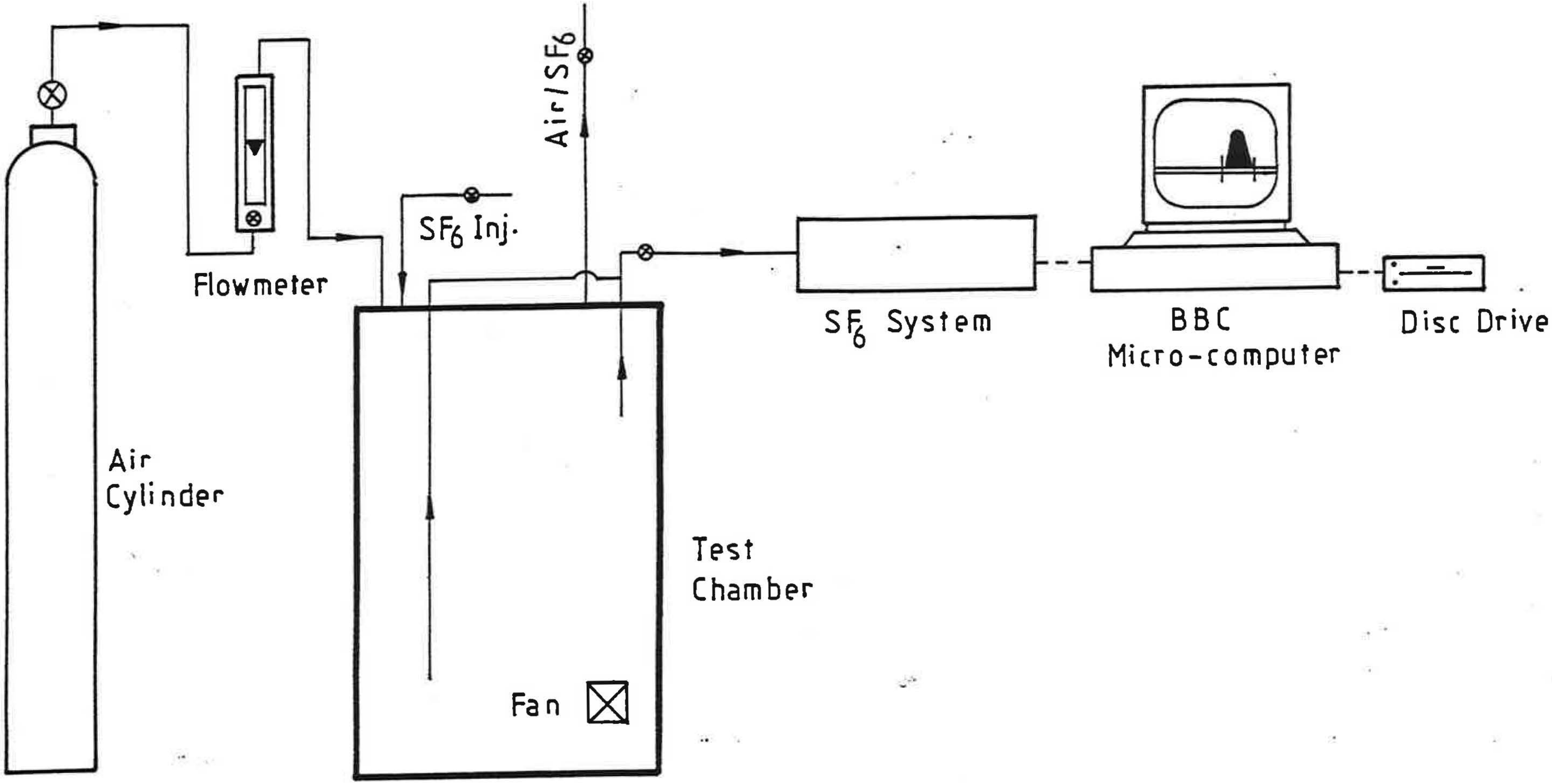




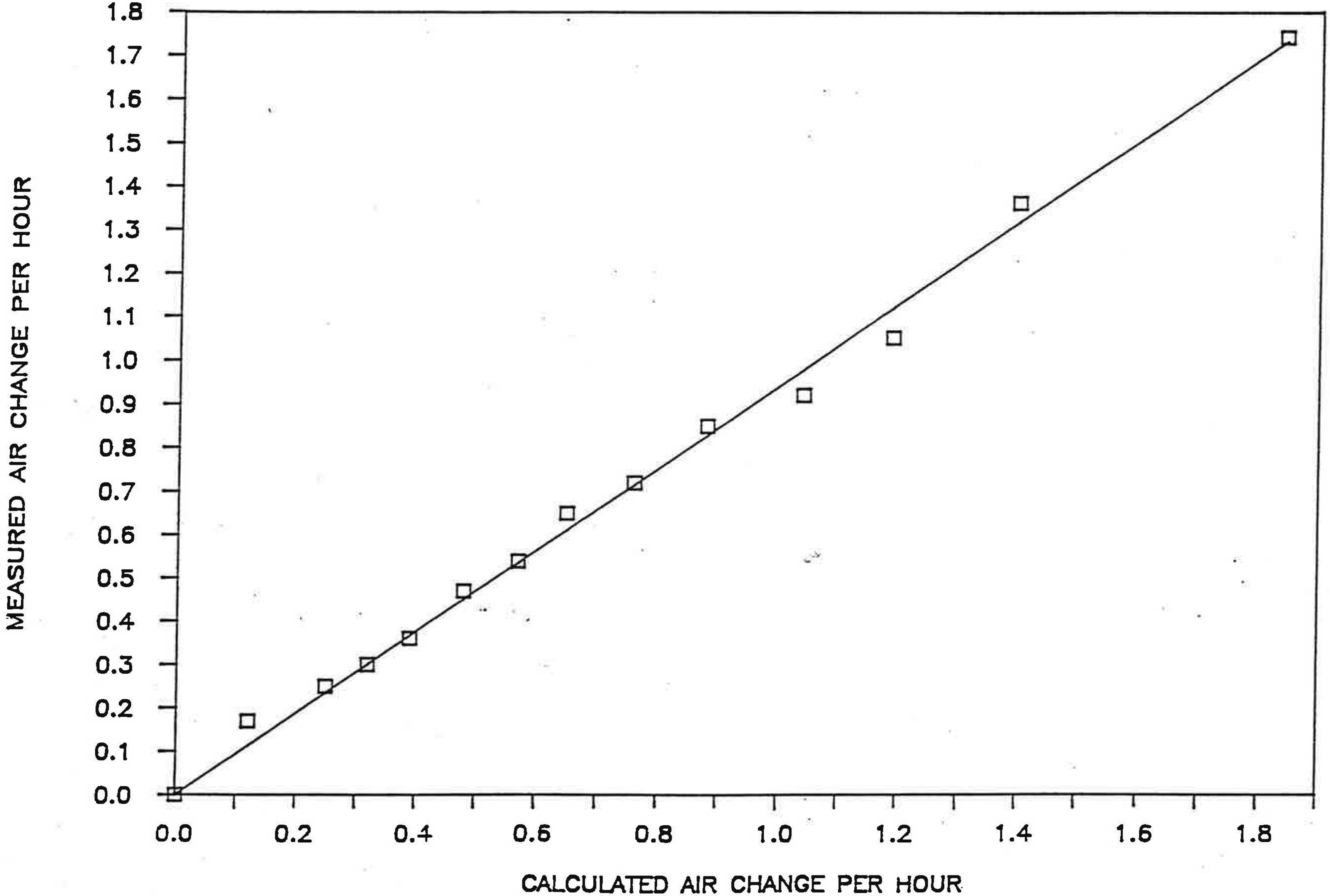
Outside Air
Motor
Sample Inlet
E.C.D.
Sampling Valve
Column
Disc Storage
BBC Micro Computer
Oven
Sample Loop
Argon
Interface Cards
Pump

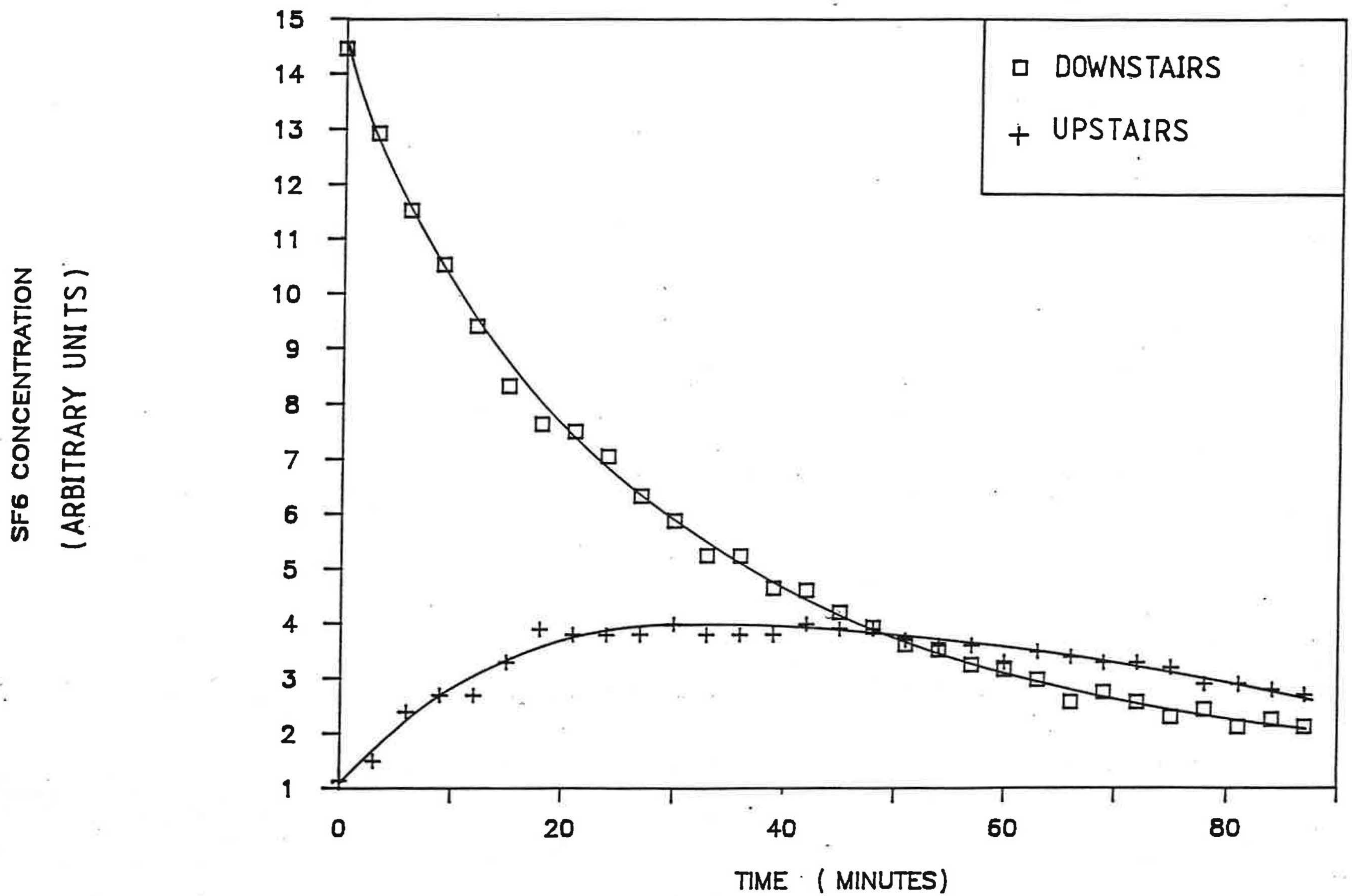


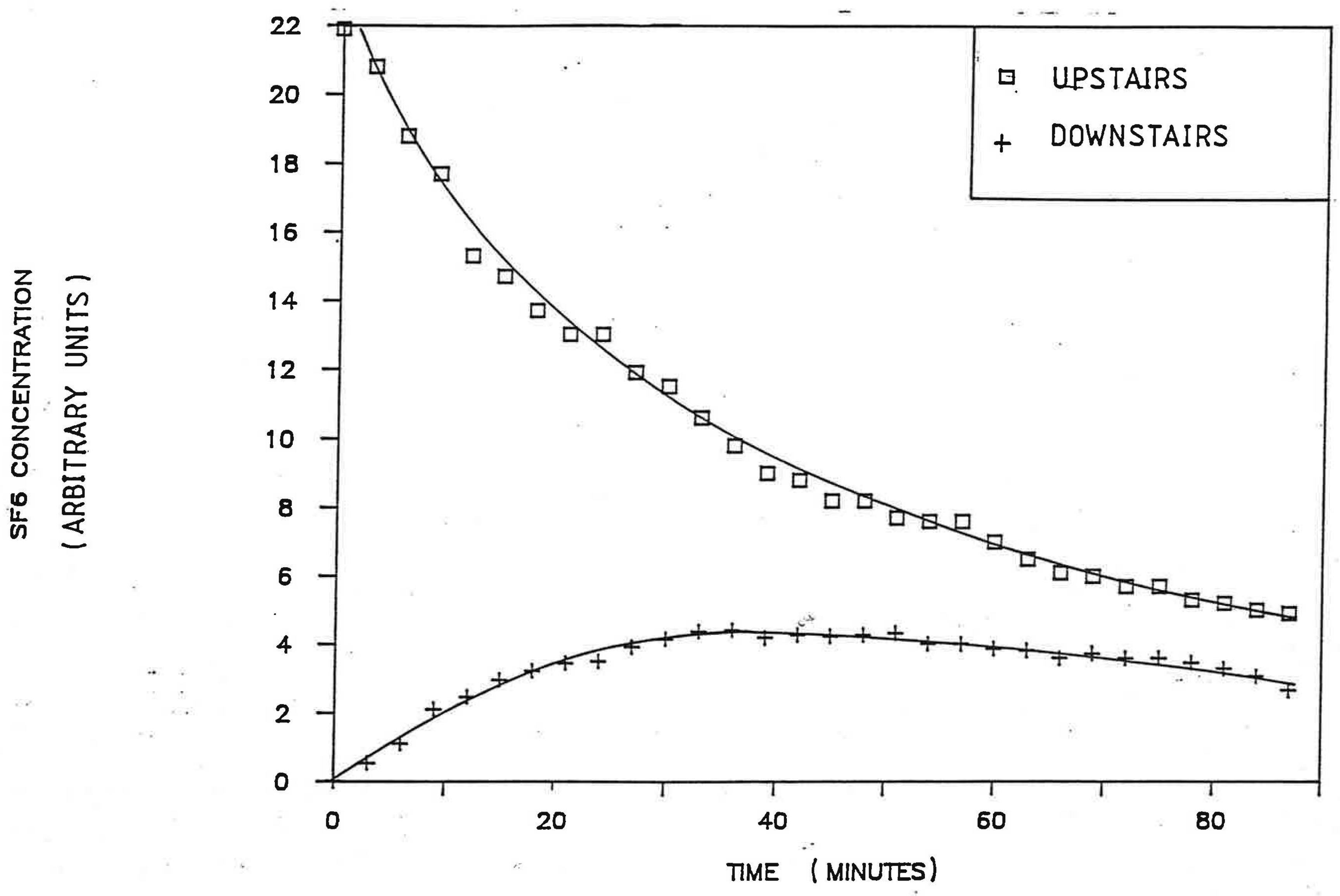
time conc
3 10.1
6 9.8 0.6
9 9.6 0.5
12 9.4 0.5
15 9.3 0.4
18 9.1 0.4
21 9.1 0.3
24 8.8 0.4
27 8.5 0.4
30 8.5 0.4
tracer gas concentration
Escape at line 760.0
detector output
RIB gas chromatograph
- integrating data from sample 11



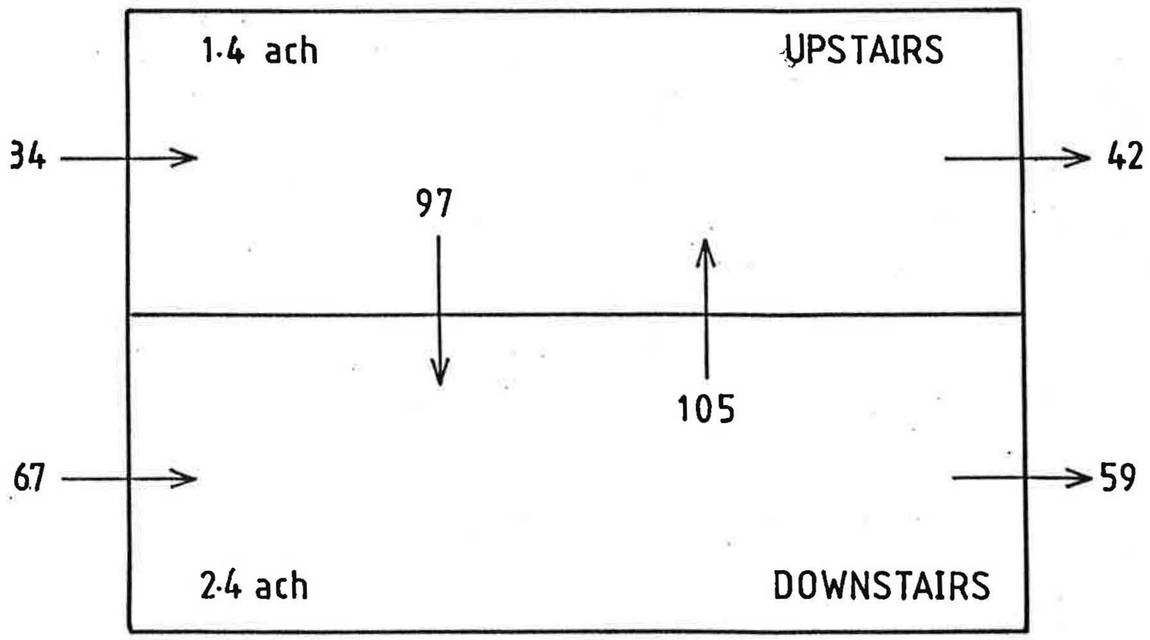
Air/SF6
SF6 Inj.
Flowmeter
SF6 System
BBC
Micro-computer
Disc Drive
Air
Cylinder
Test
Chamber
Fan

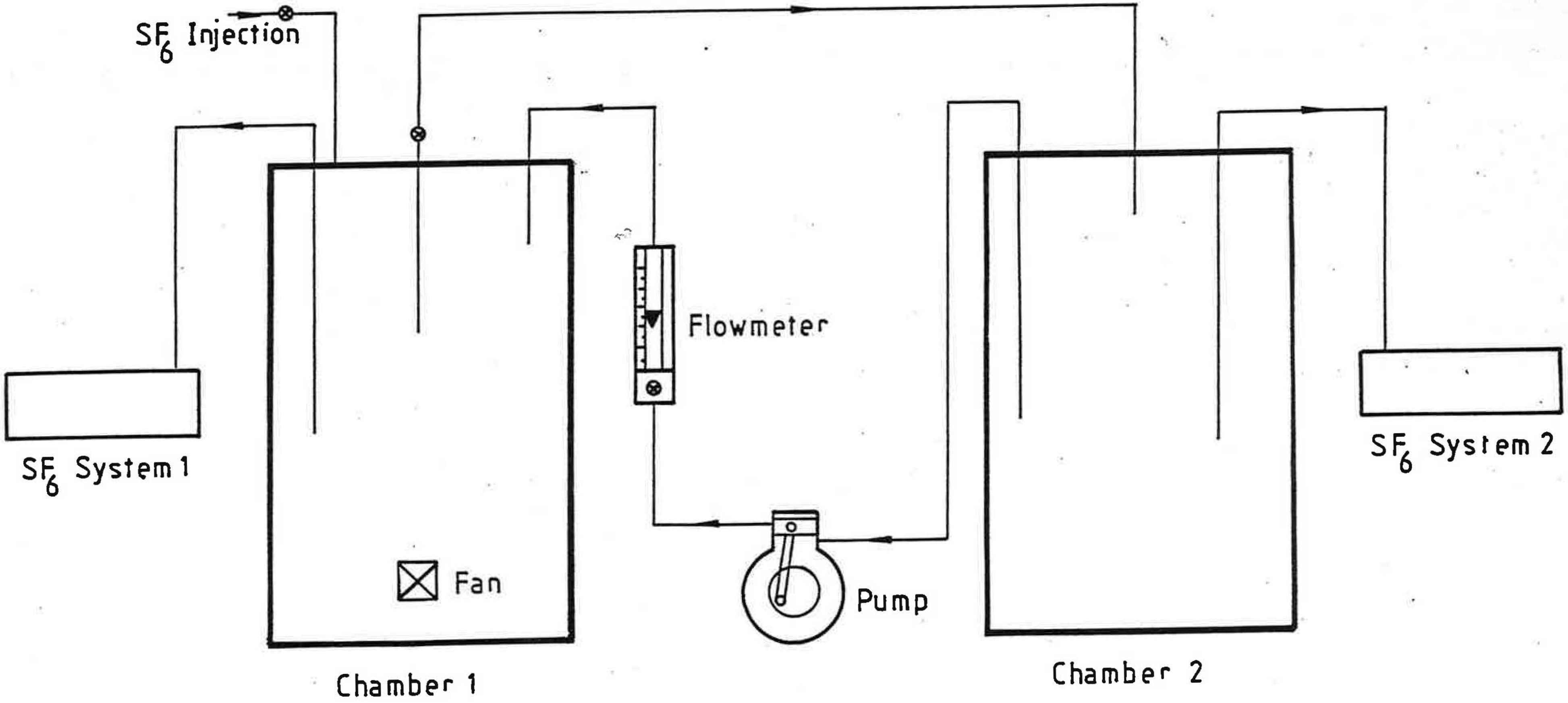

MEASURED AIR CHANGE PER HOUR
CALCULATED AIR CHANGE PER HOUR
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8


SF6 CONCENTRATION
(ARBITRARY UNITS)
DOWNSTAIRS
UPSTAIRS
TIME (MINUTES)
0
20
40
60
80
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15

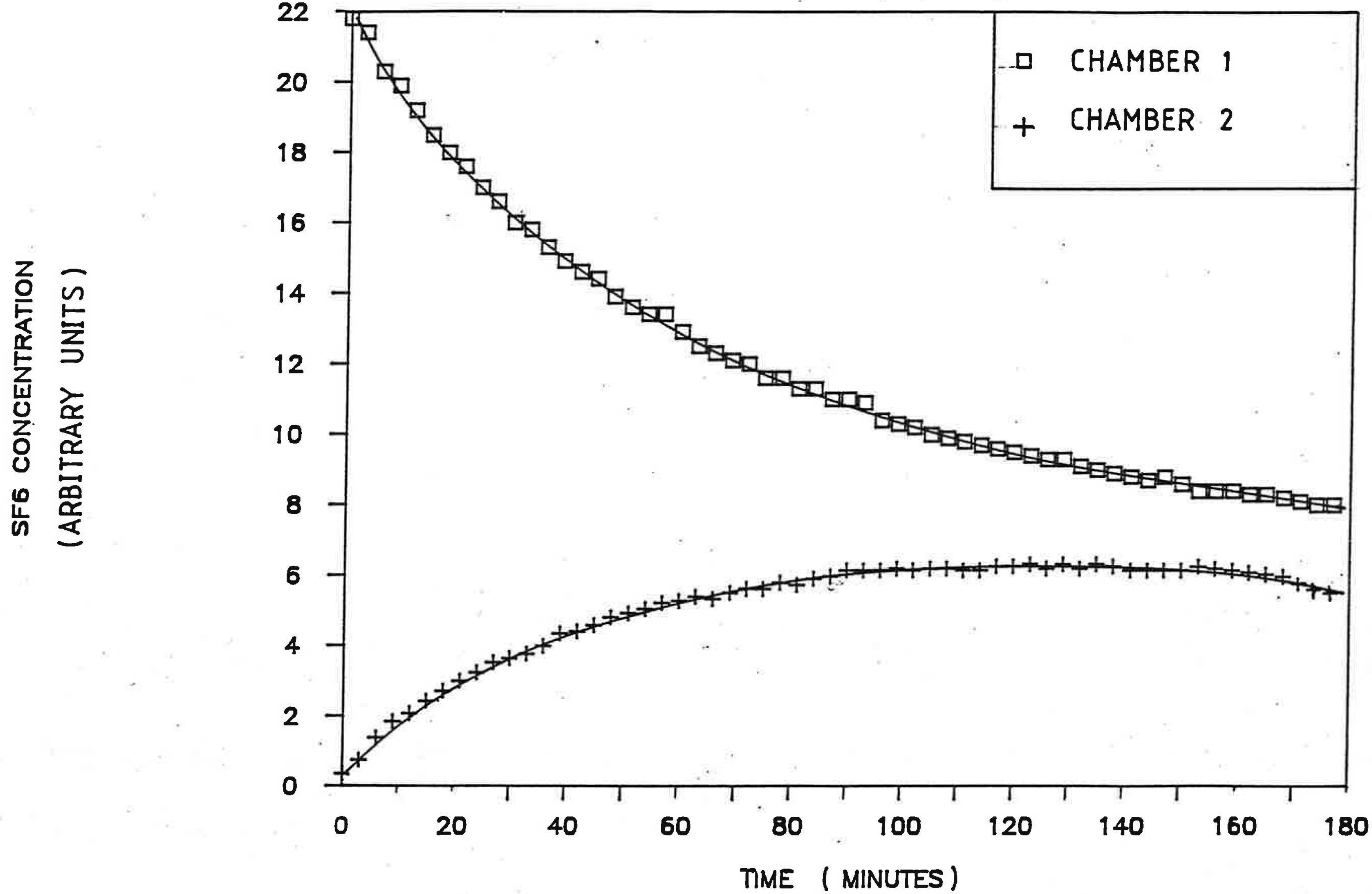

SF6 CONCENTRATION
(ARBITRARY UNITS)
22
20
18
16
14
12
10
8
6
4
2
0
0
20
40
60
80
TIME (MINUTES)
UPSTAIRS
DOWNSTAIRS

71


1·4 ach
UPSTAIRS
34
42
97
105
67
59
2·4 ach
DOWNSTAIRS



SF_6 Injection
Flowmeter
SF_6 System 1
SF_6 System 2
Fan
Pump
Chamber 1
Chamber 2


SF6 CONCENTRATION
(ARBITRARY UNITS)
22
20
18
16
14
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
160
180
TIME (MINUTES)
CHAMBER 1
CHAMBER 2