



AIR INFILTRATION MEASUREMENTS
USING TRACER GASES:
A Literature Review


By

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16. ABSTRACT The report gives results of a literature review of air infiltration measurements using tracer gases, including sulfur hexafluoride, hydrogen, carbon monoxide, carbon dioxide, nitrous oxide, and radioactive argon and krypton. Sulfur hexafluoride is the commonest tracer gas of choice, primarily because its presence may be accurately measured in the parts per billion range using electron capture/gas chromatography techniques. Most of the other gases used may be accurately measured in the parts per million range using infrared technology. There are three basic types of measurements: tracer gas decay, constant concentration, and constant injection. Investigators comparing tracer gases conclude that: (a) even though sulfur hexafluoride is appreciably heavier than air, mixing is not a problem; and (b) the inherent uncontrollable variables present in tracer gas work limit the accuracy of determinations to +/- 5 to 10%. Thus, if all other criteria are met, there is no reason why one tracer gas should be selected over another. The report describes a computer-controlled injection system.		
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Abstract

The use of tracer gases for the measurement of air infiltration into structures and interzonal flows within a structure is not new. This technique has been investigated over the past 15 years. Numerous tracer gases have been used, among which are: sulfur hexafluoride, hydrogen, carbon monoxide, carbon dioxide, nitrous oxide, and radioactive argon and krypton. Sulfur hexafluoride is the most common tracer gas of choice -- primarily because its presence may be accurately measured in the ppb range using electron capture/gas chromatography techniques. Most of the other gases used may be accurately measured in the ppm range using infrared technology.

There are generally three types of methods used: tracer gas decay, constant concentration, and constant injection.

Investigations comparing tracer gases have led to the following conclusions: (a) Even though sulfur hexafluoride is appreciably heavier than air, mixing is not a problem; and (b) The inherent uncontrollable variables present in tracer gas work limit the accuracy of determinations to $\pm 5\%$ - 10%. There is thus no reason why one tracer gas should be selected over another provided other criteria are met. In the case of hydrogen, diffusion of the gas through the surrounding walls can pose a problem.

Tracer gases may be used in air flow measurements in large buildings where the building may be treated as several coupled zones. In such a case, the decay technique can still be used by having the system repeat the injection at regular intervals. A computer-controlled injection system is described in the text.

Table of Contents

	Page No.
Abstract	ii
List of Tables and Figures	iv
Introduction	1
The Characteristics of a Good Tracer Gas	2
A Comparison Between Tracer Gases Which Have Been Used	4
Error Analysis of Tracer Gas Methods	7
Tracer Gas Techniques for Use in Measuring Air Movement in Multicell Buildings	13
Instrumentation Used in Tracer Gas Work	15
Summary and Conclusions	20
References	21
Bibliography	23

List of Tables and Figures

<u>Table</u>	<u>Page</u>
1 Published Comparisons Between Tracer Gases	5
2 Instruments Used by Various Researchers to Detect Tracer Gases	5
3 Air Change Rates	11
<u>Figure</u>	<u>Page</u>
1 Sampling and Calibration Valves	18
2 Block Diagram of SF ₆ Computer- Controlled System in Load Mode	18
3 Block Diagram of SF ₆ Computer- Controlled System in Inject Mode	19
4 Electron Capture Detector Block Diagram	19

Introduction

During the past 15 years a multitude of diagnostic procedures associated with the evaluation of air infiltration and air leakage sites have been developed. The spirit of international cooperation and exchange of ideas have greatly facilitated the adoption and use of these measurement techniques. Wide application of such diagnostic methods is not limited to air infiltration alone.

For example, they have been applied to the evaluation and improvement of radon reduction in buildings.(1) Radon problems are not unique to the United States, and the methods have to a degree been applied by researchers of other countries faced with similar problems. The radon problem involves more than harmful pollution of the living spaces of our buildings -- it also involves energy to operate radon removal equipment and the loss of interior conditioned air as a direct result. The techniques used for air infiltration evaluation have been shown to be very useful in dealing with the radon mitigation challenge. (1)

Various researchers (2,3,4) have reported that a strong relationship exists between ventilation and indoor air quality. Unfortunately, little work has been done to determine the interaction between mechanical ventilation, infiltration, and indoor air quality. One reason that such data are not available is the complexity involved in measuring ventilation rates of large buildings (4,5,6).

The American Society for Testing and Materials (ASTM) defines a tracer gas as "A gas that can be mixed with air and measured in very small concentrations in order to study air movement"(7). This definition does not go far enough to characterize a suitable tracer gas, as brought out in the next section.

The Characteristics of a Good Tracer Gas

Tracer gas methods have been used for many years to measure the air exchange rates of a variety of different types of buildings. Three basic methods are currently used for the measurement: tracer gas decay, constant concentration, and constant injection. The tracer gas decay method is the simplest and most inexpensive of the three methods to implement. A standard practice, ASTM E741-93, describes the technique (7). The constant concentration method employs an automated system to simultaneously measure the tracer gas concentration and inject the appropriate quantity of tracer gas required to maintain a constant concentration (8); the air exchange rate is related to the tracer gas release rate. With the constant injection method, tracer gas is released over extended time periods at a constant rate. The method requires a system for release at well-controlled rates because the air exchange rate is related to the tracer release rate. Both active and passive systems of tracer release and sampling have been used (9). Fundamentals and applications of tracer gas methods for the measurement of air exchange have been presented in a number of published reviews (10,11,12).

The energy cost of excessive air infiltration in buildings has spurred a sharp increase in the number of research projects investigating the magnitude of this phenomenon. The most common technique used to monitor air infiltration rates requires measurements of the concentration of a tracer gas. The tracer gas, a material easily monitored which normally is not present in the atmosphere, is injected into the space to be tested. When the injection ends, the concentration of tracer is measured as a function of time. Outdoor air, leaking into the test space, replaces the tracer/indoor air mixture which leaks out at the same rate. The rate of change of the concentration of tracer in the indoor air is therefore proportional to the concentration of tracer in the test space; i.e., the concentration decreases exponentially (13).

This verbal description of the measurement process contains several assumptions about the nature of air infiltration. For example, it assumes that the rate of air infiltration remains constant during the measurement period. In addition, it assumes that the outdoor infiltrating air mixes uniformly with the indoor air during measurement. Most investigations also assume that measured air change rates are independent of the type of tracer gas used if adequate mixing of the tracer gas occurs in the test space (13).

An ideal tracer gas should meet the following criteria (10):

- a. Be inexpensive
- b. Be easily measurable at low concentrations
- c. Be non-toxic and non-allergenic
- d. Be non-inflammable
- e. Have approximately the same molecular weight as air
- f. Not be absorbed on any surface within the space under test
- g. Not be a normal constituent of air in the test space

No tracer gas meets all these requirements. Within recent years improvements in instrumentation have permitted measurements of concentration of sulfur hexafluoride, SF_6 , at levels of parts per billion. This is three orders of magnitude smaller than previous techniques which yield measurements in the range of parts per million. The ability to observe such low concentrations makes SF_6 an attractive possibility for use as a tracer gas. However, several researchers have expressed the concern that the large molecular weight of SF_6 [146] will cause stratification of the tracer gas after injection. Hunt and Burch (14) have discussed the errors which will result if a tracer gas is poorly mixed within the test space. Stratification, which will yield poor mixing, will

lead to erroneous infiltration results unless multiple sampling and properly weighted averaging of the tracer gas from several points occur (13).

A Comparison Between Tracer Gases Which Have Been Used

The paper of Hitchin and Wilson (15) is an excellent review of the experimental techniques used in measuring air infiltration. This work has been extended to include work through 1975 by Hunt's review of current techniques. These authors cite previous direct intercomparison results. These are shown in Tables 1 and 2 (13).

Warner (16) reported comparisons between coal gas (a mixture of H_2 and CO obtained by passing steam over hot carbon) detected using a katharometer and CO_2 whose concentration was measured by Haldane gas analysis (13).

Collins and Smith (17) used the radioactive argon isotope ^{41}Ar as a tracer; its concentration was measured with a geiger counter and a ratemeter. A direct comparison was made of the infiltration rate detected using H_2 with a katharometer and ^{41}Ar ; agreement within 8% was seen in two trials.

Howland et al. (18) reported comparisons between air changes measured with a radioactive isotope, ^{85}Kr , using a geiger counter and a ratemeter. The decay rates were compared with measurements which used CO_2 as the tracer. Its concentration was determined by drawing samples of air periodically and using chemical analysis (the Haldane apparatus) to find the amount of tracer remaining in the test space. Results of three tests varied by about 9%.

TABLE 1
Published Comparisons Between Tracer Gases

<u>Reference</u>	<u>Tracer Gases</u>	<u>No. of Tests</u>	<u>Results *</u>
Warner (16)	Coal Gas, CO ₂	3	1.05 ± 0.18
Collins and Smith (17)	H ₂ , ⁴¹ Ar	2	0.93 ± 0.01
Howland, et al. (18)	CO ₂ , ⁸⁵ Kr	3	1.00 ± 0.09
Lidwell (19)	N ₂ O, C ₃ H ₈ O	1	0.97
Howard (20)	H ₂ , N ₂ O	many	agreement
Howard (20)	O ₂ , N ₂ O	many	agreement
Hunt and Burch (14)	He, SF ₆	6	1.17 ± 0.14

*The results quoted are the mean values of the ratios of the measured air change rates.
The ratio is formed by dividing the air change rate of the heavier gas by the air change rate of the lighter gas.

TABLE 2
Instruments Used by Various Researchers
to Detect Tracer Gases

<u>Research Group</u>	<u>Tracer Gas</u>	<u>Instrument</u>
Honeywell	CH ₄	IR Analyzer
Princeton	SF ₆	Electron Capture
Lawrence Berkeley Laboratory	N ₂ O	IR Analyzer
Lawrence Berkeley Laboratory	C ₂ H ₆	IR Analyzer
Lawrence Berkeley Laboratory	SF ₆	Electron Capture

Interference between CH₄ and N₂O prevented simultaneous measurements of tracer gas concentrations using these gases; therefore, the tests were organized using the schedule shown in Table 3.

Lidwell (19) compared results when nitrous oxide, N_2O , is compared with acetone, C_3H_6O , as tracer gas. Infrared absorption was used to measure the concentration of N_2O ; acetone concentration was determined by measuring the change in pH which occurred when air containing acetone is absorbed into solutions of hydroxylamine hydrochloride. A single measurement (judged to be accurate within 10%) produced 3% agreement.

Howard (20) compared N_2O with both H_2 and O_2 . N_2O concentrations were measured using an infrared analyzer, H_2 concentrations with a katharometer, and O_2 by absorption in aqueous chromous chloride. Specific results are not quoted in the paper. The author states that close agreement between decay rates using N_2O and O_2 were seen over wide ranges of wind speeds. On the other hand, H_2 decay rates were substantially higher than N_2O . The evidence suggested that diffusion of H_2 through the walls of the unpainted gypsum of the test space was the source of the discrepancy. This hypothesis was tested by repeating the tests after the walls were sealed with two coats of latex paint and also repeating the tests in a laboratory with masonry walls. The discrepancy was not present in the latex paint and masonry wall tests.

Hunt and Burch (14) compared air change rates using He and SF_6 as tracer gases to examine the influence of molecular diffusion on the infiltration process. Their test space was a four-bedroom townhouse constructed within an environmental test chamber. If molecular diffusion were important in the infiltration process, the air change rate measured with He would be significantly larger than that measured with SF_6 . In fact, slightly larger air change rates were seen when SF_6 was used as a tracer rather than He. Six trials were made. The ratio of the air change rate measured with SF_6 to that measured with He was 1.17 with a standard deviation of 0.14.

As described by Knoepke (21), SF_6 has been successfully used to determine the volumetric flow rate of flue gases. The tracer gas was injected at a constant flow rate, and a flue gas sample was taken downstream of the injection point. A mass flowmeter (Matheson Mass Flowmeter LF100 with F-100 Transducer) was used to measure injection flow rate. SF_6 was selected as the tracer gas because it:

- (1) Can be accurately measured from a few ppb to many ppm by using a gas chromatograph equipped with an electron capture detector.
- (2) Is chemically stable at red heat.
- (3) Is not present in the atmosphere.
- (4) Is non-toxic and odorless

The temperature at the point of injection was 870°C . When compared with pitot-tube flow measurements, the largest deviation was 7%, and the average deviation was 4%. The advantages of the tracer gas method over the pitot tube method include: (a) the pitot tube method requires that a traverse of the flue be made, hence, instantaneous flow measurements cannot be made, and (b) a flue survey can be completed in much less time using the tracer gas method.

Error Analysis of Tracer Gas Methods

Grimsrud et al. (13) did their intercomparisons of three tracer gases using the decay technique. After injection, the rate of change of tracer gas concentration is the product of the air change rate, A , and the concentration in the test space:

$$dC/dt = -AC \quad (1)$$

If the air change rate is constant, the solution of Eq.(1) is simply:

$$C(t) = C_0 e^{-At} \quad (2)$$

where C_0 is the concentration of the tracer at time $t = 0$.

The data may be analyzed by plotting concentration as a function of time using semilog graph paper.

Grimsrud et al. (13) compared SF_6 with CH_4 and N_2O . Tests were made in a one-story unoccupied residence in California. The volume of the living space of the house was 230 m^3 , its floor area was 100 m^2 , and the area of the six surfaces bounding the living space was 300 m^2 .

Table 3 shows the results of the measurements. The mean value of the ratio for all tests was 1.10 ± 0.10 . The mean value for the comparisons of SF_6 with N_2O was 1.09 ± 0.09 , while the value for the comparison with CH_4 was 1.16 ± 0.09 .

The uncertainties listed with each of the ratios is the standard deviation of a single measurement. The "t" distribution with nine degrees of freedom was used to calculate the expected range of the ratio. This result predicts that the actual range of the ratio, \bar{x} , lies within the range:

$$1.01 \leq \bar{r} \leq 1.20$$

at the 99% level of confidence. The "t" distribution assumes from an infinite sample in which the scatter of results is due only to random effects. Their results, therefore suggest that:

- (a) Systematic errors exist in the measurement procedure which results in SF₆ concentration decays that are too large, or N₂O and CH₄ decays which are too small; or
- (b) SF₆ overestimates the "true" air filtration rate when used as a tracer gas.

The above results refer to two independent sets of measurements of the concentration decay of SF₆ that were made using equipment at Princeton and Lawrence Berkeley Laboratory (LBL). Hunt and Burch (14) compared tracer gas measurements described by Grimsrud et al. (13) and a ratio of A_{SF6}/A_{lighter gas} of 1.13 ± 0.12. If the t- distribution with 15 degrees of freedom is used, it was predicted that the actual ratio, \bar{r} , will lie within the range

$$1.04 \leq \bar{r} \leq 1.22$$

with 99% confidence.

The results show that a difference exists between air exchange rates measured using SF₆ and air exchange rates measured using lighter tracer gases. Grimsrud et al. (13) conclude that the difference is small, representing the range of uncertainty which they estimate is present in any tracer gas measurement (5 to 10%).

An example of this is test 12 shown in Table 3. The air exchange rates measured using C_2H_6 , SF_6 , and N_2O were 0.68, 0.66, and 0.61 hr^{-1} . These values represent the range of values seen whenever air exchange rates are measured; consequently, Grimsrud et al. (13) conclude that the differences seen in this intercomparison are scarcely large enough to be significant. They examined the measurement process for physical effects which would bias the data in the direction observed. Two effects, molecular diffusion and absorption of N_2O by water vapor, were eliminated because:

(a) If molecular diffusion were important in air infiltration, air change rates measured with light gases which have higher thermal speeds would be higher than those measured with heavy gases. This is the opposite of what was observed.

(b) If a significant amount of N_2O were absorbed by water vapor in the test space, air exchange rates measured with N_2O would tend to be larger than those using SF_6 . Again, the opposite result was actually seen.

Another possibility was considered; i.e., settling of the tracer gas in the test space. Since the tracer was sampled in the return duct of the furnace, located in the ceiling in the test space, settling of the heavy gas during the course of the measurement would appear to increase the air exchange rate measured using a heavy tracer gas such as SF_6 .

Calculations showed that this was quite unlikely. The tracer gases were injected into the return duct of a forced air heating system and are well mixed after a short time. From other results, a mixing time of the order of 5 minutes was determined. Therefore, after 5 minutes the tracer gas is well mixed throughout the test space -- and this mixing continues throughout the concentration decay measurement.

TABLE 3
Air Change Rates

<u>Test No.</u>	<u>N₂O (hr⁻¹)</u>	<u>CH₄(hr⁻¹)</u>	<u>SF₆(hr⁻¹)</u>	<u>Wind Sp(m/s)</u>	<u>Δt (°C)</u>	<u>Ratio*</u>
1	0.49	-	-	4	1	-
2	-	0.75	-	5	-3	-
3	0.64	-	0.71(P)	4	-2	1.11
4	-	0.63	0.76(P)	6	-4	1.21
5	0.69	-	0.76(B)	7	7	1.10
6	0.91	-	-	8	6	-
7	-	0.89	0.94(B)	8	5	1.06
8	-	1.27	1.59(B)	9	4	1.25
9	1.25	-	1.19(B)	9	2	0.95
10	-	0.72	0.80(B)	7	3	1.11
11	0.51	-	-	4	6	-
12**	0.61	-	0.66(B)	6	-1	1.08
13	0.58	-	0.70(B)	3	-3	1.21
14	0.47	-	-	4	-6	-

* The ratio quoted is the air change rate of SF₆ divided by the air change rate of the lighter tracer gas.

** During test 12, ethane (C₂H₆) was also used as a tracer gas. The air exchange rate measured was 0.68 hr⁻¹, yielding a ratio of 0.97.

Buoyancy effects were also considered: The fractional difference in density between a macroscopic volume of gas containing air and one containing 1 ppb of SF_6 is 4×10^{-9} . Since the acceleration due to buoyant forces is $(\nabla p/p)g$, the effective acceleration of the volume element containing SF_6 is $4 \times 10^{-10} g$. It would take about 3 hours for such an element to settle 2 m in still air under an acceleration of that magnitude. However, since the furnace blower moves 6 volumes of house air through it each hour, forced mixing and convective mixing certainly dominate buoyancy effects. The conclusion was that stratification due to the heavy SF_6 molecule is unlikely after the gas is initially mixed with room air.

Perhaps more space was consumed than is justified in describing the calculations involved, but they do illustrate the many factors which must be considered in comparing the use of different tracer gases.

Other possibilities exist: One may, in fact, be comparing instrumentation systems. The SF_6 is detected with electron capture gas chromatographic techniques, while the concentration of the lighter gases is measured with infrared absorption techniques or the change in thermal conductivity of helium/air mixtures.

Another possibility is that the absorption rate could have had a significant effect in the ppb range while it would not be noticed in measurements in the ppm range.

The authors conclude that, while differences may be real, they should not preclude the use of one gas in preference for another when choosing a tracer gas.

By way of summary, variables which may affect the results when using a tracer gas to measure ventilation rates are:

- (1) Stratification of gases using a tracer gas of substantially higher density of air unless adequate mixing exists.
- (2) Changes in barometric pressure and wind velocity during the time of measurement.
- (3) Absorption of the tracer gas on the surfaces to which the tracer is exposed.
- (4) Error differences between type of detectors used; e.g., infrared absorption vs electron capture gas chromatograph.
- (5) Changes in relative humidity during measurements; e.g., N_2O will react with water vapor.
- (6) At least in the case of H_2 use as a tracer gas, diffusion may become important in measuring ventilation rates. Grimsrud et al. (13) concluded that, in any tracer gas measurements, one can expect a 5 - 10% uncertainty to exist.

Tracer Gas Techniques for Use in Measuring

Air Movement in Multicell Buildings

"The past decade has seen the development of many techniques utilizing tracer gases for measuring air infiltration, ventilation, and airflow within buildings. These range from measurements of air infiltration rate where the building is treated as a single uniformly mixed zone to more complex measurement techniques that treat the building as several coupled zones exchanging air with one another and with the outside.

"Furthermore, some techniques give air flow rates averaged over a short time interval, while others directly yield values averaged over an extensive periods of time -- from days to many weeks.

"The various methods may be grouped into the following categories-- tracer gas dilution, constant injection of tracer gas, and maintaining a constant concentration of tracer gas. One or more tracer gases may be used."

"The most common approach for measuring air infiltration in buildings uses the dilution or decay of a single tracer gas. This method assumes that the building interior can be treated as a single uniformly mixed space within which the tracer gas concentration is everywhere the same. A small quantity of a single tracer gas is injected into the building. As outside air leaks into the building, the tracer gas concentration in the building air falls. The building's air infiltration rate is determined from periodic measurements of the tracer gas concentration within the building.

"The tracer gas decay technique does not tell one the airflows in a building that cannot be treated as a single uniformly mixed zone. These include large buildings lacking a single air circulation system. Even for houses, one cannot reliably determine the air infiltration rate if there is no forced air heating or central air conditioning system and where the interior doors are kept closed.

"The single tracer decay method can, however, be adapted to a building made up of two zones, each of which may be treated as uniformly mixed. In this case, the tracer gas is injected into one of the two zones and the concentration of the tracer gas is monitored in both zones. The airflow

rates among the two zones and the outside can be calculated from the concentration measurements" (22).

An important limitation of the tracer gas decay technique is that it yields a reliable measurement only for a certain time interval following injection while the tracer gas concentration is high enough to be reliably measured. Two ways of getting around this problem have been developed. In one approach, an automated system repeats the injection at regular intervals. Air samples are also automatically collected, analyzed, and recorded at regular intervals to determine the air infiltration rate variation over extended periods of time (6).

Another approach involves injecting tracer gas continuously at a constant rate (the constant injection method). Periodic sampling, analysis, and automatic recording of tracer gas concentration permits direct measurement of long-term variations in air infiltration rates (23).

Instrumentation Used In Tracer Gas Work

Tracer gas dilution is a technique which involves releasing a certain amount of gas (usually in the heating, ventilation, and air-conditioning (HVAC) return with the outdoor dampers shut while the tracer is mixing with indoor air) into the space under investigation, allowing at least 30 min. for mixing so that the tracer concentration is uniform throughout the space, and collecting air samples as the gas concentration decays in accordance with the ASTM test for determining air leakage rate by tracer dilution (E741-93). Usually the air samples are collected in sampling bags or bottles (6,7) and analyzed later in the laboratory. There are several problems with this

method of sampling, including the possible alteration of tracer gas concentration between sampling and analysis, and the fact that, for each time period, samples must be collected throughout the building. Alevantis (24) has described a system capable of sequentially monitoring tracer gas decays at up to 16 different locations. The system allows on-site determination of the overall ventilation rate under steady-state conditions (i.e., when the slopes of the decay curves are equal).

At this time, (SF_6) appears to be the most desirable tracer gas for near real-time, single-tracer ventilation measurements (25, 13). Some advantages of this non-toxic, relatively low-cost gas are that it can be detected at very low concentrations (ppb and below) and that ambient SF_6 levels are low [$< 1\text{ppt}$ (26)] with respect to concentrations used in this method. Concerns include the ability of SF_6 to mix well with the room air (SF_6 has a higher molecular weight than normal constituents of air) and the possibility that SF_6 could decompose into harmful compounds if it comes in contact with a high temperature surface (ASTM E741) such as a burner or the burning end of a cigarette. At the present time it is not known what is a "safe" concentration of SF_6 in a building or what compounds result from its decomposition (10).

SF_6 can be detected either with infrared methods or with gas chromatograph(GC)-electron capture methods. Infrared instruments are very easy to set up, but are unfortunately capable of monitoring SF_6 concentrations only at ppm levels. The measurement results using the latter method are in the form of chromatographic peaks, which must be individually integrated and

converted into concentration numbers with the use of calibration data. Calibration of the electron capture detector (ECD) is required before each test and after sufficient time (30 minutes to 2 hours) has been allowed for the gas flow rates and the detector and column temperatures to stabilize. Recalibration will be needed if the GC column or the ECD becomes contaminated during the test or if the carrier gas flows or temperatures are changed, since the areas under the chromatographic peaks depend on the temperature, flow rates, and cleanliness of the GC column and ECD. Commercially available SF_6 detection instruments are designed basically for laboratory application, not for field use. Such systems are not capable of :

- (a) Sampling from more than one location.
- (b) Performing auto-calibration using more than one span gas.
- (c) Easily interfacing with a computer so that acquired data can be reduced.
- (d) Venting the oxygen before it enters the ECD.
- (e) Being easily transported and set up.

Alevantis (24) describes a unit capable of meeting all these requirements with the additional advantage of being able to control all the parameters as frequently as the operator wishes.

Sampling and calibration valves are shown in Figure 1. Figure 2 shows a block diagram of the SF_6 computer-controlled system in the load mode. Figure 3 is a block diagram of the SF_6 computer-controlled system in the inject mode. Figure 4 shows the ECD in block diagram form.

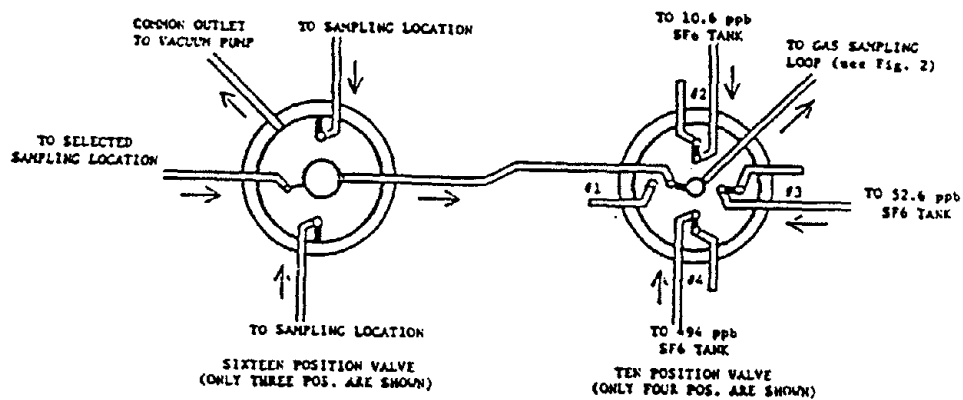


FIG. 1— Sampling and calibration valves.

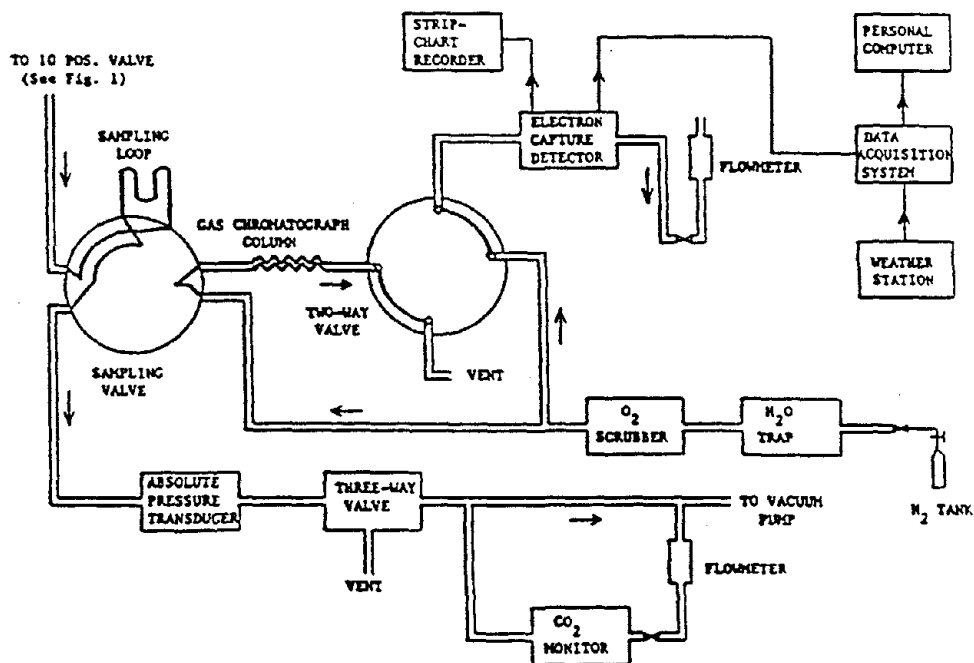


FIG. 2— Block diagram of SF₆ computer-controlled system in load mode.

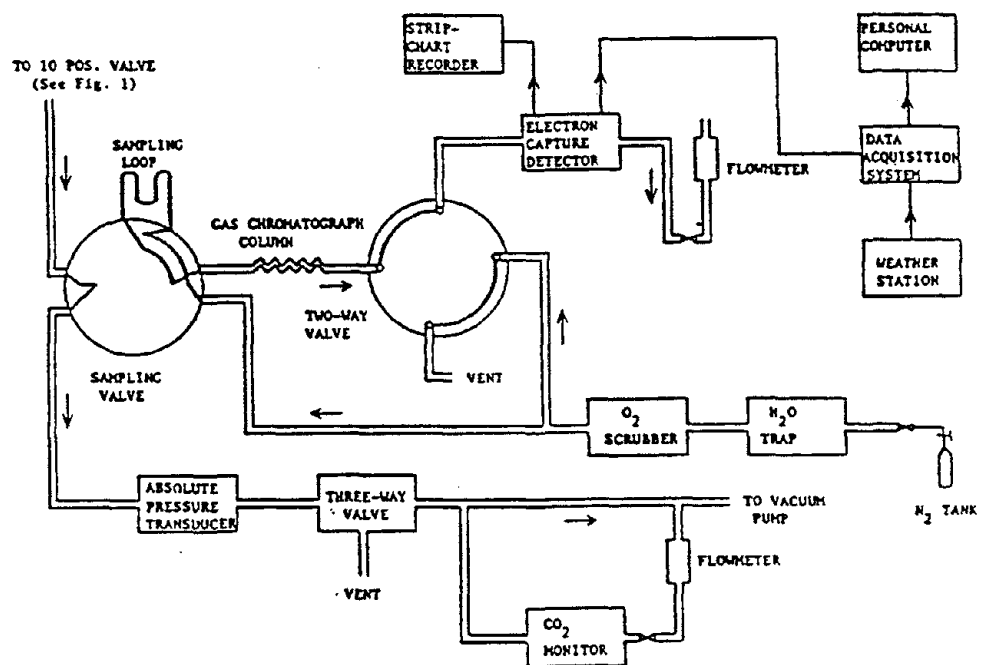


FIG.3—Block diagram of SF₆ computer-controlled system in inject mode.

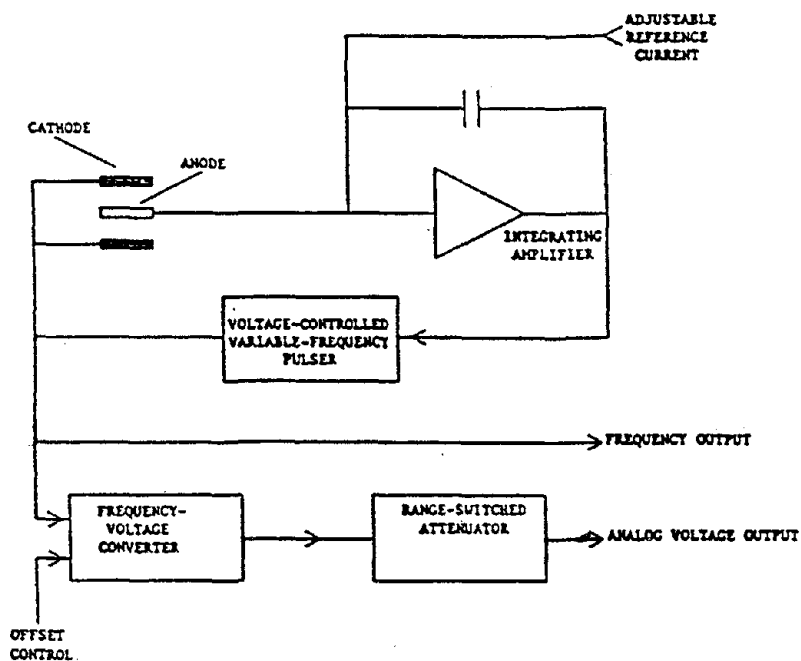


FIG.4—Electron capture detector block diagram.

Summary and Conclusions

(1) The use of tracer gases for the measurement of air infiltration into structures and interzonal flows within a structure is not new. This technique has been investigated over the past 15 years.

(2) Numerous tracer gases have been used, among which are: sulfur hexafluoride, hydrogen, carbon monoxide, carbon dioxide, nitrous oxide, and radioactive argon and krypton.

(3) Sulfur hexafluoride is the most common tracer gas of choice -- primarily because its presence may be accurately measured in the ppb range using electron capture/gas chromatography techniques.

(4) Most of the other gases used may be accurately measured in the ppm range using infrared technology.

(5) There are generally three types of methods used: tracer gas decay, constant concentration, and constant injection.

(6) Investigations comparing tracer gases have led to the following conclusions:

- (a) Even though sulfur hexafluoride is appreciably heavier than air, mixing is not a problem; and
- (b) The inherent uncontrollable variables present in tracer gas work limit the accuracy of determinations to $\pm 5\%$ - 10%. There is thus no reason why one tracer gas should be selected over another provided other criteria are met. In the case of hydrogen, diffusion of the gas through the surrounding walls can pose a problem.

(7) Tracer gases may be used in air flow measurements in large buildings where the building may be treated as several coupled zones. In such a case, the decay technique can still be used by having the system repeat the injection at regular intervals.

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