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AIRFLOW BETWEEN TWO ZONES: COMPARISON OF EXPERIMENTAL RESULTS WITH THE MULTIC COMPUTER-PROGRAMME

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SUMMARY

A tracer-gas technique is used to measure airflow between two zones of a house and experimental results are compared with airflow rates predicted by the MULTIC computer-programme. Tracer gas measurements were generally found to be in good agreement with values predicted by the MULTIC programme.

LIST OF SYMBOLS

C_i	Concentration in chamber i (ppm)
$\mathbf{C}_{(t)}$	Concentration vector (ppm)
C_s	Supply concentration (ppm)
C_d	Coefficient of discharge (dimensionless)
g	Acceleration due to gravity (m/s^2)
H	Height of the doorway (m)
W	Width of the doorway (m)
m_i	Flow rate of tracer gas (L/s)
$\mathbf{m}_{(t)}$	Tracer-gas flow rate vector
N	Number of cells in the system
p_x	Pressure difference due to ventilation (Pa)
p_u	Pressure difference due to turbulence (Pa)
F_{is}	Supply flow rate to chamber i (L/s)
F_{ej}	Exhaust flow rate from chamber j (L/s)
F_{ij}	Total flow rate from chamber j to chamber i (L/s)
F_{ii}	Overall volumetric flow rate leaving chamber i (L/s)
F^+	Inflow, positive turbulence pressure (L/s)
F^-	Inflow, negative turbulence pressure (L/s)
$\mathbf{F}$	Flow matrix
$\mathbf{F}_s$	Diagonal supply flow matrix
a	Factor
V_i	Volume of chamber i (m^3)
ρ	Density (kg/m^3)
θ	Temperature difference (°C)
v_x	Mean velocity of the net airflow through the doorway (m/s)

INTRODUCTION

Tracer-gas techniques [1], eg, concentration-decay, constant-injection and constant-concentration, can be used to determine interzonal airflow rates in buildings. Several researchers have carried out experimental work to study interzone heat and mass transfer via openings in small scale models and full size rooms [2-6]. As it is not always possible to perform an experimental study, space computer-based simulation methods are also used to estimate interzonal air movement in buildings. Accurate prediction of air movement 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-programmes, eg. MULTIC [7], BREEZE [8], MRLP[9], MOVECOMP [10] and ESPAIR[11]. However, further work to validate these models using experimental data is required before they can be used with confidence in ventilation studies.

The purpose of this investigation is to compare measured values of interzonal airflow with those predicted by the MULTIC computer-programme. A single tracer-gas technique was used to measure airflow between two zones at various temperature differences. Sulphur hexafluoride (SF_6) was used as the tracer gas and measurements were made using a microprocessor-controlled system.

THE MULTIC COMPUTER-PROGRAMME

The MULTIC programme is based on the multi-chamber theory (see Sinden [12] and Sandberg[13] and assumes that a system, eg. dwelling, consists of N chambers, Figure 1. The chambers are connected by one-way passages (eg. doorways) through which air is flowing at fixed rate. Mixing is assumed to be perfect and instantaneous in each chamber and the release rate of contaminants (or tracer gas) is assumed to be much smaller than the interzonal airflow rates in the system. The conservation of mass for chamber i shows:

$$V_i\, dC/dt = -\sum_{j=1}^{N} F_{ji}C_i + \sum_{j=1}^{N} F_{ij}C_j - F_{ei}C_i + F_{is}C_s + m_i \qquad (1)$$

The total mass flow rate of tracer-gas leaving chamber i is given by:

$$F_{ii} = \sum_{j=1}^{N} F_{ji}C_i + F_{ei}C_i \qquad (2)$$

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

$$V_i dC/dt = -F_{ii} + \sum_{j=1}^{N} F_{ij}C_j + F_{is}C_s + m_i \qquad (3)$$

Assuming that the concentrations and mass flow rates of the sources are time dependent, equation (3) can be represented by the following vector-matrix differential equation.

$$VdC_{(t)}/dt = -FC_{(t)} + F_sC_s + m_{(t)} \qquad (4)$$

The solution of equation (4) requires the determination of airflow rates between chambers. Interzonal airflow is produced by a temperature difference between the chambers (ie, natural convection) and internal movement of air in the chambers (ie. turbulence). The theory of airflow between horizontally adjacent chambers has been described by several researchers [(2-6)] and the following equations have been used in the MULTIC model to estimate airflow between two chambers:

$$F^+ = -\frac{C_d W H}{6} (a\, H/2)^{0.5} [1 - 4(p_x + p)/\rho a H] \qquad (5)$$

$$F^{-} = -\frac{C_d W H}{6} (a H/2)^{0.5} [1 - 4 (p_x - p_u)/paH] \quad (6)$$

The coefficient of discharge, C_d is given by the following equation:

$$C_d = 3.7v_x + 6.4v_x e^{-\theta} - 0.9 e^{-\theta} + 0.96 \quad (7)$$

$p_u = 0.003$ Pa

and for:

$0 \leq v_x \leq 0.05$ m/s and $0 \leq \theta \leq 3.0$K

The MULTIC computer programme was developed by Siren (7), Helsinki University of Technology , and was written on a PC computer using Fortran programming language. The programme is capable of handling a system containing not more than 10 chambers. The input data are temperatures, volumes, exhaust flow rates and initial concentrations of tracer-gas in the chambers. The net flow-rates and the dimensions of the doorways between the chambers are also required. The output data include the relationship of tracer-gas concentration in the chambers vs time and quantities related to air quality eg., purging flow rate and mean age of the air. The MULTIC programme can only be applied to horizontally adjacent chamber.

EXPERIMENTAL

Measurements of airflow between two zones were carried out in a four-bedroomed detached house. The volumes of the living room (zone 1) and the kitchen (zone 2) were $74m^3$ and $42m^3$ respectively. Airflow measurements were made by the concentration–decay technique using sulphur hexafluoride as the tracer-gas. Details of the tracer-gas equipment have been described elsewhere[12]. The experimental procedure involved the injection of a known quantity of tracer gas in zone 1 while all its doors and windows were closed. Following a mixing period of about 30 minutes, the communication door between the two zones was opened and the concentration of tracer gas in the two zones was measured. SF_6/air samples were taken from various locations in each zone using sampling tubes connected to a manifold. The effect of temperature difference on interzonal airflow was investigated by heating the living room to various temperatures using thermostatically–controlled radiators. The kitchen was unheated. Air temperatures were measured at the centre of each room and the outside temperature and windspeeds during the measurement periods were also recorded.

RESULTS AND DISCUSSION

Several tests were conducted to determine the airflow rate between the living room and kitchen at various temperature differences. Figure 2 shows the variation of tracer-gas concentration (measured values and values calculated using the MULTIC programme) with time for a temperature difference of 0.4°C. Good agreement between experimental and theoretical data was observed for zone 1. However, the MULTIC programme was found to underestimate the concentration of tracer-gas in zone 2 during the transient period of the experiment (ie, the first 10-15 minutes).

Figure 3 shows the variation of tracer-gas concentration with time for an interzonal temperature difference of 1°C. Once again, data obtained from the MULTIC programme were found to be in better agreement with measured values for zone 1 than for zone 2. The tracer-gas concentration curves predicted by the MULTIC programme overlapped when the temperature difference between the two zones was greater than

Table 1 Output file of the MULTIC programme

Parameter	θ = 0.4°C Zone 1	Zone 2	θ = 1°C Zone 1	Zone 2
Volume (m^3)	74	42	74	42
Temperature (°C)	27.6	27.2	30	29
Supply Flow (L/s)	2.8	7.4		0.0
Exhaust Flow Rate (L/s)	2.8	7.4	10.1	4.9
Purging Flow Rate (L/s)	9.38	10.07	15.0	13.68
Mean-Age (h)	3.3	3.11	2.11	2.22
Width of doorway (m)	0.75	0.75	0.7	0.75
Outflow (L/s)	-59.15	59.15	-104.4	104.4
Inflow (L/s)	59.15	-59.15	99.5	-99.5
Net Flow (L/s)	0.0	0.0	-4.9	4.9
Connection Factor	999.99	999.99	20.31	20.3
Transition Probability	0.89	0.95	0.95	0.91

CONCLUSIONS

1. Airflow measurements made using the concentration-decay technique were generally found to be in good agreement with values predicted by the MULTIC programme. The following correlation was obtained:

   $F_{MULTIC} = 1.4627\, F_{measured} - 32.15$

2. The tracer-gas concentration curves predicted by the MULTIC programme was found to overlap for temperature differences greater than 0.5°C

3. The MULTIC programme would be improved if factors such the geometry of the zones and the position of the interconnecting doorway were included.

ACKNOWLEDGEMENT

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FIGURES

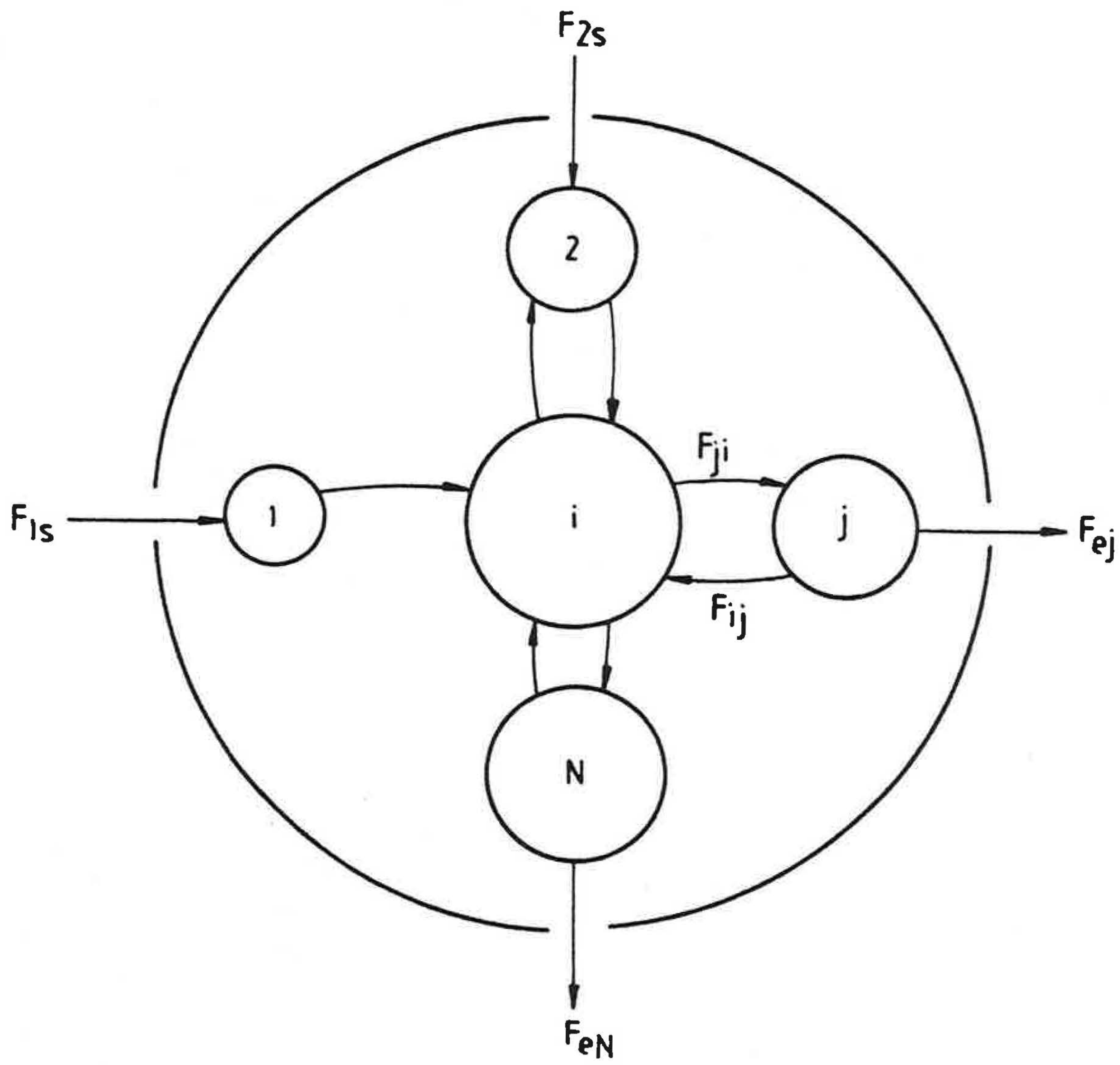
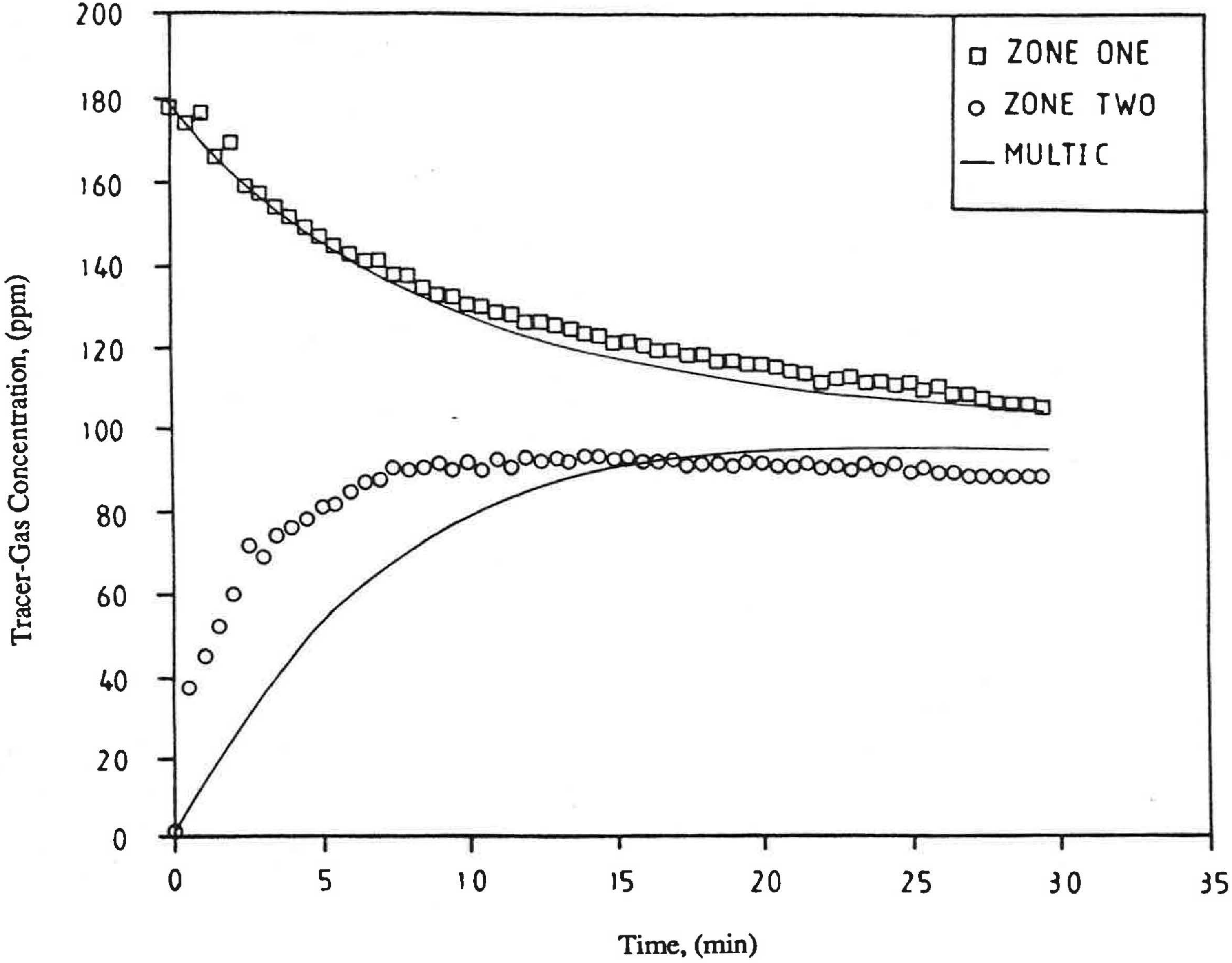
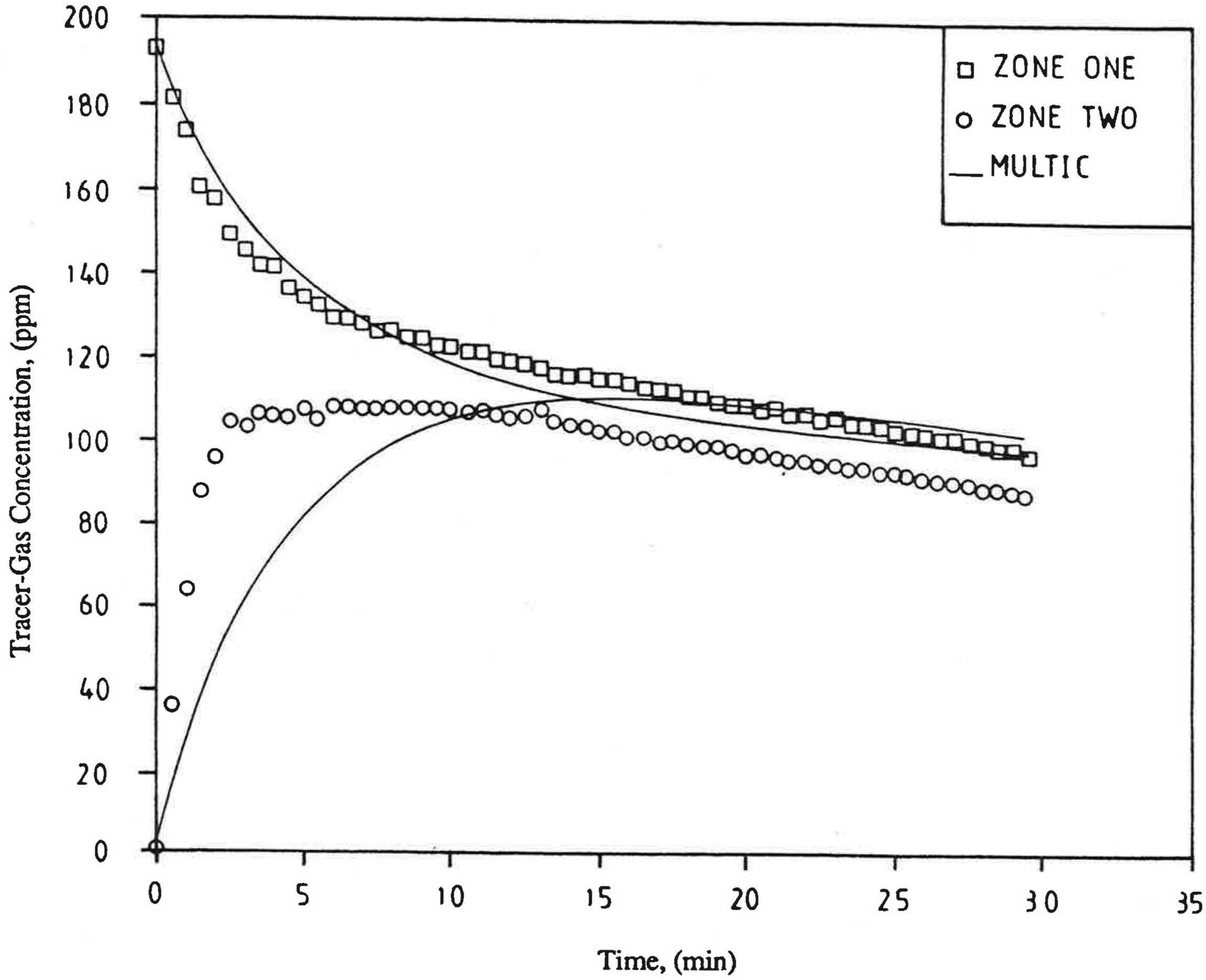


Fig. 1



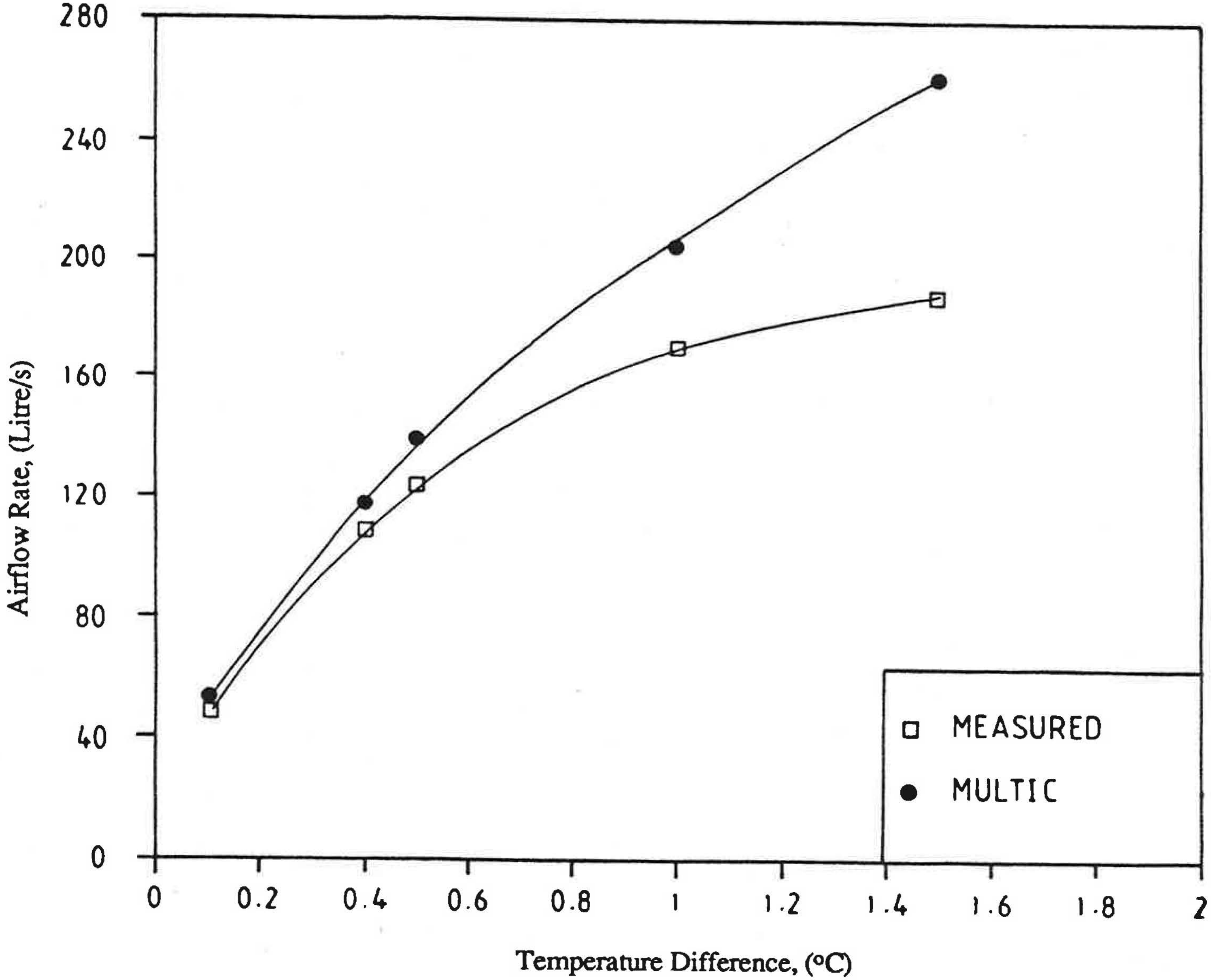
200
180
160
140
120
100
80
60
40
20
0
Tracer-Gas Concentration, (ppm)
ZONE ONE
ZONE TWO
MULTIC
0
5
10
15
20
25
30
35
Time, (min)

Fig. 2



200
180
160
140
120
100
80
60
40
20
0
Tracer-Gas Concentration, (ppm)
0
5
10
15
20
25
30
35
Time, (min)
ZONE ONE
ZONE TWO
MULTIC

Fig.3



280
240
200
160
120
80
40
0
Airflow Rate, (Litre/s)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Temperature Difference, (°C)
MEASURED
MULTIC

Fig. 4