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THE PERFORMANCE OF AN AUTOMATED SF_6 CONSTANT CONCENTRATION TRACER GAS APPARATUS FOR MEASURING AIR INFILTRATION RATES IN BUILDINGS

by

C.Y. Shaw

PREFACE

As part of the research program on conservation of energy in buildings, the Division of Building Research has been measuring rates of air leakage into and out of buildings. The apparatus that has been used for these measurements yields an average value of infiltration over a period of one half to one hour. There is a need, however, for an instrument that can monitor air infiltration rates on a continuous basis. This report presents the results of a series of tests that have been made to check the performance of a prototype of such an instrument. Although it does not meet the level of performance that is desired, it shows considerable potential for improvement.

Ottawa
July 1981

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NATIONAL RESEARCH COUNCIL OF CANADA

DIVISION OF BUILDING RESEARCH

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THE PERFORMANCE OF AN AUTOMATED SF_6 CONSTANT CONCENTRATION TRACER GAS APPARATUS FOR MEASURING AIR INFILTRATION RATES IN BUILDINGS

by C.Y. Shaw

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An automated SF_6 constant concentration air infiltration apparatus was checked in an unoccupied two-storey house where constant air leakage rates could be induced by an exhaust fan. The air leakage rates measured with this apparatus were compared with those induced by the fan and those measured by the tracer gas decay method. Based on these comparisons, the performance of this apparatus was evaluated.

Air infiltration is the leakage of air into a building through various cracks and openings in the building structure and it accounts for a significant portion of a building's heating and cooling loads. Measurements of air infiltration rates are commonly conducted by using the tracer gas technique (1). It involves the injection of a small amount of tracer gas into a test building where it is mixed with the air to a hopefully uniform composition using the air handling system. If the mixing is adequate, the tracer gas concentration should decrease with time after a peak concentration is reached. The rate of decay is proportional to the inflow of the outside air that is equal to the outflow of the inside air-tracer gas mixture under steady state conditions. Thus, the air infiltration rate of a building can be calculated by measuring the decay of the tracer gas concentration, i.e., the decay method. If additional tracer gas is injected to overcome this decay, the air infiltration rate can also be calculated by measuring the amount of tracer gas required to maintain a constant concentration inside, i.e., the constant concentration method.

The decay method has been used extensively (2,3) because of its simplicity. Air leakage rates measured by this method have been shown to be in good agreement with independent measurements under both laboratory and field conditions (4). On the other hand, the constant concentration method has rarely been used and checked because it requires equipment that is not readily available. An attempt was made recently by Kumar, Ireson and Orr (5) to design and build a fully automated SF_6 constant concentration air infiltration apparatus (DBR air infiltration apparatus). This study checks the performance of that apparatus in an unoccupied two-storey detached house under various operating conditions. The purpose of the study was to examine the performance of the DBR air infiltration apparatus, and to compare the air change rates measured by the two tracer gas techniques.

MEASUREMENT OF AIR INFILTRATION

Assuming adequate mixing, the relationship of the air infiltration rate, I, with the tracer gas injection rate, W, and the inside tracer gas concentration, C, is

$$V \frac{dC}{dt} = W - VIC \qquad (1)$$

where V is the volume of the test building and t is the time. Eq (1) can be solved for the following two conditions:

<u>Decay Method; W = 0</u>

$$I = \frac{1}{t} \ln \frac{C}{C_o} \qquad (2)$$

where C_o is the tracer gas concentration at or after the beginning of the decay. The best way to solve for I is to fit Eq (2) with the concentration data collected over a period of 30 to 60 minutes with a sampling interval of about 5 minutes (4).

Constant Concentration Method; $dC/dt = 0$

$$I = \frac{W}{VC} \qquad (3)$$

The accuracy of this method depends mainly upon how successfully the apparatus controls the tracer gas injection rate to maintain a constant concentration, C. In the DBR air infiltration apparatus, the tracer gas injection rate is regulated by controlling the number of injections of 0.0108 ml of tracer gas from a discharge unit according to the equation

$$N = N_s - m\ (C - C_s) \qquad (4)$$

where N is the number of tracer gas injections, N_s is the expected N, m is the gain of the proportional control, C is the measured concentration and C_s is a reference concentration. The values of N_s, m and C_s vary from house to house. In the test house they were assumed to be 8, 0.15 and 1500 (i.e., 15 ppb) respectively.

During a test C will be measured, and based on that figure, a certain amount of tracer gas will be injected into the test house every 2½ minutes. As there is a lag between tracer gas injection and change of concentration at the sampling location, the concentration inside will fluctuate with time. Consequently, the condition of $dC/dt = 0$ is almost certainly not satisfied. To overcome this problem, the DBR air infiltration apparatus records C and N for a period of 30 minutes and calculates the mean infiltration rate from the equation

$$I = \frac{\Sigma N\ (n/n_1)\ v \times 10^3}{V \Sigma C/n_1} \qquad (5)$$

where N is the total number of injections for each test period, n is the number of samples per hour (n = 24), n_1 is the number of samples per test period, v is the volume of SF_6 per injection in ml (v = 0.0108 ml), V is the volume of the test building in m^3 and ΣC is the sum of n_1 concentration in ppb.

TEST ASSEMBLY

The test building (Figure 1), is a two-storey detached house with basement. It has a central air circulating system with an electric furnace located in the basement. The furnace fan was operating continuously during the test to mix the tracer gas with the air. The DBR air infiltration apparatus was located in the living room on the ground floor. SF_6 was injected into the supply duct and samples of the air-SF_6 mixture were collected from the return duct.

In some tests the air leakage rates of the house were controlled and measured by an exhaust fan that discharged the air to outside through a long circular duct. Pressure taps were mounted at mid-height on the exterior walls and in the ceiling. These pressures referenced to inside were recorded as evidence that the air flow direction was from outside to inside and that the air exhausted to outside was accounted for downstream of the fan. A laminar flow element (MERIAN LFE ELEMENT), accurate to 3 per cent of the measured flow rate, was used for flow measurements.

CO_2 and occasionally CH_4 were injected into the house and the air leakage rates measured by the decay method using tracer gases. A Beckman Model 864 infrared CO_2 gas analyzer and a Meloy Model HC 500-20 flame ionization gas analyzer were used to measure the concentrations.

RESULTS AND DISCUSSION

The SF_6 constant concentration, CO_2 and CH_4 decay results as shown in Figure 2, all agree closely with the fan-induced air change rates. For comparison, Figure 2 also shows the CO_2 and SF_6 tracer gas results obtained previously using the decay method under similar conditions (4).

All the tracer gas data appear to lie evenly about the line of agreement with the root mean square errors of 0.04 air changes per hour (ac/h) for the SF_6 decay results and 0.06 both for the CO_2 decay and the SF_6 constant concentration results. These findings suggest that there is no systematic difference between tracer gas and fan-induced results for the range of air change rates shown. Further, the agreement between SF_6 constant concentration and decay results suggests that the two tracer gas techniques give almost the same results.

A comparison between the SF_6 constant concentration and the CO_2 results (Figure 3), indicates that below 0.5 ac/h the SF_6 constant concentration results are smaller than the CO_2 values. This difference is likely caused by the behaviour of the two tracer gases as a similar trend (Figure 3) has been observed for those measured only by the decay method (4). Above 0.5 ac/h the SF_6 constant concentration results appear to be smaller as well, but there are insufficient data to reach a definite conclusion.

Two tests were conducted to check the response of the DBR apparatus to a step change in air leakage rates. In the first test, Figure 4, the air leakage rate of the house was initially set and held at 0.91 ac/h for four hours and was then decreased abruptly to 0.57 ac/h for the remainder of the test. In the second test, the air leakage rate was set at 0.53 ac/h at the beginning and was increased to 0.86 ac/h one and a half hours later. The measured air change rates were compared with the induced values for both tests in Figure 4. The results indicate that the measured air leakage rates fluctuate with time when the air leakage rate of the house is constant. They also show that it takes about one hour for the apparatus to respond to a step change in air leakage rates.

As the main advantage of the constant concentration approach over the decay technique is that it has the potential of being able to follow changes in air infiltration rates (e.g., changes due to furnance operation), the slow response exhibited by this apparatus can greatly reduce this potential. The problem, however, is in the analysis of results rather than with the apparatus itself because of the arbitrarily chosen 30 minute averaging period.

Figure 5 shows that both N and C can reach a new steady value within about 5 minutes of a step change in the air leakage rate, suggesting that a much shorter averaging period, say 5 minutes, should be adopted. To reduce the averaging period, however, it is necessary to smooth out the fluctuations in the concentration data to reduce the error caused by a non-zero dC/dt. This may be achieved by using the mean value of the previous and current concentrations in place of C in Eq (4). Further, Figure 5 shows that this apparatus fails to maintain a constant concentration if the air leakage rate changes during a test. This is expected because Eq (4) with a constant N_s represents a simple proportional type of control algorithm for the SF_6 concentration. This type of control cannot maintain a constant concentration if the air leakage is changing. The control algorithm should have the capability to vary the value of N_s. The simplest method to achieve this is to replace N_s with the previous value of N in Eq (4). Thus better Eqs (4) and (5) would be

$$N_t = N_{t-1} - m\left[0.5\left(C_t + C_{t-1}\right) - C_s\right] \tag{4a}$$

and

$$I = \frac{n\ v\ N_t \times 10^3}{V\ C_s} \tag{5a}$$

where the subscripts t and t-1 represent the current and the previous values respectively. Another series of tests is needed to check the performance using these equations.

Simultaneous measurements of the air infiltration rates of the house were conducted using both the CO_2 decay and the SF_6 constant concentration methods for 14 hours. The wind speed during this period was under 3.3 m/s, so the stack action was the predominant driving potential behind air infiltration (6). The results plotted against time, Figure 6, demonstrate that the SF_6 values are smaller than the CO_2 results and that the SF_6 data appear to be less sensitive to stack action than those of the CO_2.

CONCLUSIONS

The performance of an automated SF_6 constant concentration air infiltration apparatus was checked in a two-storey detached house under the following conditions:

(1) Constant Air Leakage Rates

The measured values were in good agreement with the fan-induced values for air leakage rates above 0.4 ac/h. The SF_6 results also agreed closely with the simultaneously measured CO_2 results at higher air leakage rates but they were smaller at lower air change rates.

It was found that using SF_6 as the tracer gas, the constant concentration and the decay methods gave similar results.

(2) Step Changes in Air Leakage Rates

The DBR air infiltration apparatus failed to maintain a constant concentration if a step change in the air leakage rate occurred, but it responded to this change quickly and effectively by adjusting its tracer gas injection rate to a new steady value. The apparatus appeared to be able to detect changes in infiltration rates but needs a better control algorithm to achieve its full potential.

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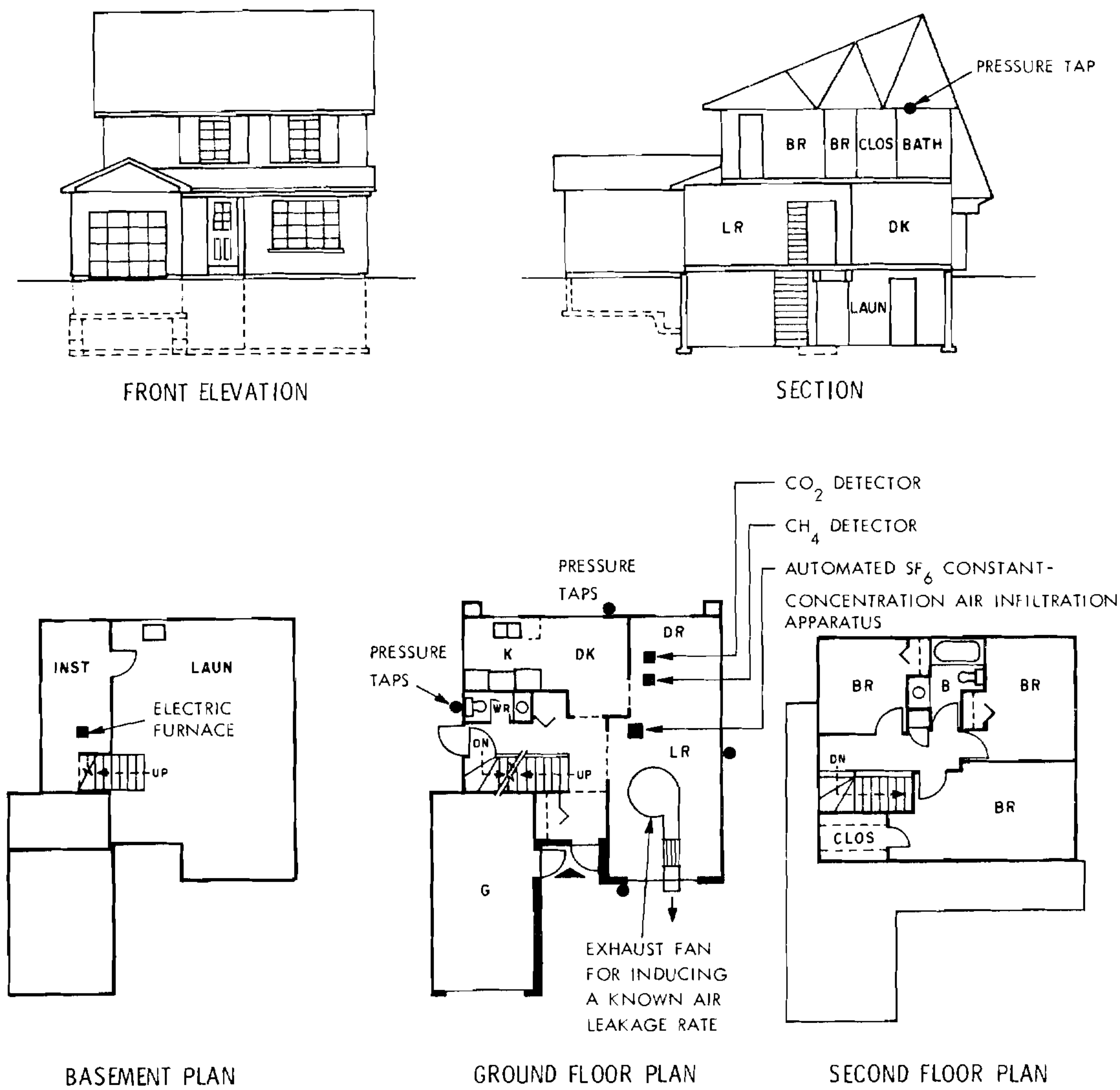

FIGURE 1

TEST HOUSE

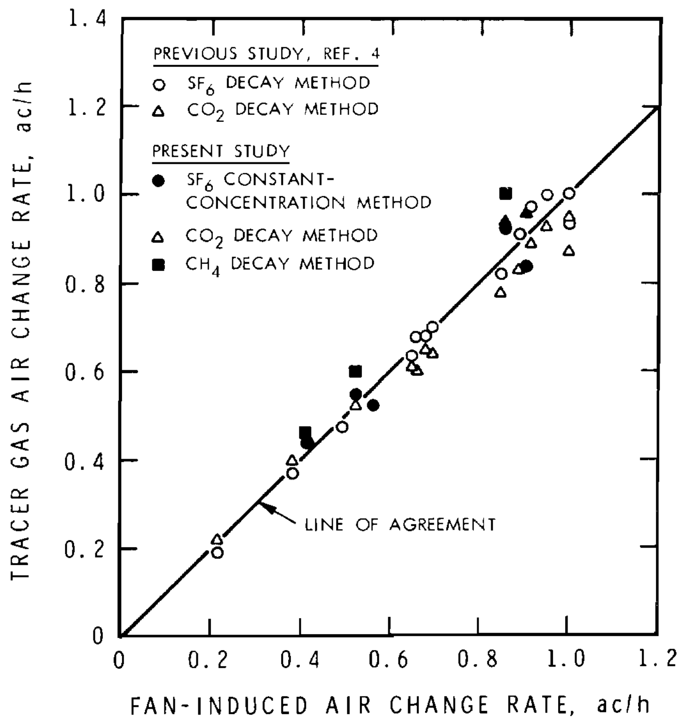

FIGURE 2

COMPARISON OF TRACER GAS AND FAN-INDUCED AIR CHANGE RATES

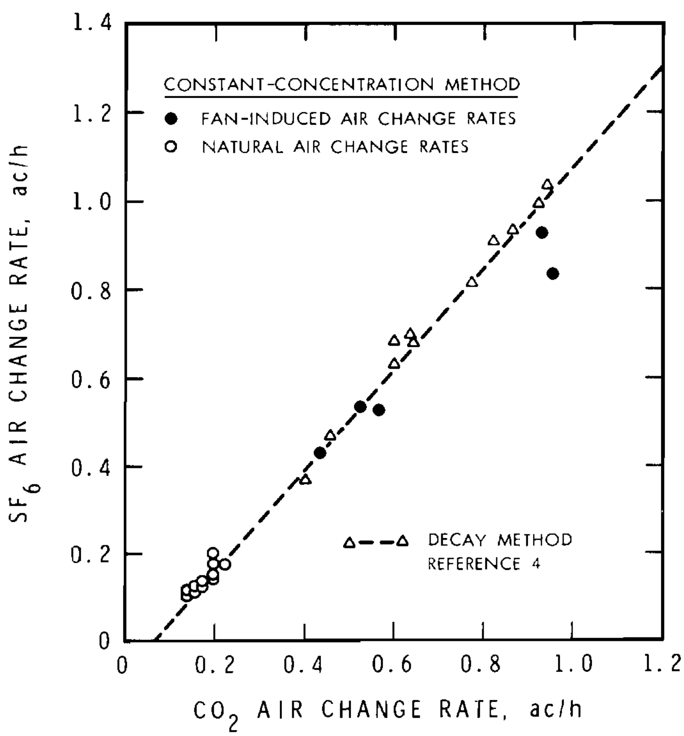

FIGURE 3

RELATION BETWEEN SIMULTANEOUSLY MEASURED CO_2 AND SF_6 TRACER GAS AIR CHANGE RATES

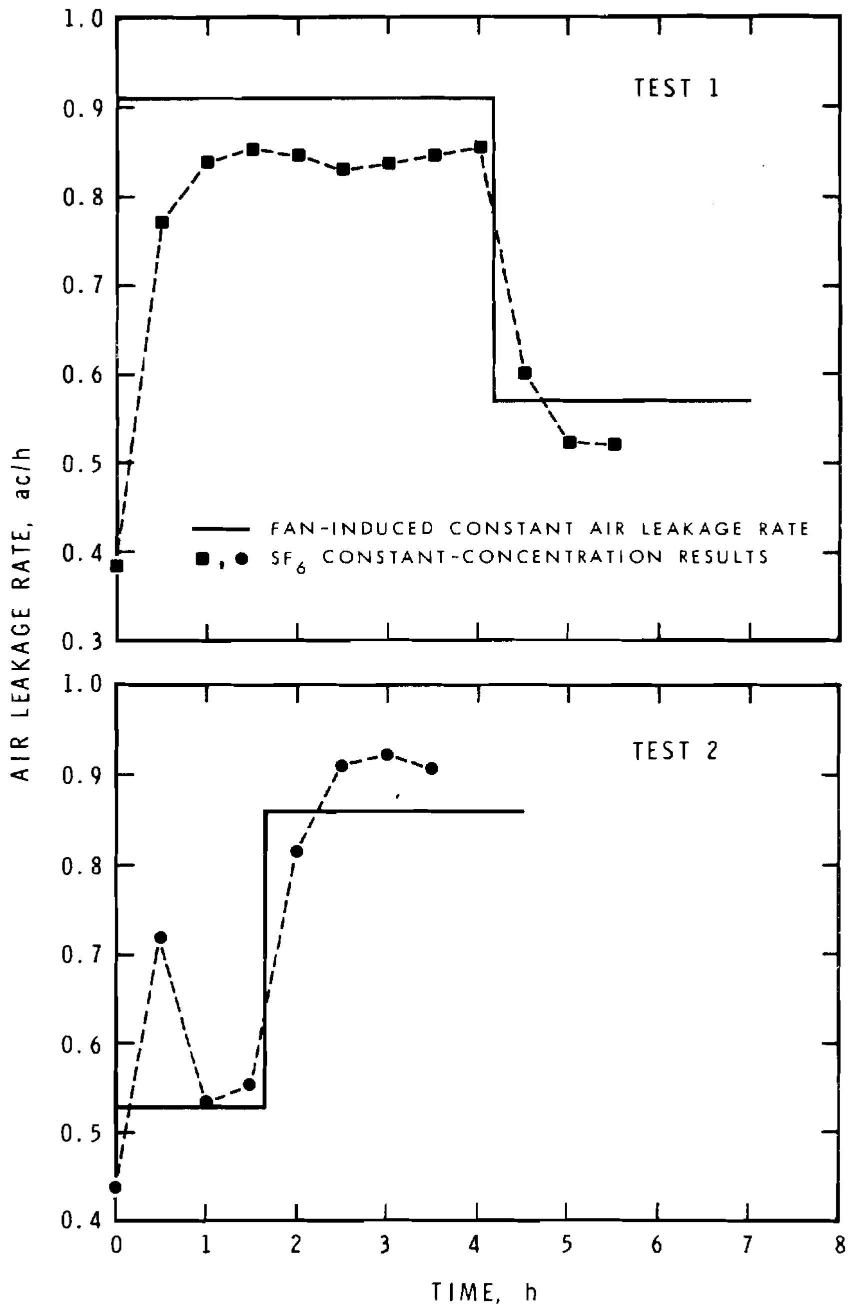

FIGURE 4

METER RESPONSE TO A STEP CHANGE IN INDUCED AIR LEAKAGE RATE

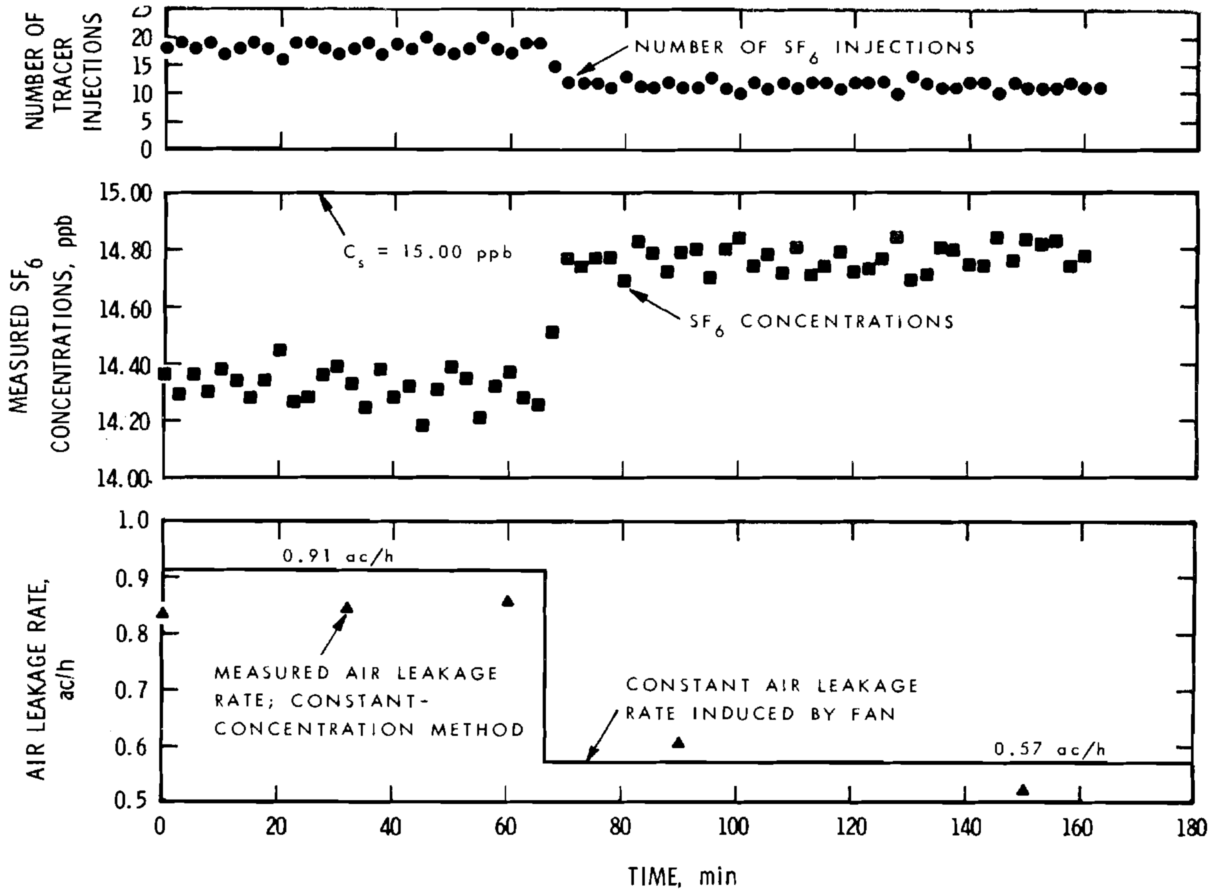

FIGURE 5

RESPONSE OF SF_6 CONCENTRATION AND INJECTION RATE TO A STEP CHANGE IN AIR LEAKAGE RATE

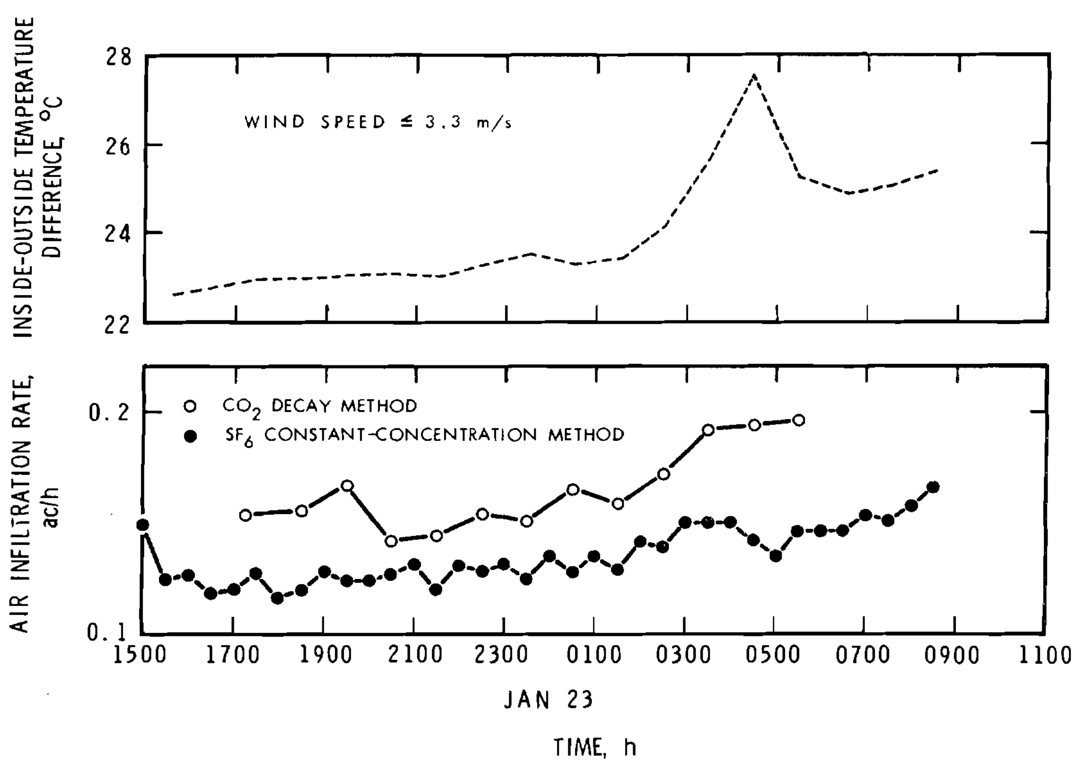

FIGURE 6

COMPARISON OF SF_6 CONSTANT-CONCENTRATION AND CO_2 DECAY RESULTS