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Summary Constant injection of tracer gas was used to determine the airtightness of a straight length of 300 × 300 mm square duct in a laboratory setting. Holes are preformed in the ductwork which is connected to a fan with variable speed control to simulate leakages. The holes can be sealed with rubber bungs to simulate an airtight ductwork. 'Stationary' and 'mobile' methods have been developed. The stationary method is suitable for conditions where the locations of the leaks in the ductwork is known. The 'mobile' method is used to determine the airtightness of ductwork without any prior knowledge of the locations of leaks. Both methods were found capable of locating the leaks and of determining the leakage rate of the ductwork without disrupting the operation of the HVAC system. Algorithms were established for leakage rates in terms of airflow rates and for leakage rates in terms of pressure drops.

HVAC ductwork: Constant-injection tracer-gas assessment of airtightness

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List of symbols

- F Airflow rate in duct (m^3s^{-1})
- F_{ci} Airflow rate measured using constant-injection technique (m^3s^{-1})
- $C(t)$ Concentration of tracer gas at time t (ppm)
- q Injection rate of tracer gas into duct (m^3s^{-1})
- L Leakage rate of ductwork (m^3s^{-1})
- ΔP_L Pressure drop across leaks (Pa)

1 Introduction

Building envelopes have become more airtight since the oil crisis of the early 1970s prompted increasing awareness of energy conservation. At the same time, indoor air quality and occupant comfort must be maintained through greater control over the ventilation process (natural or mechanical). Most large buildings are ventilated mechanically. Air is treated by an air-conditioning system before being supplied to rooms via ductwork. Most attention has been focused on conditioning the air and on its effective distribution within room spaces via air diffusers. The duct system which delivers the air has been neglected. The airtightness of ventilation ductwork is a major concern. Leaky ductwork can lead to the ingress of pollutants into the airstream, reduce the amount of conditioned air entering the rooms, and thus affect the performance of the system overall. Duct leakages would cause the actual airflow rate to be more or less than the design flow in extract and air supply ducts respectively. In addition, the pressures and sound levels in the ductwork cannot be controlled unless it is sufficiently airtight. It is therefore important to establish a method of evaluating the airtightness of ductwork that is simple to use and provides a high degree of accuracy.

Building envelope airtightness is usually evaluated by DC or AC pressurisation[1]. Building airtightness levels can be measured using a fan, temporarily installed in the building envelope to pressurise the building. The fan creates an internal, uniform, static pressure within the building. Measurements aim to relate the pressure differential across the envelope to the airflow rate required to produce it. However, this can involve a great deal of equipment. Tracer-gas techniques offer an alternative to pressurisation. Modera[2] and Robison and Lambert[3] examined residential duct leakage using tracer-gas techniques. These techniques have been widely applied to air exchange measurements in buildings[4–8] and airflow in ductwork[9–12]. Cheong[13] found that turbulence and bends in ductwork encourage better mixing between the air and tracer gas. He compared airflow rates in ductwork according to the constant injection technique with those according to the conventional pitot-static tube. The results differed by −7.1% to 2.2%.

This paper will describe the application of tracer-gas techniques to ductwork airtightness, without reference to the pressurisation method in terms of accuracy and practicality.

2 Constant-injection tracer-gas techniques

This technique is based on the injection of tracer gas into the upstream of the duct at a uniform rate q. Tracer-gas concentration $C(t)$ is measured downstream of the particular duct section (see Figure 1). Tracer-gas concentration cannot be measured immediately after injection as time must be allowed for an appropriate state of equilibrium to be reached.

Assuming that both the injection of tracer gas into the duct and the air exchange rate remain constant during the measurement, and that no tracer is present at the start of the mea-

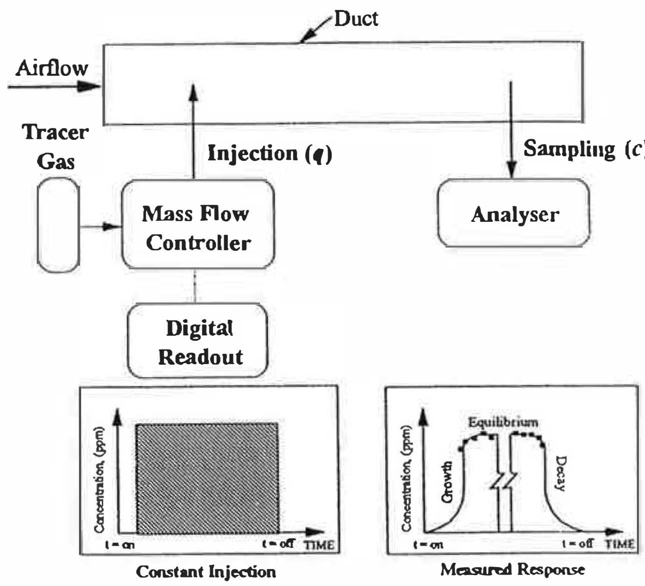

Figure 1 Schematic of constant-injection instrumentation

surement, the following equation can be used to determine the air flow rate F in the duct:

$$F = q/C(t) \quad (1)$$

This technique is appropriate for determining the airtightness of ducts before and after access holes or measuring devices have been installed. The duct system (see Figure 2) used for airtightness testing has a number of holes sealed by rubber bungs. Each of these holes is 25 mm in diameter and is used to simulate a leak in the duct after the access holes or devices have been installed.

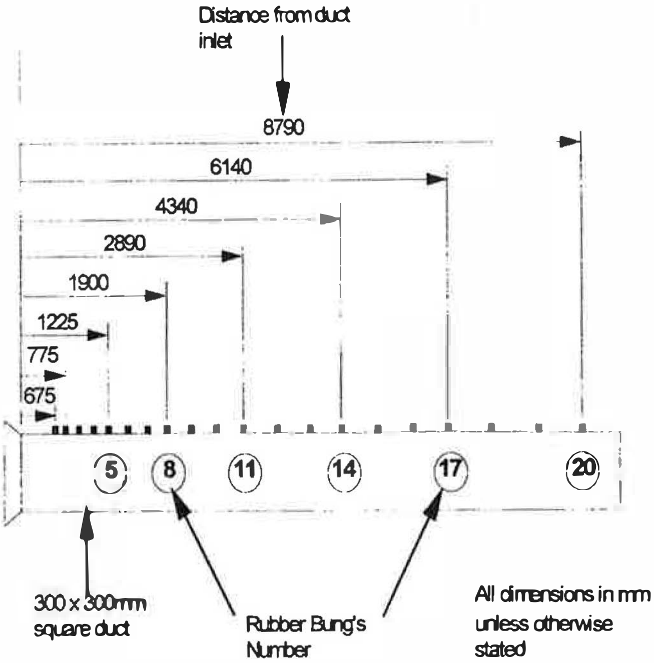

Figure 2 Positioning of rubber bungs along 300 × 300 mm duct system

There are two ways of evaluating the airtightness of ducts. The first is employed when the position of the leak is known. This applies to configurations where an airflow measuring device may be installed in the duct system. Airtightness is tested to check whether there are any leaks at the joints. In this method, the injection points are fixed and the sampling points are inserted into the duct before and after the section under test. The difference in the airflow rate before and after this section of the duct will be the leakage rate. This technique is termed the stationary method since the injection points are fixed.

The second method is used to locate the leaky section and determine the leakage rate. This is termed the mobile method because both the injection and sampling points are moved along the duct system. Any difference in airflow rate between the two sections of the duct is the leakage rate. The second method is more commonly used because the locations of leaks in the ductwork are not usually known.

3 Measurement of airtightness of ductwork

3.1 Stationary method

Figure 3 shows the instrumentation for the stationary method. 10 mm diameter holes were drilled in the top of a 300 × 300 mm square duct to simulate leakage. Tracer gas was injected into the duct at a constant rate using a mass flow

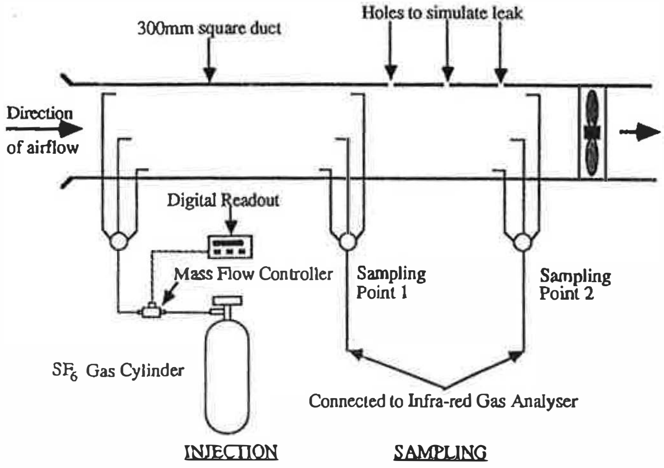

Figure 3 Instrumentation for determining airtightness of duct system by stationary technique

controller. Sampling probes were inserted into the duct at points 1 and 2 (i.e. before and after the leak respectively). The concentrations of these tracer-air samples were measured using a BINOS 1000 infra-red gas analyser. The airflow rate was evaluated using the constant-injection expression of equation 1. The difference in airflow rates before and after the leak was the leakage rate of the duct. Static pressures were also monitored over these leaks. The experiment was repeated at various flow rates.

3.2 Mobile method

In the mobile method, the instrumentation is set up as shown in Figure 4. Initially, the holes in the duct are sealed by rubber bungs. The injection and sampling points were placed at points I1 and S1 respectively. The airflow in the duct was measured using the constant-injection tracer-gas technique. Some rubber bungs were removed between I1 and S1 to simulate leaks in the duct. The airflow in the duct was once again measured using the constant-injection technique. The difference between the measured airflow rates was the rate of leakage through the holes. The injection and sampling points were moved along the duct to positions I2 and S2, respectively leaving the initial holes open to determine the total leakage rate due to the holes between points I1 and S2 on the duct. Static pressures were monitored along these holes. This experiment was repeated at various flow rates.

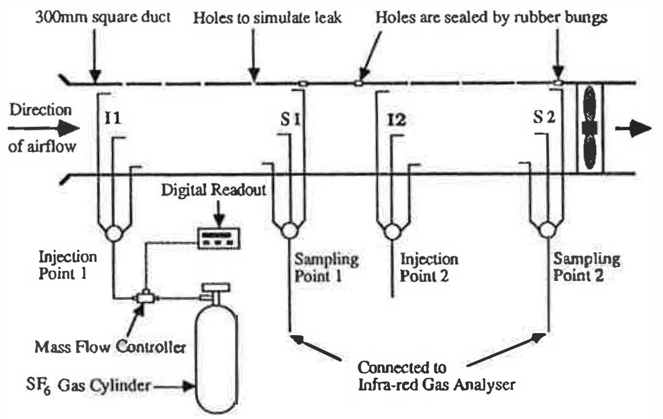

Figure 4 Instrumentation for determining airtightness of duct system by mobile technique

4 Results and discussion

4.1 Stationary method

Figure 5 shows the leakage rates of the duct at various air flow rates measured by constant injection. The leakage rate increases with the airflow rate in the duct.

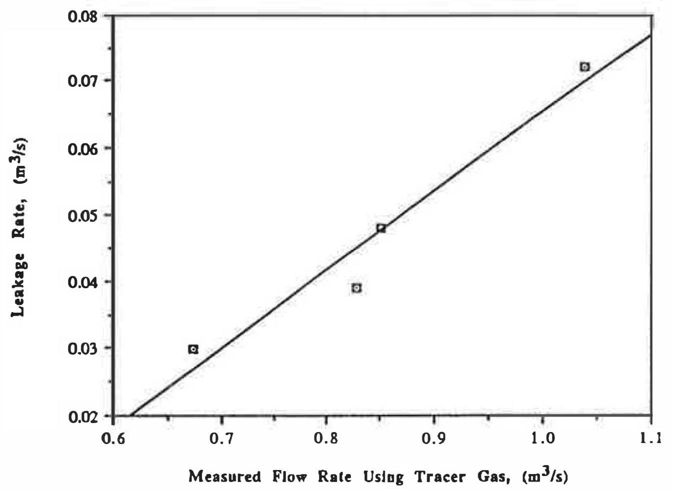

Figure 5 Variation of air leakage rate with airflow rate in duct system according to stationary technique

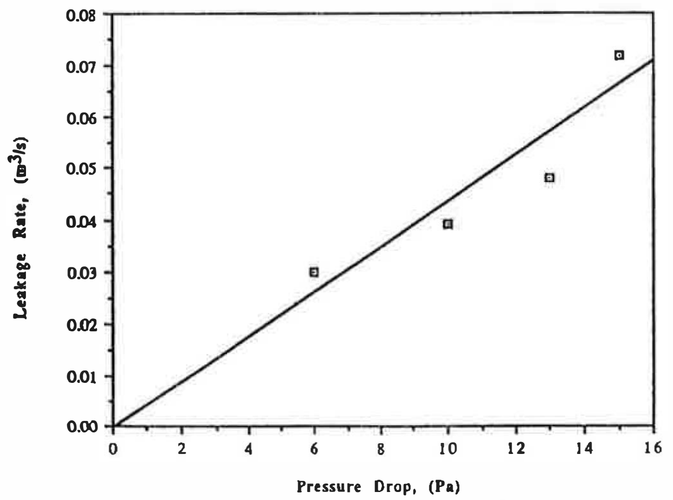

Figure 6 Variation of air leakage rate with pressure drop in duct system according to stationary technique

A relationship between the leakage and airflow rates was established for the 300 mm × 300 mm square duct as shown in equation 2. r^2 was 0.94.

$$L = 0.0644F_{ci}^{2.04} \quad (2)$$

The relationship between leakage rate and pressure drop (Figure 6) across the leaks was also established:

$$L = 0.006\Delta P_L^{0.85} \quad (3)$$

r^2 was 0.84.

4.2 Mobile method

Table 1 shows that the increasing leakage rate is due to the removal of rubber bungs on the duct and the increasing airflow rate in the duct. The relationship between the leakage rate and airflow rate for this 300 mm × 300 mm square duct is shown in Table 2.

Table 1 Airflow rate versus leakage rate in 300 × 300 mm square duct according to mobile technique

Flow rate (m^3s^{-1})	Leakage rate (m^3s^{-1})			
	Number of rubber bungs removed			
	9	18	27	36
0.975	0.0116	0.0242	0.0376	0.0549
0.999	0.0124	0.0282	0.0443	0.0625
1.093	0.0159	0.0349	0.0580	0.0871
1.128	0.0163	0.0374	0.0614	0.0922
1.291	0.0205	0.0606	0.1061	0.1593

Table 2 Relationship of leakage rate to airflow rate in 300 × 300 mm square duct with various numbers of rubber bungs removed, according to mobile technique

No. of rubber bungs removed	Leakage rate L (m^3s^{-1})
9	$0.0126F^{2.03}$
18	$0.0268F^{3.11}$
27	$0.0422F^{3.53}$
36	$0.0612F^{3.71}$

5 Conclusions

The stationary and mobile constant-injection tracer-gas methods for evaluating the airtightness of ductwork were successfully applied. They are more practical and faster than the concentration-decay technique. Relationships were established for the airflow rates and pressure drop across leaks. These were found to influence the leakage rates in the ductwork. In this study the leaks were situated on the negative-pressure side of the system. However, the methods can equally be applied to the positive-pressure section of the system. A detailed investigation of the application of these methods to ductwork airtightness would establish their viability on a wider scale.

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