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PERFORMANCE TESTING OF HVAC SYSTEMS USING TRACER-GAS TECHNIQUES

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SYNOPSIS

The constant-injection and pulse-injection techniques were used to measure airflow in a duct and small-scale HVAC system. Tracer-gas measurements were compared with measurements made using a pitot-tube. The concentration of SF_6 tracer gas, velocity and static pressure distributions were measured in the duct and HVAC system for various Reynolds numbers. Results indicated that the flow rate obtained using the pulse-injection technique is in closer agreement with values obtained using the pitot-tube than results obtained using the constant-injection technique. This paper also describes the development of a tracer-gas system which has high-sampling frequency and could be used for measurement of airflow in HVAC systems.

LIST OF SYMBOLS

C_c	Concentration of tracer gas; constant-injection technique (ppm)
C_P	Concentration of tracer gas; pulse-injection technique (ppm)
F_c	Airflow rate using constant-injection technique (m^3/s)
F_P	Airflow rate using pulse-injection technique (m^3/s)
F_u	Airflow rate using pitot tube (m^3/s)
q	Injection flow rate of tracer gas (m^3/s)
D_h	Hydraulic diameter of the duct (m)
X	Distance from the duct inlet in the direction of flow (m)
t	Time (s)
$G_{(t)}$	Pulse-injection rate (m^3/s)

1. INTRODUCTION

Indoor air quality, thermal comfort and energy use in buildings are largely dependent on the performance of HVAC systems. Incorrect ventilation rate is a common cause of poor indoor air climate in office buildings and this can have detrimental effects on the health of the occupants. If these problems are to be avoided, frequent checks on the performance of HVAC systems must be carried out. Measurement of airflow in HVAC systems is usually performed using traditional instrumentation such as pitot tubes, hot-wire and vane anemometers. This type of instrumentation is difficult to employ in practice as a long measuring duct is required for the establishment of fully developed flow. In addition, limited access to the flow passage could restrict measurements and flow velocities less than 3 m/s could lead to measurement inaccuracies if traditional instrumentation were employed [1].

Tracer-gas techniques [2] such as constant-injection and pulse-injection offer an alternative approach for measuring airflow in HVAC systems, and unlike traditional instrumentation, are not limited by the length or complexity of duct configuration. Tracer gas techniques can be used to measure airflow over a wide range of values (ie, laminar and turbulent flow) as gas chromatographs can detect tracer gases at low concentrations. Furthermore, tracer-gas techniques can be used to measure flow rates directly and do not require determination of the cross-sectional area of the duct or flow profile at the duct wall. One further advantage of tracer-gas techniques is that they can be used to determine the airtightness of ductwork. This is important if energy and noise resulting from air leakage are to be controlled.

The present study describes the use of constant-injection and pulse-injection techniques for measuring airflow in a duct and compares the results with those obtained using a pitot tube. Tracer-gas techniques were also used to carry out measurements in a small-scale HVAC system. This paper also describes a system with a high-sampling frequency which could be used measuring airflow in HVAC systems.

2. TRACER-GAS TECHNIQUES

The following injection strategies were used to measure airflow in the duct and HVAC system:

2.1 Constant-Injection Technique

Tracer gas is injected into the duct at a constant rate and the resulting concentration response is measured. Assuming that the air and tracer gas are perfectly mixed within the duct, and that the concentration of tracer gas in outside air is zero, the following equation can be used for steady-state conditions [3]:

$$F_c = (q/C_c) \times 10^6 \tag{1}$$

2.2 Pulse-Injection Technique

This technique is based upon the injection into the duct inlet of a short-duration pulse of tracer gas at a rate $G_{(t)}$. The variation of tracer 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. If the tracer gas is assumed to be purged from the duct after some time interval (t_1 to t_2) then the volume of tracer gas leaving the duct must equal to the amount injected. Applying the integral volume balance of tracer gas, we have:

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

3. MATERIALS AND METHODS

3.1 Duct System

The experimental work was carried out using a galvanised mild steel duct of 12m long and 0.56m internal diameter. The downstream end was connected to an axial fan by means of a diffuser. The flow rate through the duct was varied using a speed controller made by ABB Stromberg Drives, Finland. The fan was driven by an AC motor of 4 kW and with a maximum speed of 2880 rpm. The fan was manufactured by Elta Fans Ltd, UK.

Static, velocity pressure and tracer gas tappings were positioned along the duct. The velocity tappings allowed the insertion of a pitot tube which could be traversed across the duct cross-section in order to measure velocity at various distances from the duct wall. Velocity and static pressures were measured using an EMD 2500 micromanometer, made by Airflow Development, UK.

Use of the constant-injection technique (see Figure 1) involved supplying SF_6 tracer gas at a constant rate into the duct inlet using a mass flow controller which had a maximum flow capability of 3.9 L/min. The measurement accuracy of the mass flow controller was ± 1%.

For the pulse-injection technique, tracer gas was injected at the inlet of the duct using a syringe (see Figure 2). Multipoint injection was necessary for the approximation of a uniform concentration across the cross-section of the duct at the measurement point. It was necessary to measure the concentration of tracer gas at the downstream point, to determine the integral of the concentration. This was achieved by filling a plastic bag with a sample using a small pump. Sampling was begun 10 seconds before the pulse was injected, and continued until the pulse was completely purged from the duct.

The concentration of tracer gas was measured using an Infra-red gas analyser, type BINOS 1000, made by Rosemount GmbH & Co (RAE), Germany. The accuracy of analyser was estimated to be within ± 2%.

3.1 HVAC Systems

Experimental work was carried out in a small-scale HVAC system, Figure 3. This consisted of a fan control and instrumentation console. The fan unit had a volumetric flow rate in the range 0.1 to 0.3 m^3/s, dependent upon the ductwork resistance and supply voltage. The console contained a variable transformer for fan speed control, together with a voltmeter and ammeter for measurement of supply voltage and current. A square to round fan intake transition also accepted standard 600 x 600mm filters. The rectangular to round fan discharge transition connection to 200mm diameter ductwork using standard push fittings. The duct was manufactured from galvanised mild steel. Two types of air supply diffusers were used and the discharge flow was controlled by means of dampers. A Binos 1000 gas analyser, a pitot-static tube and a vane anemometer were used to estimate the flow rate through the system.

4. TRACER-GAS SAMPLING SYSTEM

As part of our research programme we have developed a tracer gas system with a high-sampling frequency which could be used to measure airflow in HVAC systems. The automated sampling system shown in Figure 4 is capable of taking samples as frequently as once per second. In essence, the tracer gas sampling system incorporates solenoid valves, tracer gas sampling tubes, a pump, a microprocssor-based controller, a manifold and a by-pass valve. The short sampling period was achieved using a specially designed microprocessor controller. This contained a central processing unit and programme memory with a capability of 60 input/output.

The system is flexible since the samples may be taken in any desired sequence and at any desired time. The sampling tubes may be then stored for subsequent analysis in the laboratory. A gas chromatograph, made by Perkin-Elmer Ltd, fitted with ECD and FID detectors together with an ATD-50 thermal desorber was used for separation and analysis of samples.

5. RESULTS AND DISCUSSION

5.1 Duct System

Measurements of airflow rate in the duct were carried out by means of the constant-injection and pulse-injection techniques as well as using a pitot tube. SF_6 was injected at $X/D_h = 0625$, and the concentration of tracer gas was monitored at various positions downstream. The concentration of tracer gas was found to be large close to the injection point, and decreased as X/D_h increased. The tracer-gas concentration remained constant when X/D_h was greater than 15 (for constant-injection) and 8 (for pulse-injection technique).

Figure 5 compares measurements of duct airflow rate made using the tracer-gas techniques and a pitot tube. General agreement was observed, and the best linear relationships were:

$$F_c = 1.05\ F_u + 0.112 \qquad (3)$$

$$F_P = 1.062\ F_u - 9.12 \times 10^{-2} \qquad (4)$$

These results indicate that the flow rate obtained using the pulse-injection technique is in closer agreement with values obtained using the pitot-tube than the flow rate obtained using the constant-injection technique.

5.2 HVAC System

Measurements of airflow were carried out in a small-scale HVAC system. The pulse-injection technique was used to estimate the flow rate through the main duct AB, branches BCDE and BFGHIJ and terminals 1-6. Measurement procedure involved injection of 1.5 L of SF_6 at the inlet of the fan and monitoring the concentration at various points along the HVAC system using sample bags. The pumps attached to the sample bags were switched on 10 seconds before injection was begun, and switched off after purging of tracer gas has been completed. The background concentration of tracer gas was monitored continuously and included in our calculations.

To illustrate the method of calculation we show here the equations used to determine the airflow through branches BC and BF:

$$F_{AB} = [\int_{t_1}^{t_2} C_{AB}\,dt]^{-1} \int_{t_1}^{t_2} G_{AB}\,dt \qquad (5)$$

$$F_{BC} = [\int_{t_1}^{t_2} C_{BC}\,dt]^{-1} \int_{t_1}^{t_2} G_{BC}\,dt \qquad (6)$$

$$F_{BF} = [\int_{t_1}^{t_2} C_{BF}\,dt]^{-1} \int_{t_1}^{t_2} G_{BF}\,dt \qquad (7)$$

$$F_{AB} = F_{BC} + F_{BF} \qquad (8)$$

$$G_{AB} = G_{BC} + G_{BF} \qquad (9)$$

Equations (5-9) can be solved to determine G_{BC}, G_{BF}, F_{BC} and F_{BF}. The same method was used to estimate airflow rates through other branches and terminals.

Figures 6 and 7 show measurements of airflow made in the HVAC system using the pulse-injection technique. Airflow rates estimated from tracer-gas measurements were compared with a pitot tube measurement as shown in these figures. The difference between airflow rate estimated using tracer gas measurements and measurements made using a pitot-tube [ie, $(F_p-F_u)/F_u$] were in the range -19.8 to 7.2%. However, it should be noted as to turbulence level and this can produce measurement inaccuracies. The difficulties in measuring low velocities (ie, below 3m/s) using a pitot-tube causes additional errors.

6. CONCLUSIONS

The following conclusions are drawn:

1. Results indicate that the flow rate obtained using the pulse-injection technique is in closer agreement with values obtained using the pitot-tube than the flow rate obtained with the constant-injection technique.

2. The pulse-injection technique was found to be a simple and useful method for measuring airflow in HVAC systems.

3. Depending on the flow rate, the difference between airflow rates estimated from the pulse-injection technique and obtained using a pitot-tube were in the range -19.8 to 7.2%.

ACKNOWLEDGEMENTS

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Figure Captions

Figure 1	Instrumentation for the constant-injection technique
Figure 2	Instrumentation for the pulse-injection technique
Figure 3	HVAC System for testing tracer gas techniques
Figure 4	Tracer-gas sampling system
Figure 5	Comparison of tracer-gas airflow measurements with measurements made using a pitot tube, duct system
Figure 6	Comparson of tracer-gas airflow measurements with measurements made using a pitot tube, HVAC system (unit : m^3/s, (___) tracer gas results)
Figure 7	Comparson of tracer-gas airflow measurements with measurements made using a pitot tube, HVAC system (unit : m^3/s, (___) tracer gas results)

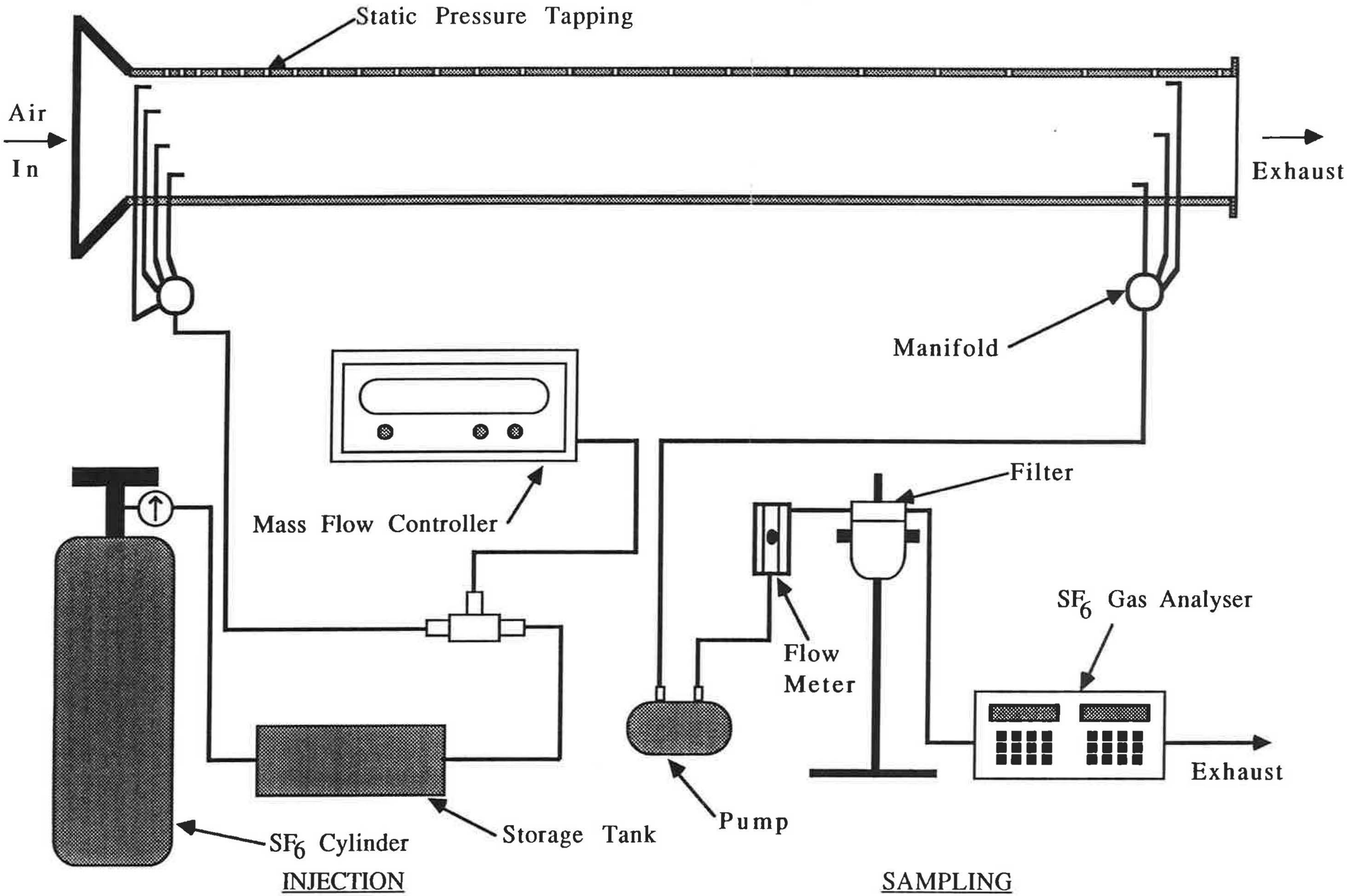

Figure 1 Instrumentation for the constant-injection technique

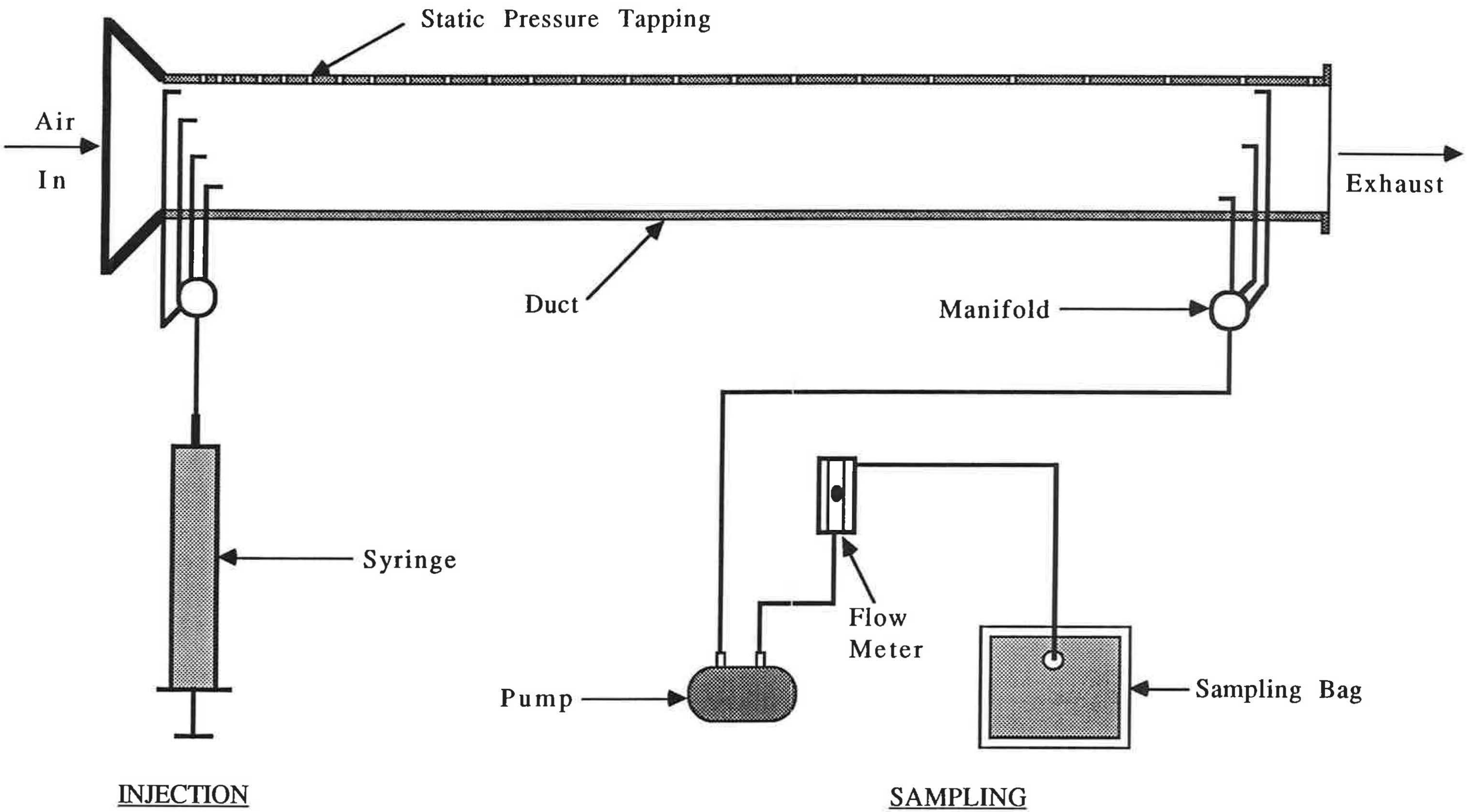

Figure 2 Instrumentation for the pulse-injection technique

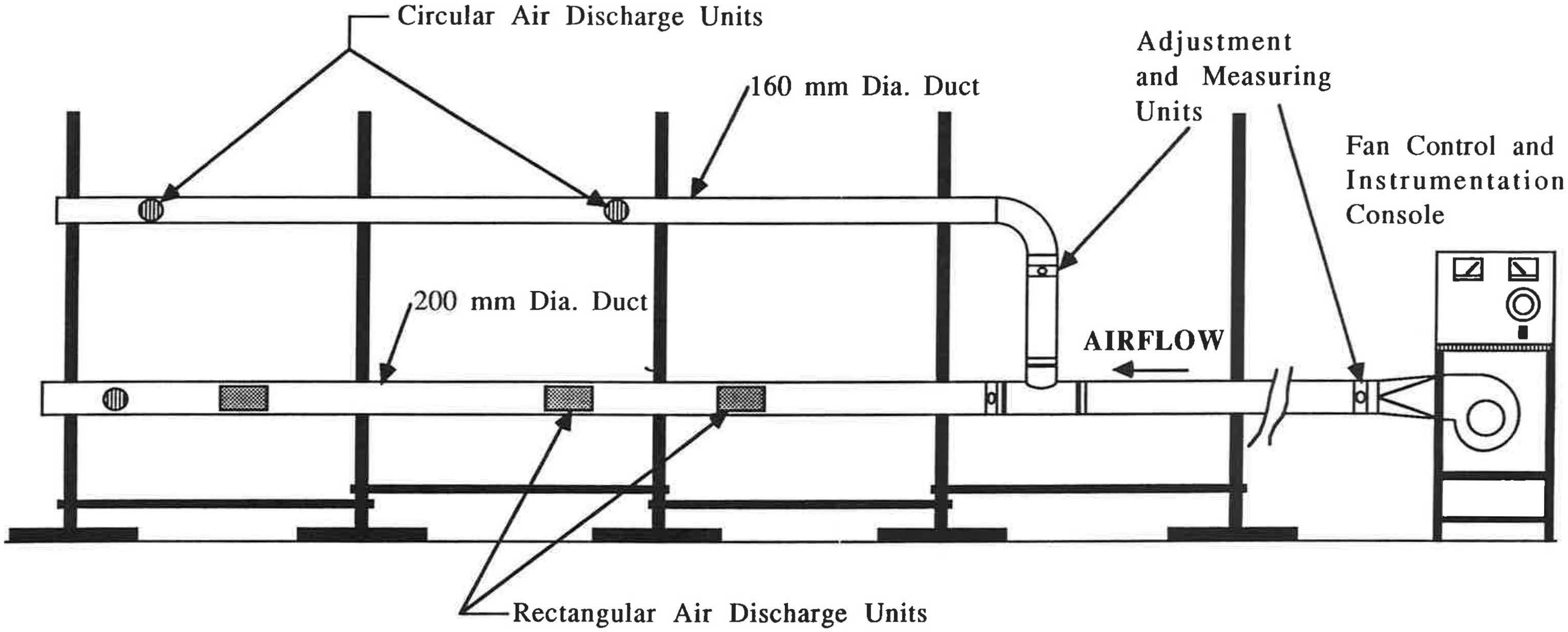

Figure 3 HVAC System for testing tracer gas techniques

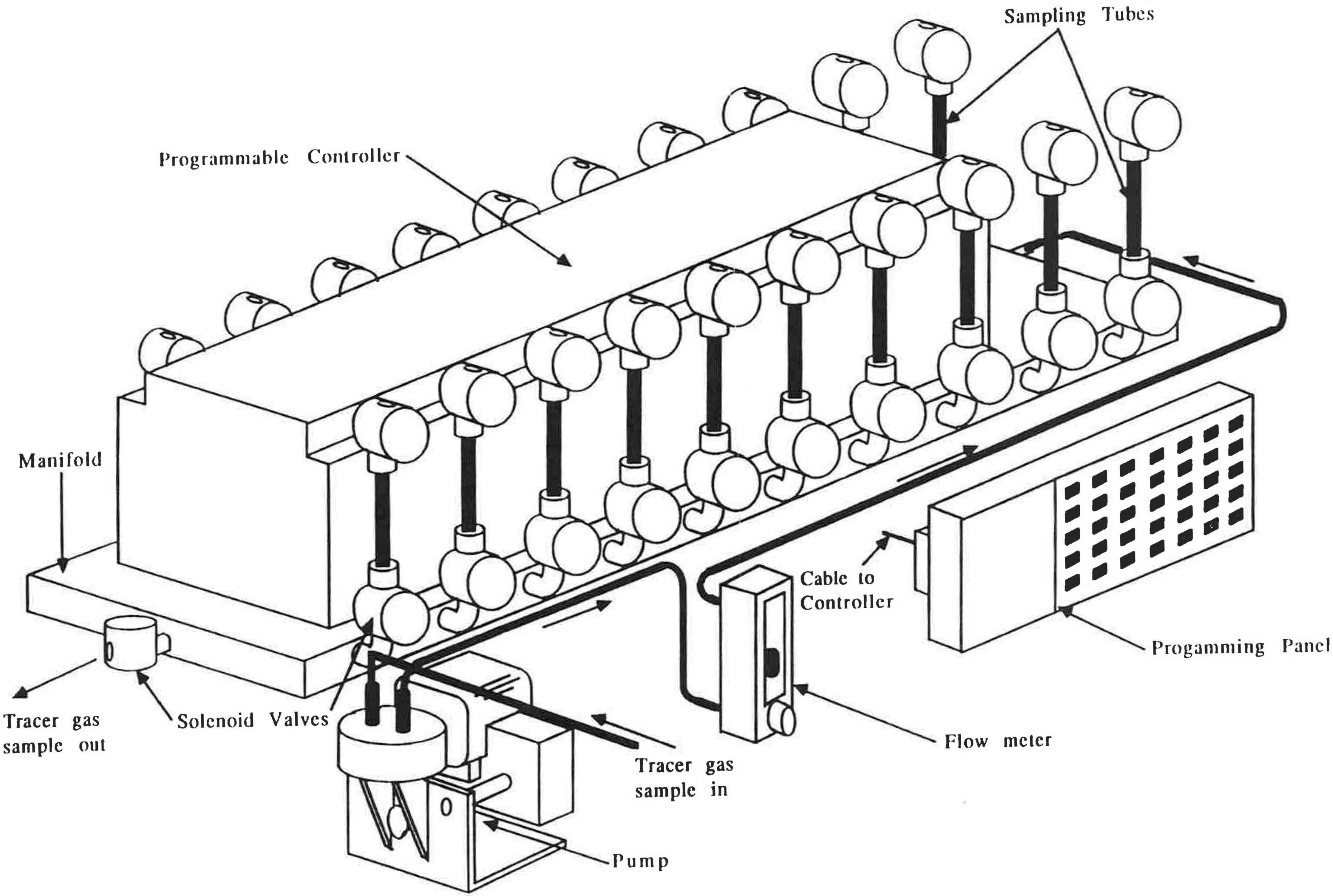

Figure 4 Tracer-gas sampling system

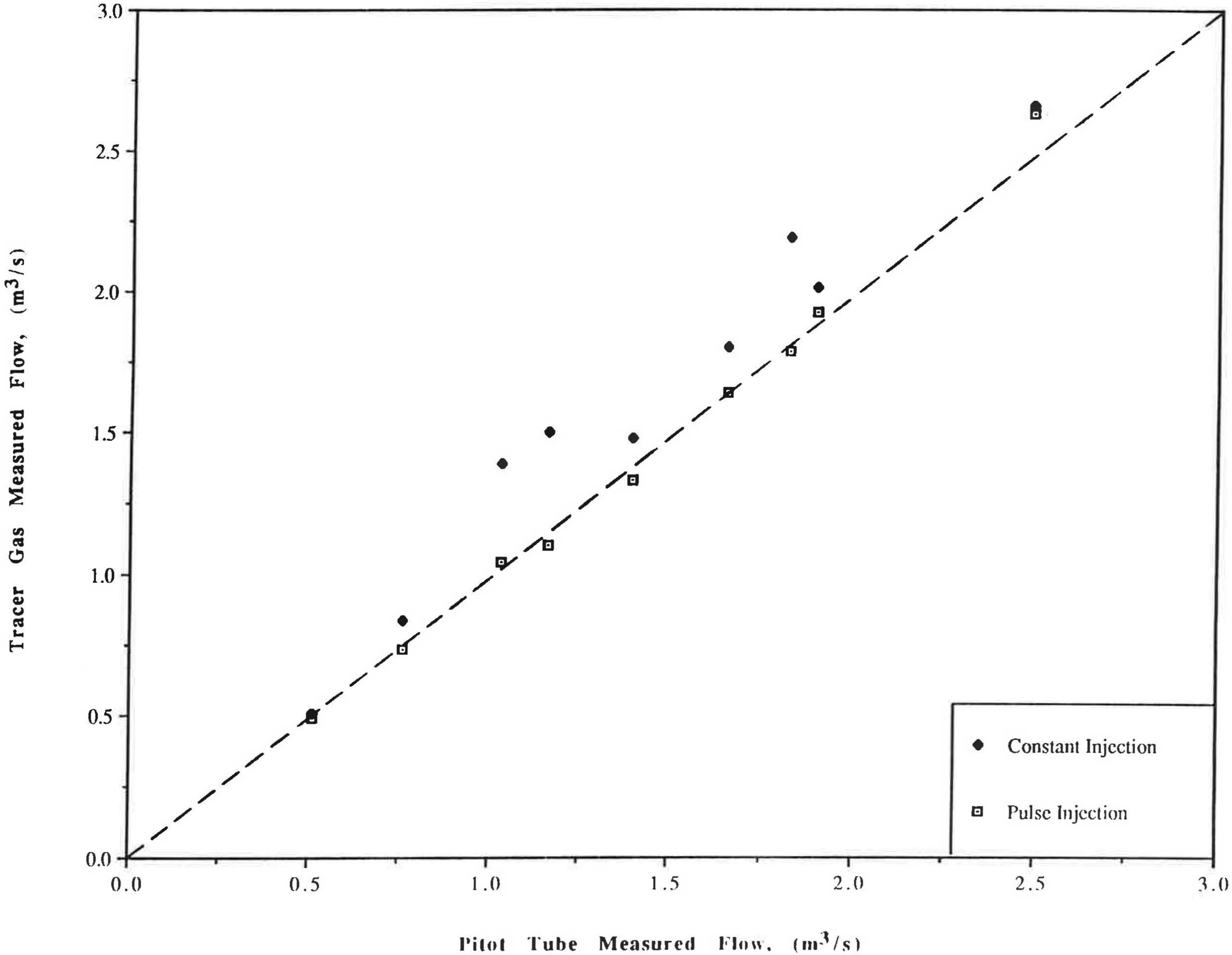

Figure 5 Comparison of tracer-gas airflow measurements with measurements made using a pitot tube

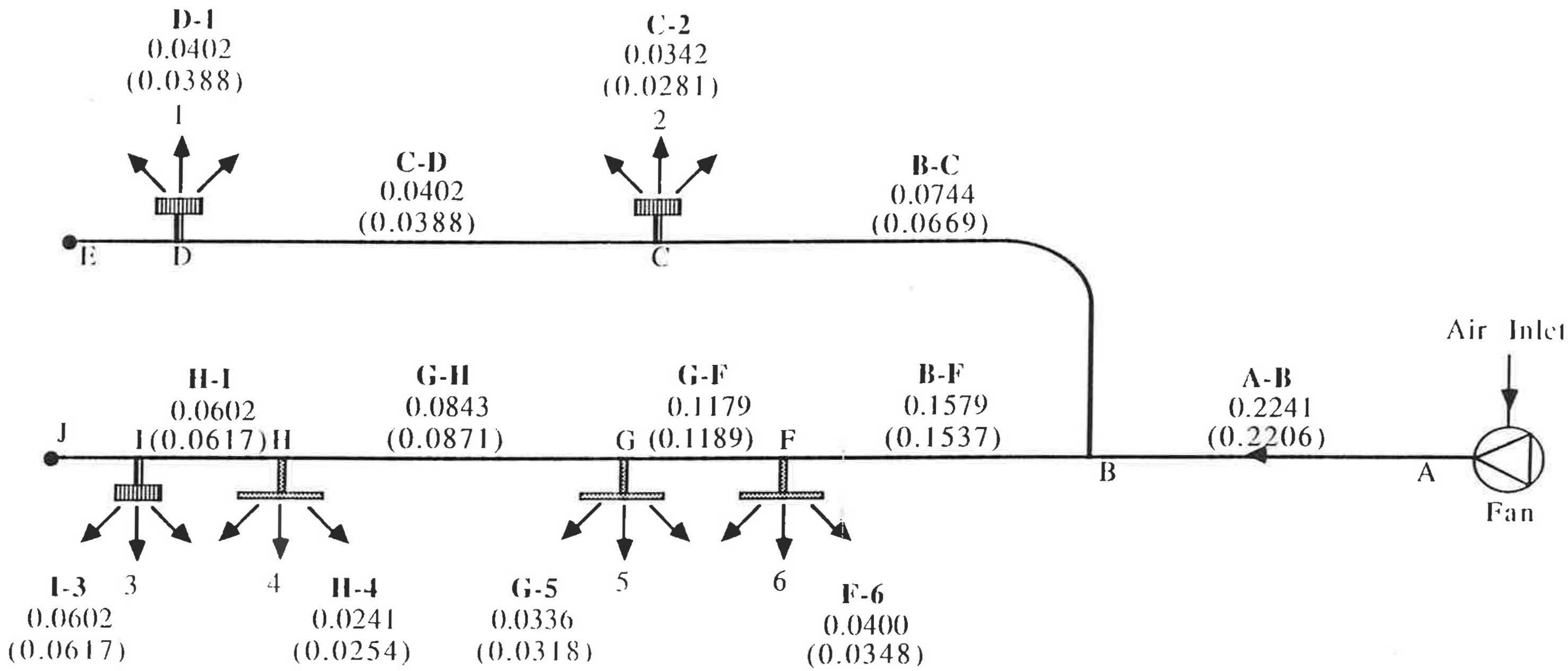

Figure 6 Comparison of tracer-gas airflow measurements with measurements made using a pitot tube, HVAC system (unit : m^3/s, (____) tracer gas results)

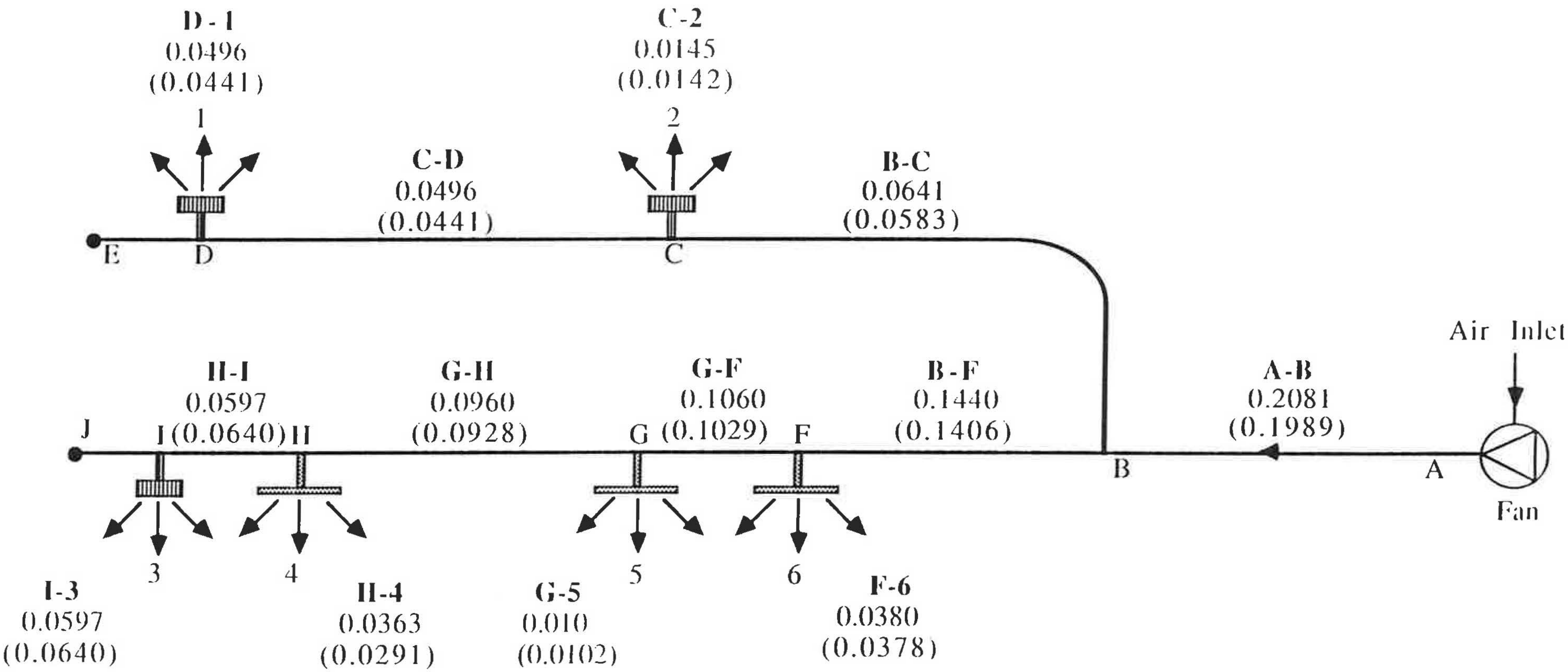

Figure 7 Comparison of tracer-gas airflow measurements with measurements made using a pitot tube, HVAC system (unit : m^3/s, (____) tracer gas results)