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BALANCING AIRFLOW IN HVAC SYSTEMS USING TRACER-GAS TECHNIQUES

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1. INTRODUCTION

Once an HVAC system has been designed and installed within a building, the air distribution network must be commissioned to ensure that the system operates in conformity with design specifications.

Regulation of airflow is normally carried out in accordance with the method set out by the CIBSE Code "The Commissioning of Air Distribution Systems, High and Low Velocity" [1]. The procedure consists of working back towards the fan from the remote branches by setting the correct "proportional" airflow at each junction of the HVAC system without regard to absolute values of airflow. Once the HVAC system has been balanced so that all parts of the system are carrying the same "proportion" of their design airflow, the fan speed or main damper may be adjusted so that the main feed duct carries 100% of its design flow.

HVAC systems are usually balanced using traditional instrumentation such as pitot tubes and vane anemometers; the measurement method depends on the size and shape of the duct and the type of terminal used. Regulation of airflow in this way is tedious and time consuming and in some cases significant inaccuracies can occur.

The present study describes new equipment which could be used to balance HVAC systems. The equipment allows the constant-injection tracer gas technique to be employed and has the following advantages over existing balancing methods:

i) It is simple to use and allows HVAC systems to be balanced in a short period.

ii) It can be used to measure airflow rates in HVAC systems directly and does not require determination of the cross-sectional areas of ducts or velocity profiles.

iii) It can be used to provide accurate measurement of airflow over a wide range of air velocities.

iv) It can be used to measure airflow in ducts of different sizes, shapes and lengths and does not require a long measuring duct for the establishment of fully-developed flow.

2. PRINCIPLE OF BALANCING HVAC SYSTEMS

This section examines the CIBSE and tracer-gas methods for balancing airflows in an HVAC system. A simple example is used to demonstrate the two methods.

2.1 CIBSE METHOD

A schematic diagram of an HVAC system is shown in Figure 1. Assume that the design airflow rates are those given in Table 1. The procedure for balancing the system is as follows:

i) Open all diffusers and branch dampers fully, together with the main damper adjacent to the fan.

ii) Measure the airflow from the discharge units (or diffusers) using a hand held anemometer. Figure 2 shows the methods for measuring the air velocity of a rectangular diffuser.

iii) Assume that the measured airflow rates with all dampers open are those given in Table 1.

iv) Branch B-C-D has the highest percentage of design flow and according to the CIBSE method this should be adjusted first.

v) Having decided that branch B-C-D has the highest percentage of design flow, the least favoured discharge unit on the line is determined.

vi) From Table 1 diffuser 3 is the least favoured (i.e., it is at the furthest point from the fan and is passing the lowest percentage of the design airflow. If the end unit had not been the least favoured it should be closed until it is the least favoured.

vii) Adjustment can now begin as follows:

Branch B-C-D

a) Adjust diffuser 4 until its percentage of the design flow matches that of diffuser 3. This involves measuring the flow from diffuser 4 and checking the flow of diffuser 3. If the diffusers do not give an acceptable balance, diffuser 4 must be readjusted and checked again against 3. The balancing procedure is given in the following example:

Measure flow from diffuser 4.

e.g. Airflow of diffuser 4	=	$300m^3/h$	% = 150
Adjust diffuser 4 gives flow	=	$270m^3/h$	% = 135
Checking diffuser 3 gives flow rate	=	$205m^3/h$	% = 136

This is an acceptable balance and diffusers 3 and 4 are said to be balanced at 135 % of design airflow.

We assume that two attempts are sufficient to achieve the same percentage of the design flow. In practice several attempts are necessary to obtain the same percentage of the design airflow.

Branch B-E-E

a) Measure airflow rate of diffusers 1 and 2

e.g. Airflow rate of diffuser 1	=	$110m^3/h$	% = 110
e.g. Airflow rate of diffuser 2	=	$120m^3/h$	% = 120

This is not an acceptable balance. Readjust 2.

e.g. Airflow rate of diffuser 2	=	$113m^3/h$	% = 113
Check against 1, airflow rate of diffuser	=	$112m^3/h$	% = 112

This is an acceptable balance since diffusers 1 and 2 are each discharging 112% of their design flow.

After adjusting all diffusers the next step is to adjust the branches B-C and B-E. First check the percentage of the total design airflow that branches B-C and B-E are carrying using a pitot static tube.

e.g. Branch B-E airflow rate	=	$475 m^3/h$	% = 136
e.g. Branch B-C airflow rate	=	$225 m^3/h$	% = 113

As branch B-C is carrying the highest percentage of the airflow, this is adjusted first. The regulation of airflow in the branches B-C and B-E may be achieved using one diffuser on each branch as a reference. In this case diffusers 2 and 4 can be used.

Measure airflow of diffusers 2 and 4.

e.g. airflow rate of diffuser 2	=	$113 m^3/h$	% = 113
e.g. airflow rate of diffuser 4	=	$270 m^3/h$	% = 135

Readjust the damper on branch B-C and measure the flow rates of diffusers 2 and 4.

e.g. airflow rate of diffuser 2	=	$115 m^3/h$	% = 115
e.g. airflow rate of diffuser 4	=	$226 m^3/h$	% = 113

This is an acceptable balance and both branches B-C and B-E are carrying the same percentage of design airflow.

The next step is to regulate the total airflow in the main duct A-B to 100% of the design value. The pitot traverse method should be used employing the CIBSE recommended measurement positions, Table 2. The damper on the main duct or fan speed should be adjusted to achieve the correct airflow in the system. The system is now balanced and operating at the "design" airflow rates.

It is clear that balancing even a simple HVAC system using this method is tedious and time consuming. In practice several attempts are required to obtain the same percentage of the design flow of various diffusers. The task of balancing of an HVAC system for large buildings would be lengthy and the use of vane anemometers and pitot tubes could give rise to significant errors in airflow measurements.

2.2 TRACER-GAS METHOD

This method is based on the application of the constant-injection technique to estimate and adjust airflow rates in HVAC systems. Tracer gas is injected into a duct at a constant rate (q) and the resulting concentration response (C) is measured. Assuming that the air and tracer gas are perfectly mixed within the duct, and that the concentration of tracer gas in the outside air is zero, the following equation can be used to estimate the flow rate (F):

$$F = (q/C) \times 10^6 \qquad (1)$$

The procedure for balancing an HVAC system is as follows:

i) Assume that the design airflow rates of various diffusers are those given in Table 1.

ii) Start, for example, with branch B-C-D. Measure the airflow rate of diffuser 3 by injecting tracer gas at point 7 and monitoring the concentration at point 3. Use equation (1) to estimate the airflow rate.

iii) Determine the percentage of the design airflow of diffuser 3 (i.e. measured flow/design flow).

iv) Assume a target concentration of tracer gas (say 200 ppm) which is required in all ducts to achieve a balanced system. Assume that diffuser 4 is carrying the same percentage of the design flow as diffuser 3 and calculate the total flow rate in duct B-C.

v) Use equation (1) to estimate the amount of tracer gas, q, which should be injected in duct B-C to achieve the target concentration of 200 ppm.

iv) Inject tracer gas at point 8 and adjust damper 4 until the concentration in branch B-C equals 200ppm. Check the concentration at point 3 and adjust damper 3 if required.

v) Apply procedure (i) to (iv) to the branch B-E-D. The concentration in this branch should be 200 ppm.

vi) Adjust dampers 2 and 4 so that branches B-C and B-E carry the same percentage of the design flow. Finally adjust the fan speed or damper in the main duct so that all diffusers carry 100% of design airflow; the system is then completely balanced.

3. DESCRIPTION OF TRACER-GAS EQUIPMENT

The HVAC system was balanced out using the tracer-gas injection and sampling units shown in Figures 3 and 4. The tracer-gas injection unit incorporates solenoid valves, a manifold, a mass-flow controller, a switch controller and a tracer-gas cylinder. The injection rate was controlled using a variable power supply and the rate of tracer gas injected was displayed on a digital unit.

The tracer-gas sampling system consisted of solenoid valves, a manifold, a switch controller and a gas analyser.

The system could be used for sampling various tracer gases. We chose to use sulphur hexafluoride (SF_6) as it has desirable characteristics in terms of safety, detectability and cost. In addition its suitability has been demonstrated previously by its successful use in air movement studies.

4. RESULTS AND DISCUSSION

A small-scale HVAC system, Figure 1, was balanced using tracer-gas equipment and a pitot tube. The constant-injection technique was used to estimate the flow rate in the main duct A-B, branches B-C-D and B-E-F and terminals 1-4. The measurement procedure involved injection of SF_6 tracer gas at points 5, 6, 7, 8, 10 and monitoring the concentration at points 1, 2, 3, 4, 9 respectively. The flows in the various ducts and terminals were then balanced using the procedure described in section 2.2 of this report.

Figure 5, 6 and 7 show measurements of airflow for three different sets of design flow. Airflow rates estimated from tracer-gas measurements were compared with a pitot-tube measurements as shown in these figures. The difference between airflow rate estimated using the tracer-gas technique and measurements made using a pitot-tube (F_{tracer}-$F_{pitot-tube}$/$F_{average}$) was in the range 0-10% (see Tables 3, 4 and 5). Difficulties in measuring airflow at low velocities (i.e. below 3 m/s) using a pitot-tube produced large errors.

The tracer-gas equipment was found to be a simple and convenient of measuring and balancing airflow in the HVAC system. The system could be balanced to high degree of accuracy in a short period.

5. MULTI-INJECTION/SAMPLING TRACER-GAS EQUIPMENT

The period required to balance an HVAC system can be significantly reduced if multi-injection/sampling tracer-gas equipment is employed. Figures 8 and 9 show the injection and sampling units. The multi-injection unit is used to release tracer gas in various branches of the HVAC system according to the design flow. The tracer-gas sampling unit is then be used to measure the airflow rate. The diffuser is then adjusted to achieve the target concentration necessary to balance the HVAC system.

REFERENCES

1. CIBSE Guide, "Reference Data", The Chartered Institution of Building Services Engineers, London, United Kingdom, 1986.

Branch	B - F		B - D	
	1	2	3	4
Measured Flow (m3/h)	110	120	200	300
Design Flow (m3/h)	100	100	150	200
% of Design Flow	110	120	133	150
% of Design Flow (branch)	115		143	

Table 1. Design flows and measured flows with all flow controls open

Duct Size (diameter)	No. of points at each traverse	No. of traverse	Location of test point from duct wall as % of duct diameter					
			1	2	3	4	5	6
150mm	2	1	12	88	-	-	-	-
150 - 240mm	2	2	12	88	-	-	-	-
250 - 435mm	4	2	4	29	71	96		
450 and over	6	2	3	14	32	68	86	97
For disturbed flow in all sizes over 150mm	6	2 or 4	3	14	32	68	86	97

Table 2. Measurement of velocity pressure in circular ducts

	F1	F2	F3	F4	$F_{A\text{-}B}$
Flow from pitot tube F_T (m3/h)	99	147	91	135	497
Flow from tracer gas F_G (m3/h)	100	150	100	150	500
$\Delta F/\bar{F}$ (%)	1	2	9	10	1

Table 3. Comparison of tracer-gas airflow measurements with measurements made using a pitot tube, Experiment 1.

	F1	F2	F3	F4	$F_{A\text{-}B}$
Flow from pitot tube F_T (m3/h)	97	149	195	197	638
Flow from tracer gas F_G (m3/h)	100	150	200	200	650
$\Delta F/\bar{F}$ (%)	3	1	3	2	2

Table 4. Comparison of tracer-gas airflow measurements with measurements made using a pitot tube, Experiment 2.

	F1	F2	F3	F4	$F_{A\text{-}B}$
Flow from pitot tube F_T (m3/h)	168	219	197	300	882
Flow from tracer gas F_G (m3/h)	170	230	200	300	900
$\Delta F/\bar{F}$ (%)	1	5	2	0	2

Table 5. Comparison of tracer-gas airflow measurements with measurements made using a pitot tube, Experiment 3.

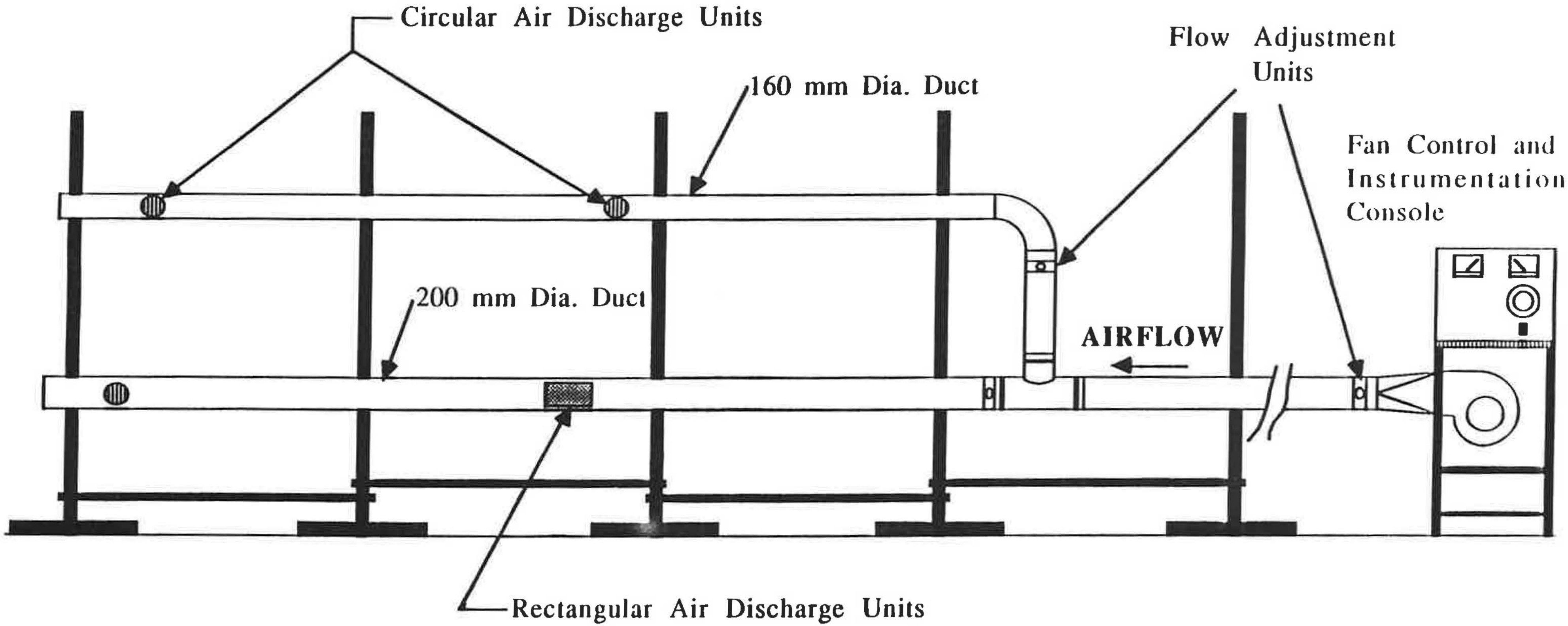
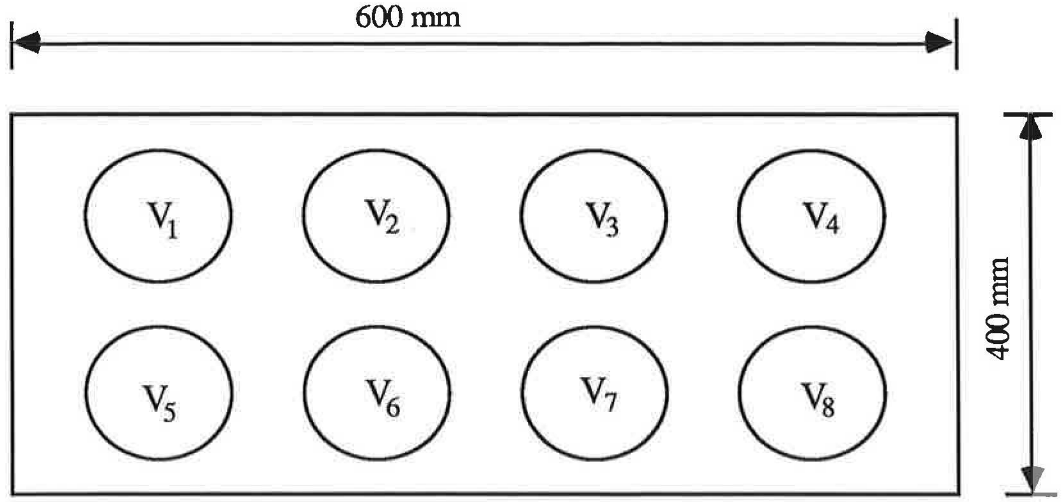


Fig. 1. Schematic diagram of small-scale HVAC system



$$\text{AVERAGE VELOCITY} = \frac{V1 + V2 + V3 + \text{------} + V8}{8}$$

Fig. 2. Method for measuring the air velocity of a rectangular diffuser

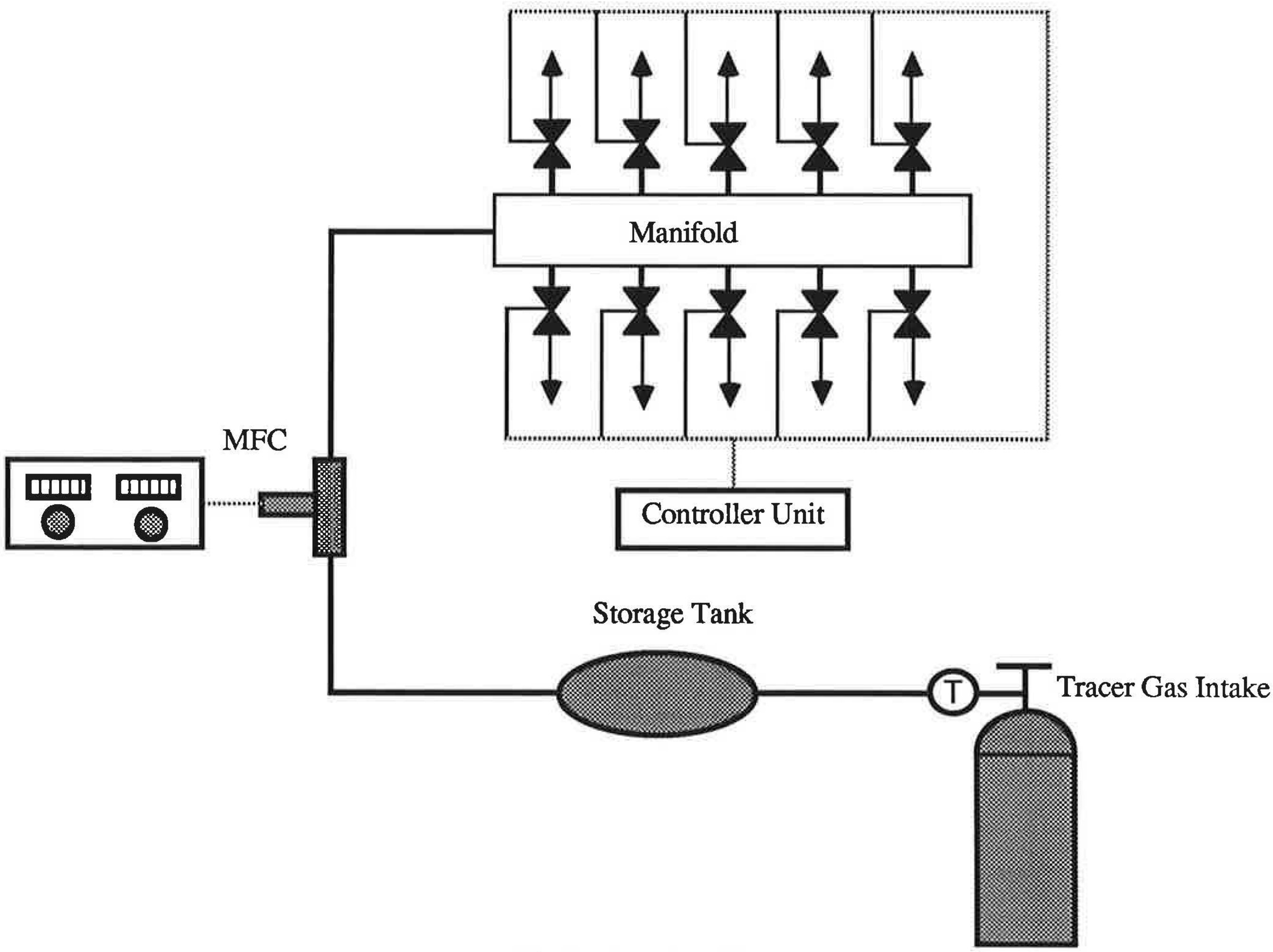


Fig.3. Injection Unit

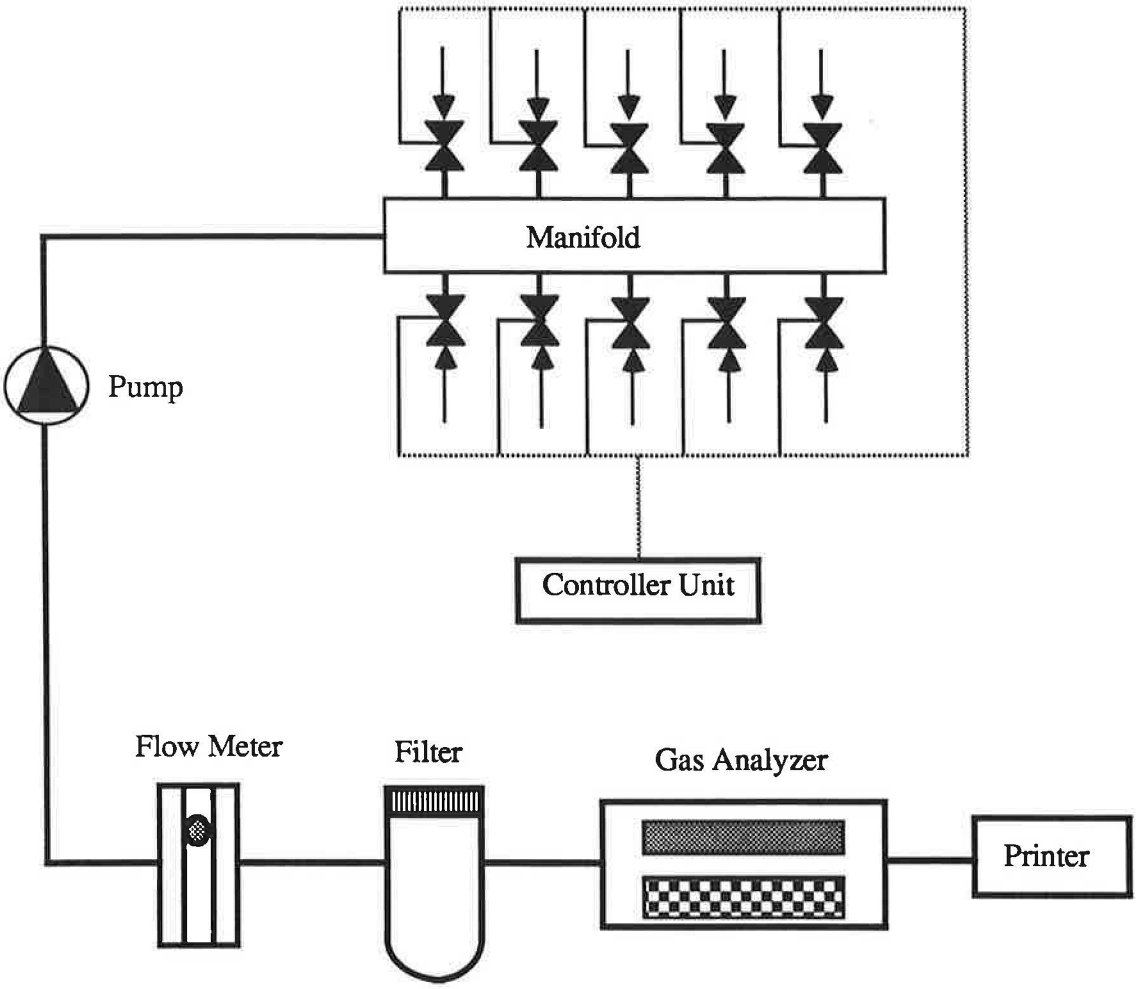


Fig.4. Sampling Unit

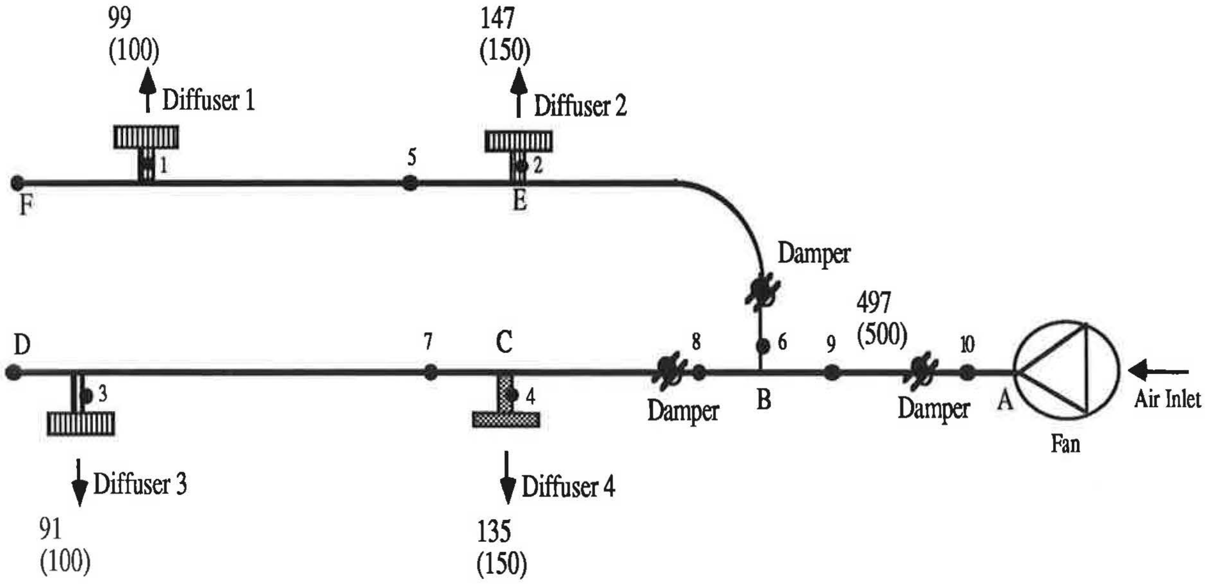


Fig.5. Comparison of tracer-gas airflow measurements with measurements made using a pitot tube (unit : m3/h, (____) tracer gas results), Experiment 1.

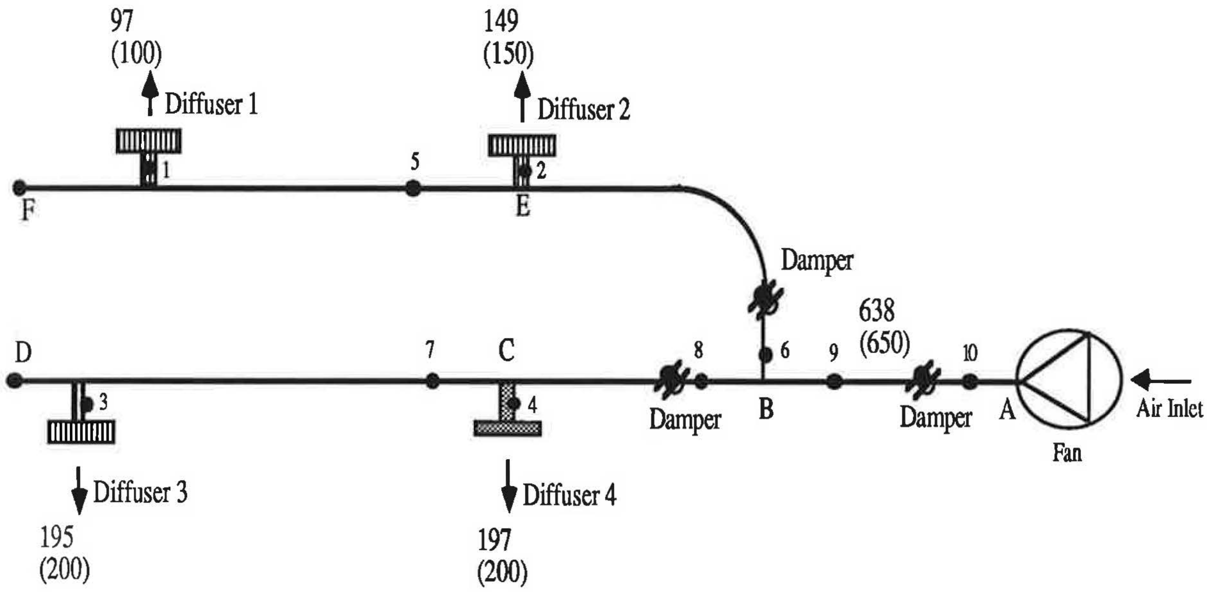


Fig.6. Comparison of tracer-gas airflow measurements with measurements made using a pitot tube (unit : m3/h, (____) tracer gas results), Experiment 2.

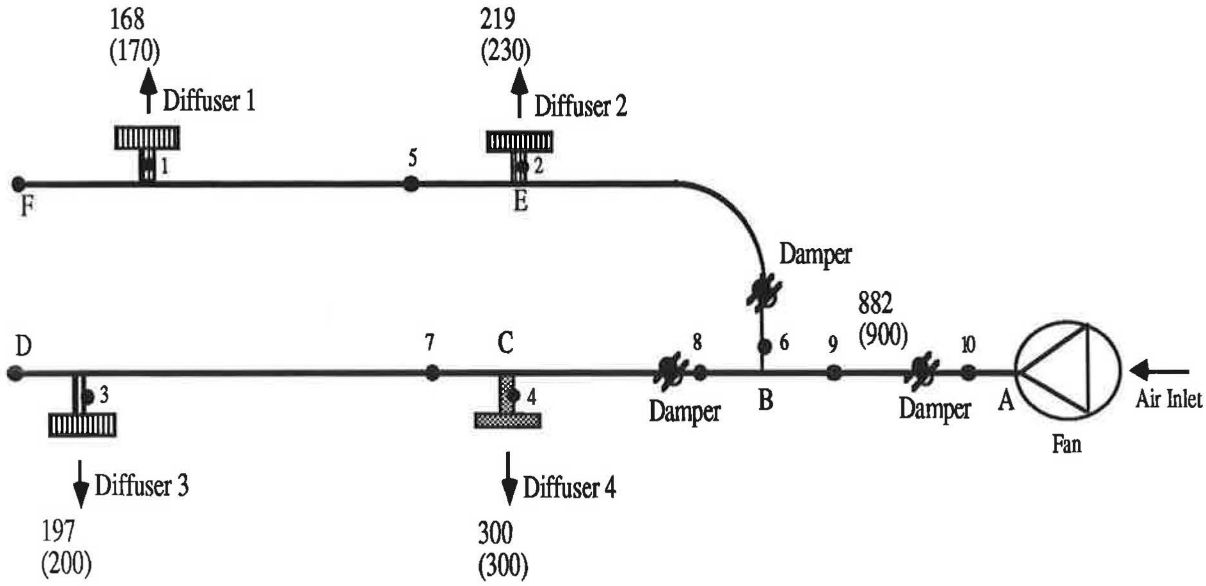


Fig.7. Comparison of tracer-gas airflow measurements with measurements made using a pitot tube (unit : m3/h, (____) tracer gas results), Experiment 3.

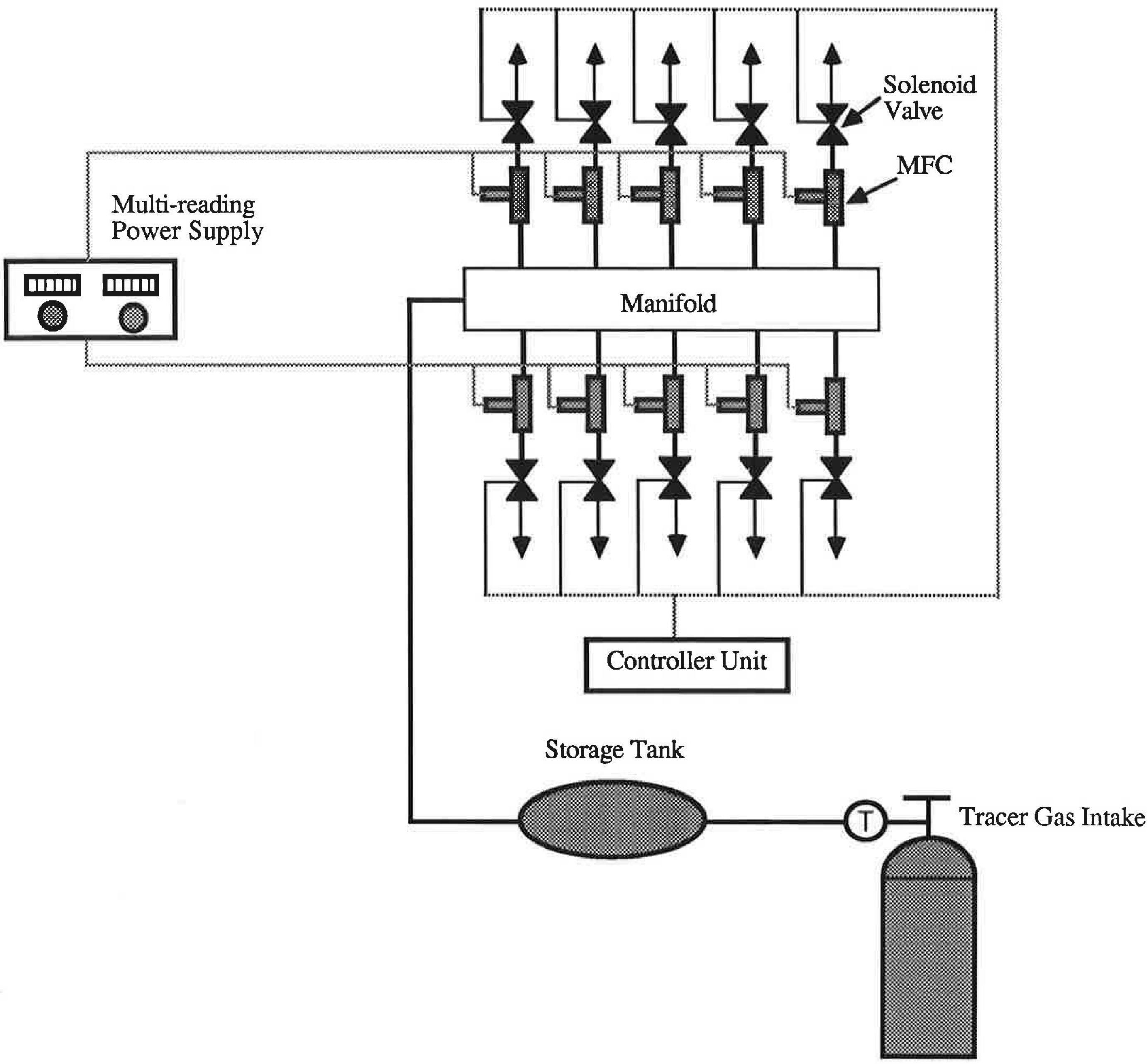


Fig.8. Multi-Injection Unit

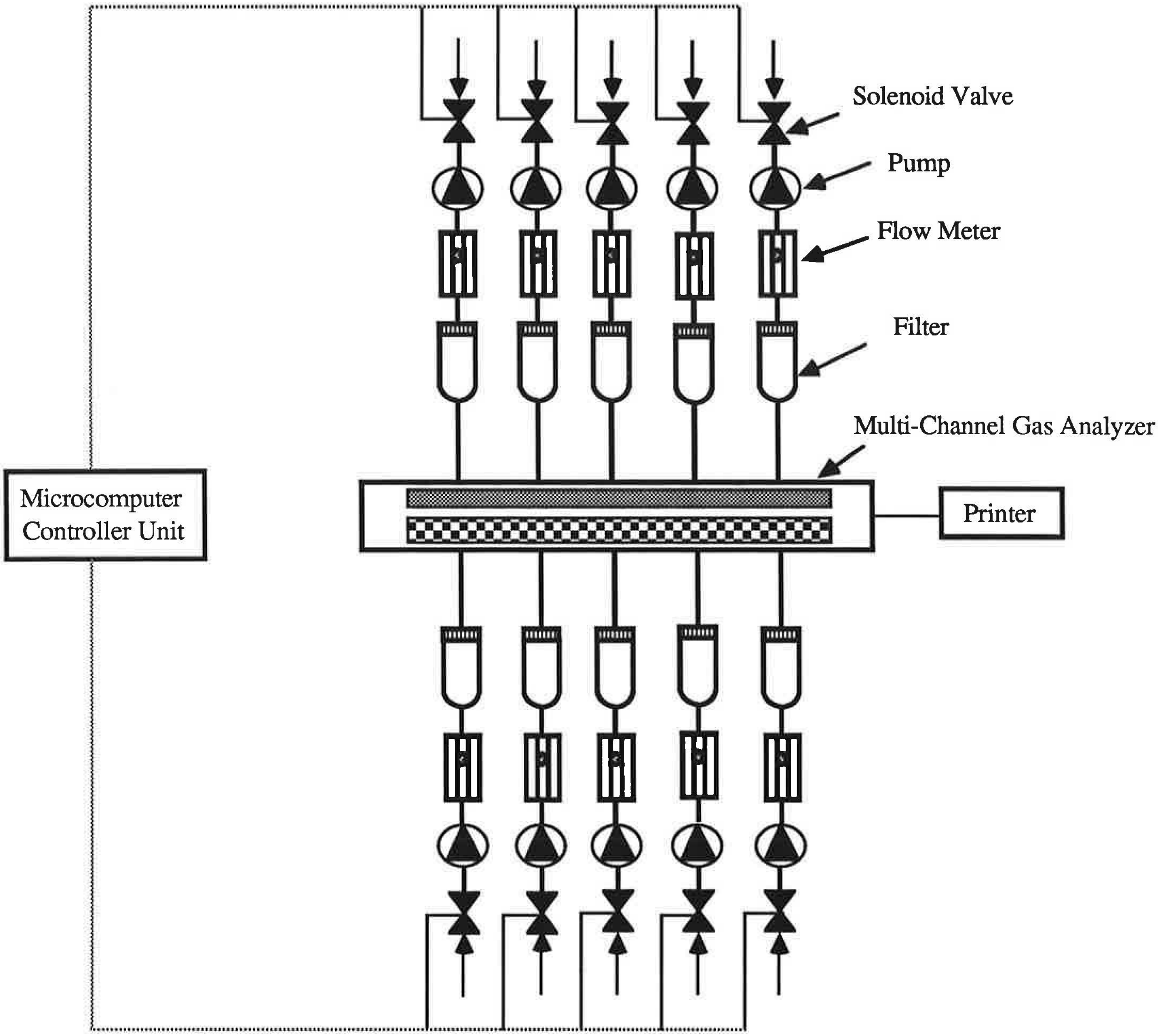


Fig.. 9. Sampling Unit